Institutionalized Effects on Innovation

A Case Study of Dental Care

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The researcher takes full responsibility for choice of methods employed and the research outcomes.

In memory of my brother, David William Makar

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SUMMARY

This thesis, by observing diffusion, improves understanding of constrains to innovation. It explores dental care in detail, the nature of the market, considerations affecting throughput, introducing the field of dentistry to innovation studies to which patterns of innovation differ from medicine. It describes how the financial managers of dental-care and other institutions mediate/organize the articulation of demand and the decisions of clinical care firms as they seek to drive profitability from dental implant technology.

The research followed knowledge at the level of a technique, where transformative effects of technology are understood in terms of technique Pavitt (1987a,c), Rosenberg (1976b, 1982) and Nightingale (2008), in real time, drawing on Granberg's (1997) mapping technique.

The research highlights the value of Chandler's (1977, 1990) emphasis on "throughput" to the dental sector (Nightingale, 2000; Lazonick, 2005: 40) and the notion that institutions make sense of the stability and structure of the collective action Lundvall (2007) and Johnson (2010), supported by Nelson (2008) and others. For effect on capacity utilization, the research drew on medical economic efficiency literature, Gelijns & Rosenberg (1994) and others of Rosenberg, in other sectors, to draw attention to the interconnectedness of efficiency and utilization to the medical specializations, institutions, bottlenecks, model of delivery and benefits of iterative learning Arrow (1962), Rosenberg (1982), David (1986), and Johnson (2010), that laid the basis to exploring bottlenecks to delivery of dental care, to medical care.

The constraint to innovation is the insurance-based financial system, as it changes the direction of learning. Trajectories of technical change have sub-sector, process-level influences that vary with dentist specialty. Learning is directed toward capacity utilization, by increasing throughput to spread costs at a given level of reimbursement, and the prime influence to practical knowledge and change to technique, is the institutionalized continuing education. The thesis shows post-adoption risks to transformation of technique are important to understanding innovation, because it can change the direction of learning, thus challenging the notion of research-based discovery as the preliminary driver of innovation.

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Figures, Tables, Diagrams and Charts

Abbreviations of Terms

AAOMS	American Association of Oral and Maxillofacial Surgeons
ADA	American Dental Association
ADAC	Alberta Dental Association and Colleges
ADEA	American Dental Education Association
ASA	American Standards Association
CAD/CAM	Computer aided design/computer aided manufacturing
CDA	Canadian Dental Association
CBCT	Cone beam computerized tomography
CDE	Continual Dental Education
CDF	Canadian Dental Fund
CDTA	College of Dental Technologist of Alberta
CEREC	Chairside Economical Restoration of Esthetic Ceramics
CERP	Continuing Education Recognition Provider
CLHIA	Canadian Life and Health Insurance Association Inc.
CIHI	Canadian Institute of Health Information
CIHR	Canadian Institute of Health Research
CME	Certified Medical Education
DCF	Dental Canada Fund
DDS	Doctor of Dental Surgery
EDI	Electronic data interchange
FAGD	Fellow of the Academy of General Dentistry
HPB	Health Protection Branch
iRSM	Institute for Reconstructive Sciences in Medicine
KRSR	Lysine-Argine-Serine-Arginine
LCIA	Libin Cardiovascular Institute of Alberta
LLUDS	Loma Linda School of Dentistry
NACTRC	Northern Alberta Clinical Trails and Research Centre
NIH	National Institutes of Health
OMS	Oral and Maxillofacial Surgery
OSAP	Organization for Safety and Asepsis Procedures
ROI	Return on investment

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Technical change plays an important role in addressing economic and social policy concerns (OECD, 2012). At the national level, "investments in technology and innovation, and to an increasing extent in scientific research, are not made for their own sake but to advance economic performance and living standards generally" (OECD, 2005: 8, 66).

Health related research is an important component of this economic and social investment, but has its own particular features. Medical innovation is often more heavily influenced by national institutions that are risk adverse. They regulate innovation through requirements for clinical trials, which lengthen the time needed for product development (Gelijns & Rosenberg, 1994; Nightingale, 2000). As a result, Gelijns and Rosenberg (1994) suggest many of the features that influence technological innovation in the production of traditional goods and services, are difficult to apply to the medical industry.

Dental innovation is a sub-set of medical innovation, and has been very much the junior partner in the innovation theory literature, with Dancer (2010) claiming dental research is under-researched academically "because it is under-funded compared to the extensive work that is funded to be undertaken in medicine and other aspects of healthcare" (: 284). The lack of qualitative work, as found by Dancer (2010) may also relate to the difficulty of reaching a group of professions who are independent and not easily accessed through a central organization, like medical doctors.[1]

Medical doctors often work in public institutions, for example in Canada, and are part of the nation-wide clinical research system. Dentists, on the other hand, typically work in firms, owned by them-selves and in 2009 only about three percent of total dentists employed in Canada, worked in academia or in public health (Papadopoulos, 2010; CDA, 2013). Therefore much of the "learning by doing and using" that affects medical

[1] Claiming originality due to this difficulty, Dancer's research on the origin, formation and growth of professional institutions exposed the potential effect of health-policy on professionalism.

innovation considered important to development and diffusion, Gelijns & Rosenberg (1994), Ramlogan, Mina, Tampubolon & Metcalfe (2007), Nelson, Buterbaugh, Perl, & Gelijns (2011) and Morlacchi & Nelson (2011) generated during clinical trials within the public medical system in Canada, is less readily available to physician-dentists working in private practice, suggesting Dentistry has an institutionalized structure that may well cause patterns of innovation to differ from traditional medical settings.

Dentistry was selected for this research because it is an under-researched, under represented in innovation theory literature, socially important Glied & Neidell (2007), science-intensive sub-sector that has an institutional structure that may well cause patterns of innovation to differ from traditional medical settings. For historical reasons, dental health care is not considered part of public health care in Canada, and therefore its delivery method is private. The Medical Care Act (1966) that established Canada's publicly funded health care system did not include dentists (Lindsay Society For The History of Dentistry, 2007).[2] As a result, the organization and delivery of dental care services, is driven less by national public health policy that is subject to political influences because of the need for medical efficiency to contain the increasing costs of health care, and therefore, innovation would appear to be driven more by the market. In support, Dancer's (2010) research comparing governance structures of medical professionals, found dentists delivery model of dental-care in the United Kingdom more independent of government bureaucracy than medicine (: 284).

In Canada, the dental-care industry is partly market based, according, to dental health regulators but also has a non-market, professionalized structure. The notion that dental-care is partly market based, is challenged in Ch. 4, revealing real markets are obscured. This influences how dental practices achieve economies of scale and scope when adopting new technology. As the thesis will show, it influences the structure of organizations (specifically their division of labour and extent of specialization), business processes and standardization, financing, continuing education and the planning, coordination and control used to increase throughput and profitability (see Ch. 4). The thesis aims to help understand how these institutional (organizational) features of dentistry in Canada influence innovation in dental-care firms' processes. The high-level research question this thesis addresses relates to how innovation takes place in

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[2] Currently, Oral health is not part of *Alberta Health & Wellness or Health Canada*'s portfolio although the Health Protection Branch of *Health Canada* provides a pre-market and a post-market surveillance of dental materials and equipment. This separation of dentists from medical physicians is historical, dating back to (c.936-1013) when an Arabian medical surgeon, Albucasis, made a formal complaint protesting that in spite of their ignorance they were permitted to work upon the teeth and repair small wounds (Bruno di Longoburgo, 1498; Chauliac, 1778; Weinberger, 1940 #1095: 2; Gold, 2001).

dentistry, as a sub-set of medical innovation. A particular focus, relates to the relatively slow diffusion of techniques despite their benefits, which is suggestive of organizational and other constraints on innovation.

Dental implant technology was selected as the focus for the research because although it is almost three decades old it is still not fully diffused, even though it is considered to have significant medical and aesthetics benefits, such as nutritional distribution that can lead to higher life expectancy, over other options. More often, it addresses the problem of jaw-bone loss, a major problem with the aging population (Preston, 1993; Ring, 1995; Loma Linda University School of Dentistry, 2003: Ref 28; Albrektsson & Wennerberg, 2005; Tosto, 2006; Paterson *et al*., 2009; Validation section 3.3.1). Despite its benefits, the implant technology has not become part of standard dental care in Canada, considered by customers a proxy for what is required for good health Schnitman (1990), Litaker & Cebul (2003) and Grignon, Hurley, Wange & Allin (2010), similar to health care (Gelijns & Rosenberg, 1994). Hence it offers a research site where one might expect to see the influence of constraints on the diffusion of new technology to be particularly evident.

The structure of the study is exploratory. The field of Dentistry is highly under-researched and with dental professions less accessible than medical doctors, it lacks both existing data and studies. This makes the methodological approaches different to a field that has well articulated, empirically and theoretically supported categories that could have been further explored. As such, the goal of the research methodology was not to capture all possible theoretical variations to identify gaps in theory but rather to aid the development of concepts and to deepen the understanding of the research subject (Ch. 3; Glaser, Barney & Strauss, 1967; Ragin, 1994, 2008; Bryan & Ragin, 2009). As it is the case of this thesis, theory to real world data fit is important when engaging practical knowledge (Van de Ven & Poole, 2007). The analytical frameworks that incorporate throughput and institutionalized activities closely relate to the real world of dental-care firms.

This study follows knowledge at the level of a technique to understand post-adoption constraints to innovation in dentistry. It reflects the theory of the firm where empirical evidence supports development of theory (Chandler, 1962, 1990; Freeman, 1982; Lazonick, 1991; Pavitt, 1999). The transformative effects of technology are understood in terms of technique Pavitt (1987c, 1987a), Rosenberg (1976b, 1982), Nightingale (2008) and see Ch. 2.1 definitions, where functionally linked technical and organizational factors to the technique, are seen to create innovative responses to create new technological and market opportunities Lazonick (1991: 214-216) supported by Ch. 2 theories and historically supported by Weber, Babbage, Smith, Schumpeter and Marx (Nightingale, 2008). Smith (1776/2000) originally explained factory production using concepts that applied to markets. Babbage (1832) explained how firms outperformed markets by increasing capacity utilization.

The dental-implant tooth-replacement technique is a complex, non-linear process involving many steps and stages, many other technologies and multiple dentist specialties and their associated firms. Matched with other features of dentistry already mentioned, such as the preference to operate as owner run, solo practices Papadopoulos (2010), similar to the United States Bailit (1992) and Valachovic (2009), the importance of "output per unit of time" Beazoglou & Heffley et. al. (2002: 1403),[3] University of Alberta Faculty of Medicine and Dentistry, Fee Schedule (2007-2008) and lack of insurance coverage previously mentioned, that affects the number customer's seeking the treatment, it therefore provides a useful case for exploring organizational elements, knowledge flows and how they affect diffusion.

Diffusion is a critical element to understanding innovation (Fishlow, 1966: 635; Rosenberg, 1976a, 1982a; Kline & Rosenberg, 1986; Rogers & Kincaid, 1981; Rogers, 1983, 2003; David, 1986; Metcalfe, 1994: 931, 1995). Dental-care service firms adopt new technology to innovate their techniques, in ways that illustrate learning to achieve economies of scale or scope (Ch. 4).

Dentist's modifying the technique of the implant application process to lower costs by increasing performance of the high-priced implant technology has precedence in North America. In the early 1980s, the dental implant was initially introduced by Nobel Pharma in Sweden, as a Brånemark prosthetic system for edentulous (toothless) patients, who wore dentures. A group of North American clinical dentist's that included Dr. Harold Bergman,[4] who is also an owner of an implant training centre in Canada, author of over 50 scientific and technical publications and 34 years of experience in placement and restoration of dental implant, concluded there was a limited market for a

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[3] Productivity of the American dentists has tripled over a span of 40 years, with half of this due to dentists' increasing "output per unit of time". Calculated by holding the following factors constant: dentist-to-population ratio, dentist hours of work, real disposable income and number of operatories. This has occurred despite the dental force aging, its gender mix shifting, and on average practitioners working fewer hours per year.

[4] Dr. Bergman, DDS, Dipl. OS&A, MScD(Path), MRCD(C) is an Oral and Maxillofacial Surgeon. The historical information was the result of numerous email and telephone conversations (2010).

$25,000 restoration procedure and they began to explore how to lower cost to the patient. This occurred as a refinement to the technique, leaving the Brånemark dental-implant unchanged, illustrating the learning associated with achieving scale economies that resulted in increasing the speed of technique, increasing reliability of the implant technology, and reduced uncertainty to both the patient and the dentist, by increasing performance of the technology. For example, to lower costs, other restorative techniques were developed, including “soft tissue supported and soft tissue/implant supported” removable dentures that reduced maintenance cost to the patient (the Nobel Pharma prosthesis was fixed). Costs fell because the modified denture system, used as few as two Brånemark implants rather than the suggested four or six under Brånemark’s dentures and snapped into place, thus increasing speed of application and the removal dentures, reduced maintenance cost to the patient and dentist. For edentulous persons, the implant-denture placement fee fell from $25,000 to about $4,000. This example, illustrates learning to scale can lead to expanded capacity utilization of a large fixed asset, resulting in cheaper per unit costs typical of mass production technology (Babbage, 1832; Rosenberg, 1994: 26; Jackson, 1998: 81; Ch. 4).

This thesis has nine chapters. The rest of Chapter 1 provides an overview of factors that may affect dental innovation and explains why it is important. It explores the theoretical underpinnings of the thesis and provides a description of the methodology employed. It continues by setting out the major observations and conclusions that emerged, and the theoretical contributions that have been made. The chapter concludes with comments on limitations and ideas about future extensions to the research.

Chapter 2 presents the literature review and the theory the research work built upon. Chapter 3 describes the methodology used in carrying out this research. This included a pilot study to verify the functional and utilization claims and to clarify if studying post-adoption constraints in the application of dental technology, would provide a useful case for exploring organizational elements, knowledge flows and how they affect diffusion. Chapter 4 describes the Dental-care industry in detail, the nature of the market and considerations affecting throughput. This chapter outlines and operationalizes a theoretical framework. Chapter 5 is an analysis chapter. Based on the observations of this research, it addresses the institutionalization of dental care, one of the key factors affecting dental innovation. Chapters 6, 7 and 8 present the cases and observations. Chapter 9 provides a summary of the complete thesis.

1.2 Dentistry, the dental implant and its application technique

As the literature review in Chapter 2 highlights medical innovation is characterized by a number of features that make it distinct from the industrial innovation, which has been the traditional focus of innovation studies. Medical innovation is complex, professionally regulated and structured by distinct professional boundaries; it is typically regulated by risk-averse national regulators, and combines both market-based, profit focused, competitive economic activity with non-economic, public good, often co-operative activities; it combines a strong science intensive element with a dependence on learning by doing, practice based knowledge and accumulated tacit understanding; and typically the final user and the payer may not be the same because of the importance of institutions that consider social risk in the provision of healthcare.

Dentistry shares many characteristics with medical innovation. However, in the particular Canadian setting studied by this thesis, it differs in a number of ways. It tends to be privately provided and undertaken in much smaller settings than hospitals. Fifty four percent of dental practices are solo run and only seven percent of dentists in Canada work in groups larger than five (Papadopoulos, 2010). As a consequence they do not have the concentrated purchasing power of large hospitals or private health-management organizations in the United States that have the market power to influence innovation patterns (Gelijn & Rosenberg, 1994).

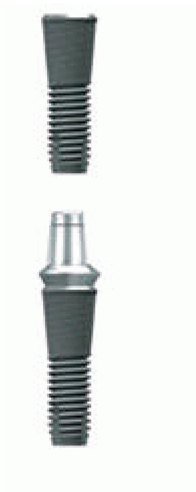
As well, the information asymmetry between patient and dentist-physician differ from medical care, based on the mode of delivery of care. The extreme information asymmetry between the patient and the physician, particularly the case where third-party payments[5] insulate the patient and physician from the financial implications of medical-care decisions, higher-priced technology may be adopted even if the health benefits are small (Gelijns & Rosenberg, 1994). In Canada, even though clinical dentists are free to adopt technology and expand their scope of business as long as they operate within the Canadian dental regulatory provisions, the third-party payment system does not completely insulate the dentist from financial implications and consequently, adoption patterns differ (Ch. 4).

[5] Generous insurance, fee-for-service physician payments & hospital reimbursements.

Like medicine dentistry is very specialized, professional and involves a complex division of labour. Complex procedures may involve many different specialties that are distributed across many small-scale practices. Knowledge is typically accumulated by learning-by-doing, although continuing dental education (CDE) plays a key role. This is often provided by private the sector that seek to influence the techniques and products, used by dentists.

Unlike the Canadian medical system, as previously described, which is deeply embedded in the national science system, dentistry in Canada draws on a wider international system of innovation, which may well create complications in the accumulation of new knowledge and the diffusion of new innovations.

The particular technology and technique that is the focus of this thesis is the endosseous dental implant[6] and the technique or application process that dentist's use to repair a damaged tooth with the dental implant. In this study, single-tooth implants are used for people who are generally missing one or more teeth. In such cases, the dentist places the implant directly into the jaw bone in place of a natural tooth root; the implant is a substitute metal root in the shape of a screw (see Figure 1).



The 'implant' is the titanium screw that is 'placed' into the jaw or sinus bone. This part is the dental 'implant' and acts as an anchor or a socket for the abutment.

The 'abutment' screws into the 'implant socket'. It resembles a titanium post and usually has two parts – an upper unit and a lower unit. The lower unit is screwed into the implant socket and the upper unit, referred to as a 'screw', is screwed into the lower unit and is the portion that the laboratory-built crown sits on.

[6] The word endosseous means that the implant is shaped like the natural tooth root form. When placed (or dropped) in a hole drilled in the jaw or sinus bone, it is allowed to integrate or attach to the bone. It acts as the root for the crown of a lost tooth.

Once the implant and abutment are in place, the laboratory fabricates a crown to fit the upper part of the abutment. The dentist fits the prosthetic device, a crown, on the visible upper part of the abutment completing the dental implant installation process.

Figure 1. Parts of the typical Astra Tech Inc. dental implant.

The endosseous dental implant is a technology that enables the replacement of the entire dentition,[7] thus enabling the physical mimicking of natural teeth and the accompanied health benefits.

Within time, the endosseous implant may facilitate major change in dentistry. The study began by engaging a small number of knowledgeable members of the dental community (see Ch. 3 Methodology, Section 3.3.1) to investigate and validate functional and utilization claims associated with the dental implant technology (Appendix A, research report). This report validates, based on its life expectancy if installed and loaded properly, it can simplify the tooth repair process by replacing procedures such as dentures, bridges, large crowns[8] and root canals,[9] however as the cases illustrate, it's a complex, time consuming procedure. A procedure that some dentist's have abandoned because of the time is takes to learn, to do well.

This is a complex, advanced procedure, with significant medical benefits. However, despite its benefits its diffusion has been slow. Hence it offers an informative case for understanding the interplay between knowledge accumulation in clinical practice, knowledge flows and innovation in a highly regulated, distributed medical setting. The rest of this section provides a brief overview of the technology to argue that it is a useful technology and technique to observe, for innovation studies.

The implant, like much medical innovation, has important historical roots in the Second World War (Rosenberg, 1994: Ch. 3). The root form dental implant, made of stainless steel, has been around for more than fifty years but was not considered a reliable

[7] The making up of a set of teeth including their kind and number arranged in the order of natural teeth.
[8] Sometimes termed a 'normal crown' to differentiate from an implant crown.
[9] These procedures are considered complicated because root canals may fail in treatment, bridges require adjustments to be done to healthy teeth nearby, and dentures are usually not stable.

procedure until Dr. Brånemark's (1952) serendipitous discovery that titanium fused to living bone (Loma Linda University School of Dentistry, 2003).

Conversations with the late, Dr. Brånemark, then living in Brazil provided the history to the implant research. He was a research Professor of Anatomy and an Orthopedic Surgeon at Gothenberg University, with other colleagus and in 1952, was researching bone healing and regeneration when he discovered that titanium affected the intermolecular healing response of bone. The discovery occurred when researching blood flow in the hipbones of rabbits. The cone-shaped "titanium inspection chambers"[10] were inserted into femurs of rabbits and secured for the duration of the experiment. This experiment used titanium inspection chambers rather than tantalum microscopic devices because titanium is less expensive and the titanium chambers were readily available.[11]

When the experiment was completed, the titanium chambers could not be removed. The two substrates – living bone and the metal fused. Dr. Brånemark (1952) coined the discovery "osseointegration" (Lozada DDS & Goodacre DDS MSD, 2003). This discovery became a game changer for implant technology because it solved a generic bone problem (widely supported by dentist's interviewed). This led to his subsequent development of a root-form titanium implant technology (1965). Once Swedish Health authorities (1978) approved the insertion of implants for clinical purposes, Dr. Brånemark partnered with a Swedish defense-research firm, Bofors, later Nobel Biocare to further develop and market dental implants.[12] They tested dental implants as a way of providing dental care to edentulous (toothless) veterans of the war. As previously mentioned, the product was introduced commercially, in the early 1980s, as a prosthetic system for dentures. As of 2010, the dental implant is the fastest growing product category in the global dental device market (Morgan Stanley Research Europe, 2013).

As previously mentioned, clinical evidence continues to demonstrate the advantages of dental implants, including decreased bone loss, more secure tooth placement and longer life span, previously mentioned. It also has the ability to simplify the tooth repair

[10] Developed by the British at Cambridge University in 1950 to study blood flow in vivo.
[11] Tantalum, even more expensive than tantalum, was a preferred choice at the time because it is a metal that is highly resistant to corrosion by most acids and was commonly used in chemical, dental and surgical instruments and apparatus.
[12] The corporate continuum - Bofors (1978), Bofors Nobelpharma (later Nobelpharma, 1981), renamed Nobel Biocare (1996) and became the global leader in restorative and esthetic dentistry, then Nobel Biocare Holding AG, new parent company founded and headquartered in Zurich, Switzerland (2002), sourced from corporate history ://corporate.nobelbiocare.com, last modified 23 August 2011.

process, lessen risk to the patient, and in the longer term, lower costs. It also decreases the instability and functional difficulties associated with dentures, a problem the aging population faces. The dental implant is a technology that enables the replacement of the entire dentition, thus enabling the physical mimicking of natural teeth and the accompanied benefits.[13]

Despite its benefits, the implant has not fully diffused and become a standard part of dental care in Canada. Manufacturers argue the long-term benefits are enough to drive significant demand, however, in interviews dentists suggested implant technology diffusion has stalled. While the study focuses on the transformative effect of the dental implant technology in terms of the technique (its application process) to draw out post-adoption constraints that affect innovation in dentistry, and to ultimately understand institutional influence on demand, the technology in this case has specific features that sharpen that focus. The procedure is expensive to patients and to the managers of the dental-care system, complex thus costly to dentists as the learning-by-doing curve is high Teece (1976) and Mansfield (1977), failures are easy for patients to see, and each brand is associated with costly application kits, make switching costs high (Monteverde & Teece, 1982; Nightingale, 2008). These features and others in Chapter 4, make more pronounced the need for dentist's to transforms techniques to increase profitability from the application of the dental implant technology and complementary technologies.

There are country-specific influences on the diffusion of dental implants (Paterson *et al*., 2009; iData Research, 2009).[14] These highlight national differences and the importance of different institutional setups in influencing the diffusion of the technology. In Israel, for example, there is a greater focus on aesthetics, with the country having twice the number of dentists per capita than some European countries. In Korea there is price competition from South Korea's local implant producers. In Germany implants are considered a superior health and aesthetic option despite their high cost, and the country has the highest uptake of the seven-country comparison undertaken by Paterson. Brazil has the lowest implant prices in the world, and the government provides loans to encourage patients to adopt the technology over other procedures.

Germany, like Canada, allow large dental implant firms to direct-market to dentists, creating a higher-value market for the producer firms and higher costs to patients

[13] This section drew on Dr. Bergman, Professor's Dr. G. H. Sperber and Dr. James Yacyshyn, University of Alberta Dentistry, Interviewee 24, 2 and 4 respectively.
[14] Additional sources for country specific implant placement /population ratios, follows the bibliography section.

supports the need to understand how dentists' create value with high priced technology.

1.3 The research questions

The general research question that this thesis seeks to address relates to "**How do institutions affect the demand for dental technologies?**" as part of a more general interest in the influence of institutions on innovation.

Answering the question requires understanding how new technology diffuses through the dental-care system of innovation. Initial pilot interviews highlighted the economic importance of through-put, defined as the number of procedures that can be undertaken in a given period of time, and the high level of "learning by doing" in dentistry and its influence on how whether innovations advanced or were constrained (Ch. 3).

This resulted in two sub-questions:

a) **How does the need for high-throughput influence innovation in a dental technique**?
b) **How do institutions and institutionalized activities influence innovation in the particular dental technique being explored**?

These research questions influenced the selection of the theoretical frameworks used in the analysis. The concept of institutions and institutionalized activities as driving routinization, standardization exhibiting stable patterns of behaviour Douglas (1987), Nelson (2008b: 4), Searle (2005) and Johnson (2010) and Chandler's concept of capacity utilization by increasing throughput to spread fixed costs, needed to be explored. Hence, understanding dentists' need for higher throughput for capacity utilization, as driving innovation and understanding how institutionalized activities influenced that capacity utilization, provided the means to understand the affect of institutional demand on innovation in dental technology. The higher level goal is to understand how innovation occurs in dentistry, by aiming to understand how these institutionalized/organized features of dentistry, influence innovation in dental care service firm's processes.

Previous research in this area is relatively limited, but as the literature review will show many features are similar to the broader category of medical innovation found in

(Gelijns & Rosenberg, 1994). For example, innovation involves iterative feedback between clinical physicians as users and producer firms, and high degrees of uncertainty continuing long after initial adoption (Ibid.: 32). In particular, this work and others of Rosenberg in relation to other sectors more generally, draws attention to the interconnectedness of efficiency and utilization to the medical specializations, institutions, mode of delivery, bottlenecks and benefits of the iterative learning between learning by doing and using Arrow (1962), Rosenberg (1982) and David (1986), that laid the basis to exploring bottlenecks to delivery of dental care.

1.4 The theoretical base and contribution to theory

The literature review in Chapter 2 and the preliminary validation work were used to select the theoretical framework. Interviews highlighted how dentists in Canada are motivated by throughput considerations. As entrepreneurs they aim, among other things to increase their throughput and hence profitability. At the same time, they work in a highly institutionalized (organized) and professionally regulated environment. Innovation in the dental-care sector is predominately privately funded and needs to contribute to business practices that generate increased profits, for example by generating economies of scale and speed. Speed is listed separately here only for clarity, but it is part of the economies of scale equation (Teece, 1993; Chandler, 1990: 429; Lazonick, 2005: 40; Ch. 4).

A dentist’s clinical practice involves the use of high-cost equipment and expensive labour. Reliable routines, interchangeable tools and instruments, and compatible processing equipment can spread these costs and contribute to profitability. At a different level of complexity, this is the process highlighted by (Chandler, 1977; Hughes, 1987). Clearly, dentistry differs in being a high-tech service that adopts producer/supplier technology to innovate in technique, but the economic importance of spreading fixed costs by increasing throughput is similar. Dentistry also differs from the industries studied by Chandler and Hughes by the extent to which institutions structure demand, particularly the insurance firms that manage the dental care financing system.

1.4.1 Economies of scale

To understand the economic importance of increasing the throughput of patients at a given level of reimbursement, the thesis draws on the work of Chandler (1977, 1990), whose work explores the interplay between investments in high-cost equipment, changes in organizational practices and structures and the ability to generate higher profits. The search for economies of scale and scope that govern a firm's business capabilities, as applied to a large manufacturing firm provides a potential framework for looking at economies of scale in other applications, such as the dental industry (Ch 4).

Chandler explored the emergence and risk of the large firm during industrialization of the late 19th century America. Large firms emerged during the late 19th century when economic growth in America was commonly associated with adding labour. Instead of adding labour, Chandler argued for increase to scale, internal specialization and coordination of a business (Marshall, 1890; Lazonick, 2005). To exploit scale economies Smith (1776) and Babbage (1832) that could result in competitive advantage, the firm required managerial structures and systems to interrelate planning, coordinating and control. Capital investment was a key requirement to expanded output. The expanded output came about by improving (complementary technologies) and rearranging input (standardization, etc.) resulting in increases in volume and velocity (speed) of throughput rather than growth is size of factory.
A visualization of the Chandler theoretical framework, outlined in Ch. 2 (Diagram 1).

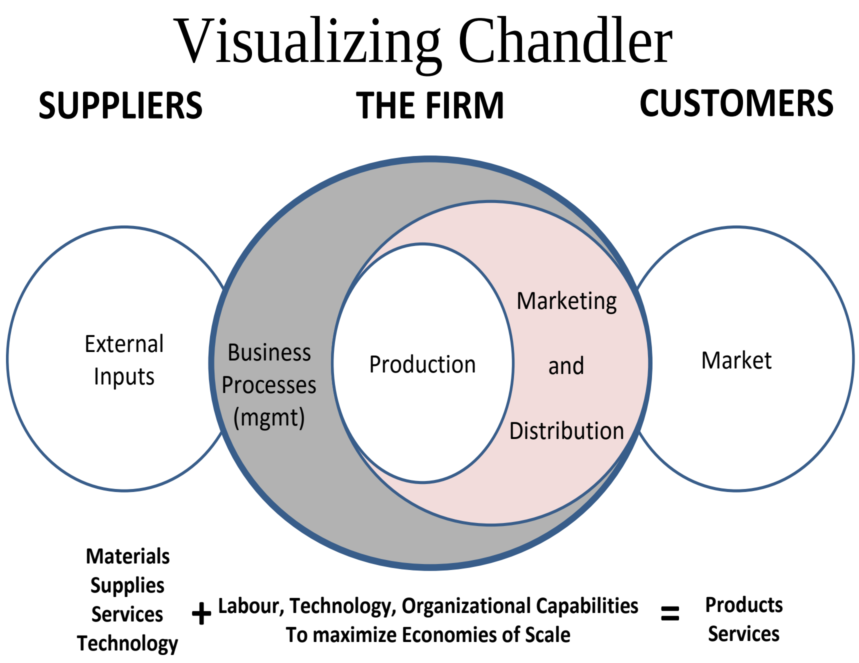


Diagram 1. Visualizing Chandler to understand how throughput is created

The above illustrates, the large Chandlerian firm, out performed smaller traditional enterprizes, only when the high fixed costs of mass production technologies were coordinated with management process, such as finance, procurement, etc along with standardizing organizational or work processes along the lines of division of labour, to maximize productivity, lower costs. This in turn, allowed them to makes favourable arrangement for external inputs and to lower costs to the market. Although the size of markets was implicit in Chandler (1977, 1990), their importance was not (Lazonick, 2005).

Chandler developed theory for a semi-skilled production oriented manufacturing application. A more dynamic and modern view of the Chandlerian framework highlights achieving high throughput or speed, *requires an effective division of labour and functional integration of both technical and organizational factors*, to *enable collective and cumulative learning* Lazonick (1990: Ch. 7, 8) and Chandler, Amatori, & Hikino (1998) in Lazonick (2005: 40-41), supported by Dosi & Teece (1993) and Patel & Pavitt (2000).

This research adapted the model to the highly skilled activities of professionals as part of the dental-care production function (Diagram 2), see Ch. 4 for interconnectedness.

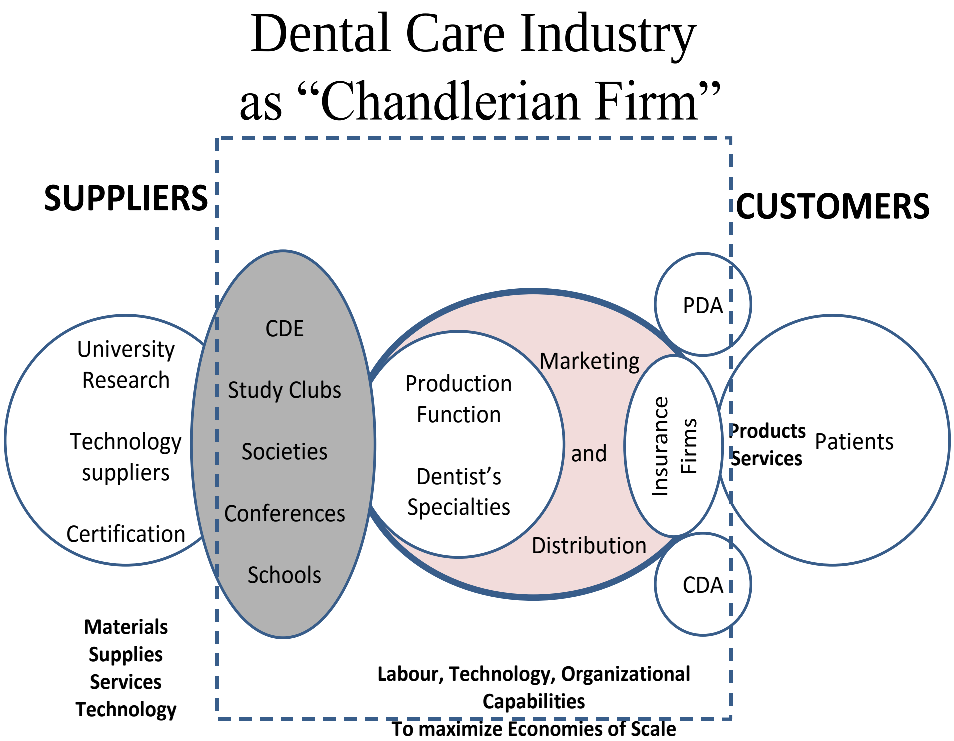


Diagram 2. Vizualizing Dentists as the Production Function in Chandler

While the Chandlerian framework is focused on large firms, the same economic influences can be at work in smaller firms. One might expect a dentist's clinical practice, for example, that uses high cost equipment and labour to utilize implant technology, would benefit from using reliable routines to increase throughput. The process a dentist follows to replace a diseased tooth with a dental implant, involves a complex division of labour between specialists, specialized equipment and techniques intended to increase throughput.

The key insight taken from Chandler (1977) is not the importance of scale (as in size) but instead the importance of capacity utilization, its influence on cost structures and how they can be improved by better co-ordination.

However, while Chandler's approach provides insights into the economic drivers of innovation in the dental industry and can be applied to the dental industry, it needs additional theoretical dimensions to address the nature of technological innovation and iterative learning in a professional service firm, in particular how co-ordination take place beyond the dental-service firm.

Because dentistry isn't integrated within large firms, and is instead typically distributed across small firms, the opportunities for managed co-ordination are less extensive, which may make organizational adaptation more difficult, particularly if organizational practices are structured by institutions in a highly regulated market. The economic benefits to the adoption of new technology may well require simultaneous organizational innovations, and networks of dental practitioners will lack the centralized managerial co-ordination available to larger firms. Instead, external co-ordination is structured by a heavily regulated market. It may well be the case that innovation will be constrained, even (as is the case with dental implants) if the technology is superior. To understand the potential conflicts it is necessary to explore innovation theory in more detail.

1.4.2 Innovation theory

Innovation theories have evolved from simple linear models (science push, market pull) to feedback models (chain link) and to more iterative, systemic approaches that are more suitable for understanding the process of dental innovation which is complex and distributed across a number of different actors, providing a more useful heuristic for understanding dental innovation. The literature review explores more recent theories that explore innovation beyond an individual firm, and pays attention to interactions between technology users and producers. These frameworks highlight the importance of learning, problem solving, the distributed nature of technical change, and the roles of managerial, market and non-market forms of governance.

In particular, this theory draws out the importance of understanding that technical change advances along a trajectory, reflecting path-dependent, firm specific, know-how about how to advance practice (Metcalfe, 1995; Nelson & Winter, 1977; Rosenberg, 1976; Dosi, 1982; Nelson, 2008). Equally important is that, technique and knowledge tend to become associated with particular sectors Malerba (2005) which in turn, can be associated with particular occupations and professions (Nelson, 1967, 2005; Nelson & Winter, 1977; Schon, 1991; Rogers, 983, 2003). More recent work has extended these ideas beyond the product development process and hence beyond the boundaries of the innovating firm. Iteration between a technology and the market inevitably exposes technical imbalances that impact diffusion and provide opportunities for further innovation. For example, in the development of medical technologies, Gelijns and Rosenberg (1994) found iterative feedback effects between clinical physician users, producer firms and a technology used for a clinical condition. Physician users help direct technological development, advance scientific and engineering knowledge and articulate demand.

In particular, this work draws attention to the interconnectedness of efficiency and utilization to the medical specializations, institutions, mode of delivery, bottlenecks and benefits of the iterative learning between learning by doing and using (Arrow, 1962; Rosenberg, 1982; David, 1986). These iterative effects are considered important because of two forms of learning (and their associated technology transfer mechanisms), can be considered as “learning curves of experience”. The accumulation of experience in production and use, helps sustain a continuing flow of incremental innovation along a trajectory. This lowers the costs of successive vintages of technology and extends penetration into new markets and areas of application (David, 1986: 384). The potential existence of irreversible, dynamic scale economies, under conditions of increasing returns, can in theory become cumulative. This creates the potential for a particular product, process or system design to potentially lockout rival technologies, and become locked in (David, 1986: 385).

Any decision to introduce a new technology often requires discontinuing the operation of an existing facility or technology. It takes time to supplant old technologies particularly if they are embedded in wider systems David (1986: 382) and knowledge needed to use them is costly to acquire (Teece, 1976; Mansfield, 1977). If the relevant operational information is held by others, if specialized equipment, product or services, are needed, and if interrelated complementary assets are required, displacement is more difficult.[15] New technologies may therefore be at a disadvantage if they disrupt existing procedures and have high switching costs (Monteverde & Teece, 1982; Nightingale, 2008). The use of dental implants to replace other dental services can be perceived, as putting some high cost professional knowledge at risk and thereby the viability of some dental-service firms, as previously mentioned.

Understanding the process of innovation and diffusion in dental techniques therefore requires an understanding of how demand is articulated, and how that demand is mediated by economic requirements to increase profitability, which in this case, will often be related to the ability of a procedure to reduce treatment times, and hence increase the number of patients that can be treated with a fixed level of costly equipment and people. However, understanding how these economic and organizational influences interact requires understanding about how they are positioned within an institutional setting.

1.4.3 The importance of institutions

Institutions play important roles in determining regularities in firm behaviours that influence how firms innovate and adopt and transform techniques. ‘Institutions clearly have a certain stability” (Nelson, 2008b: 4), regardless if the distinction between institutions and organizations are fuzzied (the way firms tend to be organized and managed) or understood as a “basic rules of the game”, “institutions define or mold the way economic agents interact to get things done” (Williamson, 1975, 1985; North, 1990a, Nelson, 2005: 153; 2008b).

This distinction is fuzzied in dentistry. Therefore this section is not about unpacking the concept of institutions, or discussing institutions as social technology (Nelson, 2008b), is about understanding institutions in an economic context (Johnson, 2010). This research followed knowledge at the level of technique to understand the transformative effects of technology Pavitt (1987c, 1987a), Rosenberg (1976b, 1982) and Nightingale

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[15] For example, name-brand dental implants each require specialized training, and complementary tools. The division of labour in dental care means that if a surgeon dental firm uses a particular brand, the referring dentist will need the tools to complete the procedure or lose the customer.

(2008: 562) in terms of techniques that provide the medical services, doctor's perform in their practices. This sheds light on how dentists do things in particular economic contexts, where the interactions and activities are functionally linked to a number of institutions and other private organizations that have the ability to mold and determine what is economically feasible for dentists to achieve in their practice.

The historical division of labour between different types of dentists (and their respective categories of knowledge) is protected by their professional bodies (established 1867), dental regulating authorities (established 1902) and dental societies (established 1906) and sustained by the financial managers of the dental care service and disseminated by dental teaching schools.

This makes the distinction between governance of the profession and the organizational principles employed by dentist's to organize the private practices of their firms, not clean.

However, the knowledge specialization of dentists (established 1906) influences how a technology is used and how it diffuses. Thus, the notion of institutions as exhibiting certain stability, "can only exist if people have particular beliefs, have collective intentionality", hence, an "institution is a special type of social structure that involves potentially codifiable rules of interpretation and behavior" Searle (2005), as supported by Hodgson (2006: 5).

As previously mentioned, institutions play a key role in generating the rules and routines that provide structure to economic activity, in dental service firms and create the conditions for collective action in the following ways (Johnson, 2010: 34-38). Within a firm, the learning by doing is often a routinized activity (Arrow, 1962). This is the complementary internal learning important for dental firms to utilize external knowledge. Similarly, between firms, learning by using can become routinized. The iterative learning between learning by doing and using, increases the learning curve of experience incrementally along a trajectory, lowering costs and penetrating into new markets and areas of application Rosenberg (1982) and David (1986), and can exhibit exclusion effects to other technological possibilities (Dosi, 1982; Metcalfe, 1995). Learning by interacting or searching is the systematic search for new knowledge and generally connected to organizations that do basic science (Lundvall, 1985, 1988, 2005).

As dental firms take time to update practices, “a successful competitive firm has to anticipate changes, suggesting that dynamic capabilities are shaped by markets and technologies and direct its capabilities to the present and future capabilities of consumers and suppliers” von Tunzelmann (2009: 442), supported by (Helfat, Finkelstein, Mitchell, Petraf, & Singh, 2007). Learning from the markets is an essential complement to drive innovation (Baumol, Litan, & Schramm, 2007; Edquist & Hommem, 2008; Foster, 2010; Dodgson, Hughes, Foster, & Metcalfe, 2011: 1154). Absorptive capacity and routinized activities are important Cohen & Levinthal (1990) and Cohen, Burkhart, Dosi, Egidi, & Marengo (1996) if links to specific resources of knowledge within the supply chain (suppliers and customers) are to be relevant for innovation (Fitjar & Rodriguez-Pose, 2013; Berg Jensen, Johnson, Lorenz, & Lundvall, 2007; Tether & Tajar, 2008).

Johnson (2010: 32) positions institutions into economic activity through within and between firm interactions and activities, building on the innovation systems theory of Lundvall (2007), providing a framework for understanding institutionalized activities. Johnson argues, “modern firms search systematically and in organized ways for new knowledge to be used in the production of new products. The regularities in their learning become institutionalized.

In this case, institutions can either increase or decrease the uncertainty associated with innovation in dentistry and hence potentially constrain the diffusion of new techniques.
Theories of institutions therefore help understand the regularities that influence firms to innovate. Understanding how communication is organized and the market and non-market interaction patterns between firms and other organizations, assists institutions to help structure learning and direct it toward the production of new goods and services.

Learning is viewed an important element for understanding regularities. Johnson’s (2010: 31) work builds on the iterative learning models, previous mentioned in his chapter.

Non-market forms of governance are a particular feature of medical practice. Hence theories that address institutions are valuable for understanding some of the regularities in how firms innovate and adopt and transform techniques. The professionalized, regulated and medical nature of dentistry means many activities are difficult to capture in terms of market interactions. Institutions external to the firm can generate regularities in behaviour that lessen uncertainty by reducing the amount of information needed for individual and collective action, acting as signposts, for relations between and among, people (Lachmann, 1978).

The empirical chapters highlight how institutions in dentistry, such as requirements for dentists to undergo continuing professional development training, influence the accumulation of knowledge and the diffusion of new techniques. As Abramovitz (1952) recognized, these institutions can have both stimulating and retarding effects. One of the empirical aims of the thesis is to better understand how these interactions occur in the Canadian dental sector and how they influence patterns of innovation.

1.5 Developing a theory of dental innovation

While care must be taken in generalizing from cases, the empirical work highlights the value of exploring the role of economies of scale and throughput for understanding how innovation takes place and how demand is articulated in comparison to a medical innovation system. The thesis highlights that the more market-based organization of dentistry, makes it slightly different from typical medical settings when it comes to patterns of innovation. However, the importance of understanding institutions in explaining actors, configurations and roles remains vital for understanding dental innovation. While one might expect a superior technology to diffuse rapidly, this research suggests the complex organizational and institutional structures complicate the flows of knowledge, and the accumulation of expertise in practice, that would, in a counterfactual world, make diffusion easier.

The institutionalized nature of dental care influence on innovation (Ch. 5) explains in Ch. 9 how it lies beyond the present scope of theory relating to economic efficiency in medical care.

1.6 Thesis structure, Chapters three to nine

1.6.1 Research approach and methodology, Chapter three

Chapter 3 explores the research methodologies and the use and weaknesses of using semi-structured interviews in a case study approach. It highlights how preliminary research was based on exploratory, semi-structured, interviews supplemented by a review of academic and professional literature, while the second phase involved engaging with 39 individuals in the dental-care sector. The chapter concludes with a discussion of the data gathering and analysis protocols.

The study set out to explore the ***process of innovation*** in dentistry by understanding perceived constraints on the diffusion of dental implant technology, in terms of its application technique. The introduction and literature review highlighted, dentistry remains under-researched, and while it shares many features with medical innovation, there are important differences that may well limit the extent to which concepts and frameworks from medical innovation can be extended.

This research is exploratory in nature, with the aim to understand how innovation occurs in dentistry that can be challenged and extended by future research. The high-level research question this thesis addresses relates to how innovation takes place in dentistry, as a sub-set of medical innovation. A particular focus, relates to the relatively slow diffusion of techniques despite their benefits, which is suggestive of organizational and other constraints on innovation.

A research setting that is characterized by both lack of existing data and studies, is exploratory, in nature, as such less theoretically and empirically structured than research that could rely and draw on well-established theories and well-defined concepts to assist in formulating the research idea at the beginning (Phillips & Pugh, 1994; Ragin, 2008). Given the focus on a “how” question, the early stage of the research and the relative lack of existing data and robustly tested theories, the research design involves a case study approach.

Table 4 of Chapter 3 summarizes social science research methodologies and their appropriateness for use in the analysis. Ethnoscience, ethnography and semi-structured were considered as meaningful primary data source tools to the case approach. As Ragin (2008) highlights, cases are “meaningful but complex configurations of events and structures”. They are single, purposefully chosen examples that are empirically explored, in parallel with concept formation and elaboration. Hence they contrast with variance approaches, where homogeneous observations are chosen at random from a pool of equally plausible selections and tested using well-established theories and well-defined concepts. With cases, the concepts themselves and their appropriateness to the case, being studied, are uncertain and flexible.

To generate a degree of variance the study explores three distinct settings, where it was initially assumed that the innovation process would be similar enough to make comparisons meaningful (Bryan & Ragin, 2008). This ended up being the case.

As Morgan (2012) has highlighted, case studies involve open-ended investigations of a bounded object in all the complexity of a real-life setting to generate a complex, narrated account. Case studies allow for clarification of weaknesses of existing explanations (i.e. by highlighting how dentistry differs from medicine and how these differences make models of medical innovation inappropriate), because as Popper highlighted single falsifications can be applied to universal statements.

The research process involves three phases. A pilot study and a research report was used to clarify the functional and utilization claims associated with dental implant technology and to clarify if the application process that utilizes dental implant technology that is distributed among numerous dental specialities would provide a useful case for exploring organizational elements, knowledge flows and how they affect diffusion. This work was supplemented by a review of academic and professional literature.

This pilot work satisfied the condition that the dental implant would be an interesting research project for innovation studies and confirmed that the dental-care sector was reachable, but not easily. This phase raised questions about how the technology would be transformed into regular practice. The data from this phase lead to the wider engagement of other players, with refined questions leading to more in-depth understanding of systemic constraints to technology application in practice and linkages to institutions and industry.

Phase 2 of the research, engaged 39 individuals in the dental-care sector, or associated with it, and involved with dental implant and complementary technologies, including industry, in a semi-structured interview approach. Dentist interviewees identified other some of the industry players. Semi-structured interviews were used to allow interviewees to express in their own language what they felt was driving innovation and hence to avoid imposing frameworks on them in an inappropriate way. The interviewees’ responses were then triangulated against each other and other material.

Care was taken to observe appropriate protocol to maintain confidentiality. References are discreet unless anonymity was not requested, and in the former, the data is cited by code rather than by name. The interviews were typically recorded, with permission, and transcribed using Dragon Naturally-Speaking voice recognition software.

This phase was to understand a) what corrective action the technology was to provide, b) what technology was used before, c) what factors would influence technical change, and d) who controls the factors. The results of this phase raised important concerns about factors that needed to be further explored. For example, throughput, as reflected by a dentist's time at chair, and mode of delivery issues related to insurance eligibility, reimbursement and patient coverage, kept surfacing.

Phase 3, involved a multi-case study of three dental firm dentist practitioners to follow the progress of knowledge at the technology (dental implant) level, using a modified Granberg (1997) analytical framework, to identify the actors involved and how they perform. The selected dentists were all owner-operators of dental-service firms, as are 93% of all Canadian dentists (solo or small-group practice firms). To collect the data, two specialists were observed in real time: Oral and Maxillofacial Surgery Dental-care Service (Ch. 8), Prosthodontic Dental-care Service (Ch. 7), as well as a General Dentist Dental-care Service (Ch. 6).

The case method was supported with semi-structured interviews and semi-ethnographic methodologies oriented toward the dental specialities and utilization opportunities and constraints, involving primary sources. For consistency, common interview questions were used to begin the interviews. For effective control, case study observations were limited to dentists and work they do that is explicitly associated with installing and maintaining dental implants. Supplementary interviews supported case data collection and written case descriptions.

The structure of the empirical case chapters reflects the generic sketched dental implementation process (Diagrams 5 and 6 of Ch. 3) and provided a framework to guide the researcher's observations of dental implant practices, and to identify and understand the opportunities and constraints associated with increasing returns from scale.

This chapter concludes with a discussion of the data gathering and analysis protocols, as follows.

Understanding innovation in dentistry, required observation of real-time iteration effects and the dentist to identify problem solving actors and the reasons for the interaction.

The qualitative method was chosen to construct in-depth representations of phenomena; often addressing phenomena researchers feel have been misrepresented or not represented at all. The in-depth investigation focuses the researcher on a case, on the commonalities among separate instances of the same phenomenon, or on parallel phenomena identified through a deliberate strategy of theoretical sampling, within or among cases (Ragin, 1994).

A multi-method research approach is appropriate for a broad topic area and seeks to validate data through triangulation by combining a range of data sources, tools and methods to widen the scope of study to include contextual aspects of the situation (Yin, 1994: 91-93). If two case studies are shown to support the same theory, replication can be claimed as two-level inferences providing reasonable confidence to support policy and theory (Ibid.: 31).

To Ragin (1994), the strategy of theoretical sampling Glaser, Barney, & Strauss (1967) is not to capture all possible variations, but rather to aid the development of concepts and deepen the understanding of research subjects. A researcher's sampling strategy evolves as the understanding of the research topic matures (Ragin, 1994: 99). Triangulation provides a better fix on something that is only partially known; it can be a powerful tool to build analytic frames (Ibid.: 100). However, Ragin (2008) claims, casual processes are best observed at the single case level, through in-depth research (Ragin, 2008; Ragin, 2009). Such research is considered successful even if it only succeeds in showing that the existing theory is inadequate (Bryan & Ragin, 2009).

There can be no sharp distinction between causal conditions and outcomes. Generally researchers examine causation holistically in terms of convergence of structures, actors and events (Ragin, 2008; Ragin, 2009). These researchers are centrally concerned with sequences and timing of events, with an eye toward path dependence, making case study research focused almost entirely within case patterns Ragin (2008), supported by Van de Ven & Poole (2007).

Cross case analysis is central to the process of constructing generalizations. Researchers are required to make strategic comparisons and thus need diverse cases, but at the same time need to maintain case homogeneity because their cases should be instances of, or candidates for, the same outcomes (Byrne & Ragin, 2009). The prime objective of comparative research is not theory testing, but concept formation, elaboration and gradual refinement.

Sharpening the definition of a set of relevant cases is often an important theoretical advance itself (Ragin, 2008). This involves making cross-causal correlation symmetries.

Table 5 illustrates areas to which dental care service firms could apply throughput, to transform new technology into existing routines, economizing the dentists'-time, by innovating their techniques. The two mapping tools, Diagrams 5 and 6 provided a framework to guide the researcher's observations of dental implant practise, and to identify and understand the opportunities and constraints associated with increasing returns from scale.

The wider group involved in Phase 2 of the study built on and verified the insight gained during validation by involving a broader range of interviewees, including dentists, regulating institutions, insurance, researchers and the producer industry. This allowed the researcher to progressively build a map Buzan (2002) of the systemically linked incentives and constraints of the implant technology in relation to practice.

The regulating institutions and insurance firms helped the researcher verify the gatekeeper role of dentists in technology adoption and also added depth to understand reimbursement and billing procedures.

To draw out findings and conclusions, the end of each case (Ch. 6, 7, 8), identifies indicators that illustrate how specialties apply economies of scale. These indicators are compared to identify commonalities and differences (Ch. 5). The researcher has also added the throughput provisions, to illustrate their application, at the end of each case chapter.

Chapter 9 illustrates, there is a pattern to the application of throughput, however the internal pressures or interrelatedness Chandler (1977), Rosenberg (1976, 1982) within the technique can largely be attributed to the specialized knowledge of each specialty Nelson & Winter (1977), Rosenberg (1982) and Dosi (1982) – the pattern changes according to the knowledge base of the technique. The knowledge is paradigmatic and transforms slightly with each technological change to the knowledge base. Thus the transformation of one technology progressively changes the performance criteria of the next and transformation of the next – change builds on previous technological achievements.

Chapter four will present the constraints, to the adoption of new technology, that were acquired through semi-structured interviews.

Chapter five applies the institutional framework, utilizing the data from interviews and cases (Ch. 6, 7, 8) to identify instituting factors that can be applied to Johnson's (2010) theoretical framework that supports the iterative learning models in Ch. 2 to triangulate and expose institutional effects and institutional actors, associated with learning by using. Table 9, Ch. 5 triangulates the results.

Ch. 9 observes the institutional theory at the national level talks about supply of knowledge, but not how that knowledge is conditioned by institutional demand. Thus the combined throughput and institutionalized effects, observed suggests the cases support the same theory.

1.6.2 Theoretical framework, Chapter four

Dental care is a partly market based, but also has a non-market professionalized structure. This influences how dental practices achieve economies of scale and scope when adopting new technology. This chapter will show, it influences the structure of organizations (specifically their division of labour and extent of specialization), business processes and standardization, financing, continuing education and the planning, coordination and control used to increase throughput and profitability.

Dentists' operate their firms in an institutional setting where many activities are distributed between organizations. In other sectors, utilizing a Chandlerian framework, similar activities might be internal to the firm.

Chapter four outlines and operationalizes a theoretical framework. It describes in dental care in detail, and the nature of the market and considerations affecting throughput. While the theoretical underpinning of this thesis and chapter is iterative learning Arrow (1962), Rosenberg (1982), and Kline & Rosenberg (1986) interaction with the dentist in the position as the user, to understand how that learning is directed and/or molded, this chapter draws on scale economies literature and the economic value of higher throughput rates in settings where fixed-costs are high Chandler

(1990), Nightingale (2000) and Lazonick (2005: 40), and draws on medical economic efficiency literature Gelijns & Rosenberg (1994) to highlight and contrast constraints to innovation in dentistry to the medical sector, and draws on the notion that institutions help make sense of the stability and structure of the collective action Lundvall (2007) and Johnson (2010), supported by Nelson (2008) and others Ch. 2, in this hybrid market-non-market setting.

In the, Canadian dental sector, revenue is largely controlled by others. The financial managers of the dental care system, in consultation with dental accreditation boards (dental societies) attribute specific time for a procedure that includes associated material and technology. In this environment, high throughput or speed per procedure becomes an important surrogate marker of profitability, as real markets are obscured. Hence dentists tend to adopt specialized machinery, techniques and instruments associated with higher throughput. The chapter hypothesizes that particular institutional set ups, such as the financial managers that mediate the dental-care market, can obstruct the flow of information between users and supplier firms and hence constrain dental-care innovation.

This chapter begins by exploring the nature of innovation in the dental-service firm in Canada by visualizing the sector as a modified Chandler framework, in Section 4.2. linking elements of this framework to actors illustrated in Table 8 that summarizes the major actors of the dental-care industry, their function or service they provide, and the mechanisms by which they link to entity in column 4. Chapter 5 will illustrate how these functional connections become institutionalized, drawing on the cases. The rest of the findings that address the importance of economies of scale, learning and institutionalization are brought together in Ch. 9.

The rest of the chapter rationalizes the need to functionally integrate organizational and technical factors to achieve competitive advantage through opportunities from new technologies that functionally link interdependent structures, as the dental implant does (Lazonick, 2005; Nightingale, 2005).

Section 4.3 discusses how division of labour between specialists is related to increasing throughput and profitability and how institutions influence their business practices through standards, specialization and continuing education. Section 4.4 considers the nature of the market and in particular, the influence of institutions on technology adoption and diffusion. This section talks about the importance of market size to assess the throughput requirement of new technology, implicit in Chandler

Lazonick (2005), highlights market distortions Gelijns & Rosenberg (1994), demonstrates the distortion of the "market-based fee schedule" and how these distortions separate the business function of finance from the production function, associated with dental-care service delivery. This section concludes in a non-market environment where the articulation of demand is distorted and where revenue is largely controlled by others by attributing specific time to a procedure, high throughput or speed, becomes an important surrogate marker for dentists in the adoption of specialized machinery and instruments. As shown in sub-section 4.5, reliable routines, interchangeable tools and instruments and compatible processing equipment can spread the cost and contribute to profitability, however in dentistry, insurance firms alter the articulation of demand. Section 4.5 explores throughput in the dental-care business, and provides a modified Chandler framework for the dental care industry.

The key insight taken from Chandler is not the importance of scale in terms of increasing size, as in spreading the cost over large amounts of output by adding more dentist's chairs, but instead the importance of increasing speed of treatment at a given level of reimbursement and that is the capacity utilization of the dentist's time, its influence on cost structures and how they can be improved by better coordination.

From this work, *to utilize implant technology*, a dentist's clinical practice would be expected to use of high capital cost equipment and labour, that builds on the economies of scale arising from reliable routines, that may increase speed and throughput. To increase the reliability of routines, to reduce the uncertainties associated with implant failure and other technologies, while sustaining the rated capacity (time in chair), possible quality improvements, the cases could reveal, include:

a) Specialized diagnostic equipment and instruments,
b) Compatible processing equipment,
c) Technologies relating to implant success,
d) Reducing maintenance and return visits,
e) Decreasing learning-by-doing time, and/or
f) Expanding the scope of practice.

To facilitate comparisons and generalizations between case studies, the boundary of the cases are drawn around the functions/techniques generated by each dental-firm specialty.

Cases explore role of economies of scale and throughput to understand how it takes place, and how demand is articulated within a dental medical innovation system. A multi-case, comparative study of the specialties was undertaken to follow the progress of knowledge at the technology (dental implant) level. This allowed for a degree of variance. Following Granberg (1997) the dental implant system was decomposed into its components and interactions, to explore how the actors in the technology system functionally align and link their activities around a production process or technique. Because dentists' require services from other specializations and firms, the cases illustrate these **functionally linked industry and institutional structures.** Each case captures a map that provides insight into the processes involved, specialties distribution within the system and how they relate to knowledge flows. Each case identifies how the different types of dentists generate improvements in throughput in their operations. These are compared to identity commonalities and differences (Table 9, Ch. 5). Cases employ division of labour between specialties and technique to increase throughput. While there is a relatively standard pattern, differences occur because of differences in the knowledge of each specialty about the technique.

1.6.3 Institutionalization of dentistry, Chapter five

This chapter five is an analysis chapter. Based on observations, describes the institutionalization of dental care. It builds on Ch. 4, the observed constraints Gelijns & Rosenberg (1994) and the modified Chanderlian framework for the dental care industry and the cases (Ch. 6, 7, 8) that have observed a number of mechanisms associated with increasing returns to scale that are used by the three dental firms involved with the dental implant, and the functionally linked external entities that these dentist's use, to solve technological problems associated with the implant placement technique.

This chapter has four sub-sections.

5.1 Introduction and objective.

5.2 Professional organizations and the institutionalization of dentistry - describes the institutionalization of dental care.

5.3 Learning techniques of the dental-care service firms - demonstrate how dentist specialties associated with dental implants, in this study, are conditioned by institutions.

Section 5.4 The case regularities and learning categories. It demonstrates how linkages to learning approaches emerged from the case results and the learning regularities they exposed, related to the implant technique. It concludes with demonstrating how similarities and differences were found among the cases with final observations in Ch. 9.

5.1 Introduction - suggests it is helpful to visualize, in contrast to the Chandlerian firm, where internal business functions plan, coordinate and control their activities, the dental care industry relies on external organizations, within the dashed square, such as dental associations, producer firms, and insurance companies to plan, coordinate and control their activity (Diagram 3).

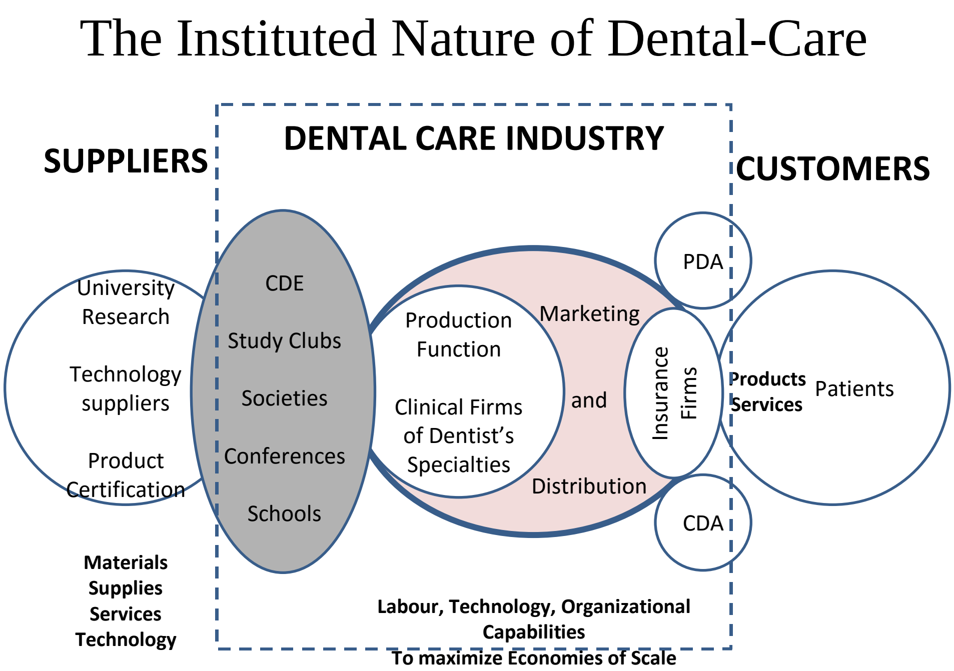

Diagram 3. Instituted nature of dental-care

The following Table 1 is a refined list of functionally linked entities that will guides this visualization.

Communication and interaction entities in the dental-care industry

Canadian Dental Association, CDA, and equivalent
Clinical Dental Practitioner
Clinical Research Hospitals
Dental Society
Health Authorities and Nat. Medical Association, CIHR and affiliates
Health Canada, Health Protection Board, HPB
Insurance Firms, Consultants, Employers, Customer
Private Policy Organizations
Private Training and Research Institutes (in Canada)
Producer Firms
Provincial Governance Associations, ADAC, BCDA
Study Clubs
Supplier Firms, promotional
University R&D, direct
University R&D, indirect
University/Private School of Dentistry

Table 1. Functionally linked entities to dentists, observed in the study

The following section, 5.2 Professional organizations and the institutionalization of dentistry - addresses how these functionally-linked entities and others influence dentist and possibly innovation. Each bolded entity represents the observations of this study, described in detail with some entities grouped i.e. Professional organizations include CDA, ADAC, Dental Societies and Study Clubs.

Section 5.3 Learning techniques of the dental-care service firms - demonstrate how dentists' learning, in this study that are associated with implant technology, based on the observations in section 5.2, are conditioned by the same institutional influence. They are:

a) Their specialization societies, including education acquired in graduate school,
b) The required scale of throughput, and
c) Market distortions, caused by the dental-care financing system.

By applying Johnson (2010) economic logic to learning by doing and using Rosenberg (1982) and searching Lundvall (1985, 1988, 2005) this study observes that their learning is all related to the economic logic of the firm. This reveals the dental-care service firm's access to knowledge within the institutionalized non-market structure they work within, noting Ch 4 already established that real-markets are obscured from the dentist. It is an institutionalized profession comprising with particularly important influences from:

- Canadian Dental Association (CDA), regulating association
- Province Governance Associations (ADAC), regulating association
- Dental Society, facilitates the accreditation boards
- Study Clubs/University/Private School of Dentistry, and
- Insurance firms, act as a bank

The purpose of this thesis was to illustrate post-adoption constraints to innovation, to understand innovation in dentistry. The effect of these distortions will be presented in Ch. 9.

Section 5.4 Case study regularities and learning categories – demonstrates how the researcher found similarities and differences among the cases, that emerged from the case results as the dentist's intended to increase returns to scale, from the adoption and use of high priced technology such as the implant technology.

The case studies (Ch. 5, 6 and 7) observed a number of mechanisms associated with increasing returns from scale and throughput that are used by the three dental firms involved with dental implant technology. They are summarized in the following Table 2, which provided the basis for triangulating observations among and between cases, explained in Ch. 9.

The mechanisms focused on learning by doing are all associated with the production process itself and do not reflect marketing and distribution or other business processes to a significant degree. This would seem to relate to the non-market nature of the sub-sector in which costs beyond throughput improvements are mediated by non-market actors such as dental associations and insurance. Regularities in learning by doing are associated with division of labour through referral leading to specialization, reducing complexity through technology and increasing speed and or reliability through technology (all cases do this).

Throughput Factors	**Case Ch. 8, Surgeon**	**Case Ch. 7 Prosthodontist**	**Case Ch. 6, General Dentist**
Learning by Doing/Producing			
Division of labour	Specialize on implant installation only All work by referral	Specialize on crown and restorative Refer implant to Surgeon	Specialize on simple cases Refer complex cases
Eliminate steps	Knowledge reduces		

	steps required (i.e. stent)		
Decrease complexity	Bone regeneration	Semi-sterile approach	Simulation +3D X-Rays CAD/CAM chairside crown milling
Inter-changeable equipment	YES – install one brand	NO – 3 brands – 3 kits	YES - Install one brand
Standardization	Install one brand	Works on multiple (3) brands	Install one brand
Increase Speed		Internal lab	External lab
	High end diagnostics – 3D, X-ray	High end diagnostics – X-ray	High end diagnostics – X-ray
	Advanced coatings for osseointegration	Impression plates	Reliable anaesthesia
	Tools for bone harvesting	In-house lab – custom work	Multiple kits for multi-maintenance
Reduce uncertainty - (failures, maintenance)	Screen for osteo issues before implant installed	Screen patients for health issues (ie smoking)	Screen out patients with complexity
	Reduce speed to reduce failures		
	Fully sterile infection control (regulated)	Modified infection control In-house lab – high quality, low cost	Switch to "one" more reliable brand
Learning by Using			
Increase Speed – upgrade skills to reduce "learning by doing"	CDE (university), conferences, specialist society	CDE (university), supplier training, conferences, specialist society, study club	CDE (regional university providers), supplier training, conferences, society meetings
Uncertain insurance coverage	Insurance eligibility pre-screened by referring professional	Prescreen for insurance eligibility	Prescreen for insurance eligibility
	Enable user "direct pay"	Enable user "direct pay" Use materials acceptable to insurer	Enable user "direct pay".
		Leadership in Dental and Specialist organizations	
Expand scope	Hi end equipment (Simulation+3D X-Rays)	Multiple kits (3) to service multiple brands = more patients.	Multiple kits (3) to service multiple brands = more patients. (CAD/CAM chairside crown milling) threatens specialist market
Learning by Searching			
Bypass institutional constraints	Direct interface with basic science	Interface with basic science, lecture in graduate school	Incidental interface with basic science (local)

Table 2. Case mechanisms affecting throughput

A key difference is that the more highly skilled professional is more likely to rely on personal skill for throughput improvement and technology to reduce uncertainty of performance while the lesser specialized professional relied on technology to reduce complexity and skill and also standardized around a single reliable brand.

Learning by using is associated mainly with continuing education, a mandated and regulated requirement for continuing practice, and therefore a regularity. Incidental benefits from CDE include learning about new technology and how it can be used.

Insurance imposes another external learning by using requirement on the dentists – how to work with the insurance industry – which is their primary financial connection with the market. Uncertainties in this aspect result in the three cases observed each taking some steps to improve predictability by pre-screening patients or choosing lower cost materials that will be accepted by the insurer. There appears to be minimal customer influence except to accept a user-pay option. All three cases enable that approach.

Learning by searching is possible, and all three maintain some level of connection with the scientific community, but it is unclear that any of the firms are employing a structured search process, perhaps a reflection of the non-market nature of dental care.

The final observations in Chapter 9, will be based on viewing learning at various levels of the economy. Learning is the result of routine activities in economic production of products, then, innovation must also be rooted in the prevailing economic structure of technological opportunities and income elasticities Johnson (2010: 35), as supported by many others Ch.2.

What will be observed in Ch. 9 is the institutionalized nature of the dental care industry, and how that lies beyond the scope of present theory related to economic efficiency in medical care and the dental care sub-sector, in particular.

1.6.4 The cases, Chapters six, seven and eight

These ideas were used as a framework to understand the distributed work-flow of three types of dentists involved in the placement and maintenance of dental implants – General Dentistry, Prosthodontics, and Maxillofacial and Oral Surgeons. A multi-case, comparative study of the specializations was undertaken to follow the progress of knowledge at the technology (dental implant) level. This allowed for a degree of variance. Following Granberg (1997) the dental implant system was decomposed into its components and interactions, to explore how the actors in the technology system functionally align and link their activities around a production process or technique.

The application of a dental implant generally requires services from other specializations and firms. The chapters illustrate these functionally linked industry and institutional structures. This decomposition method does not codify all the dentist's medical skill or imply that all sub-routines are codified or even codifiable. Instead, it captures a map that provides insight into the processes involved, their distribution within the system and how they relate to knowledge flows. In the decomposition rectangular boxes represent techniques. The arrows represent stages to another step with different functional requirements, which in some instances requires a change of dental specialty.

The data collection, in real time and at each level of specification, broke the workflow into knowledge components or techniques, and the artifact input to make the technique function (operational). This was further specified into the firms that produce the artifact (i.e. dental device, tool, instrument, material, chemical, software process or item of process equipment), and who the dentist's turn-to, to solve or explore operational problems with the artifact, thus making up the industrial and institutional (competence centre) structure of the technique. The following diagram 4 represents the generic work-flow dentist, generally follow to place and restore an implant.

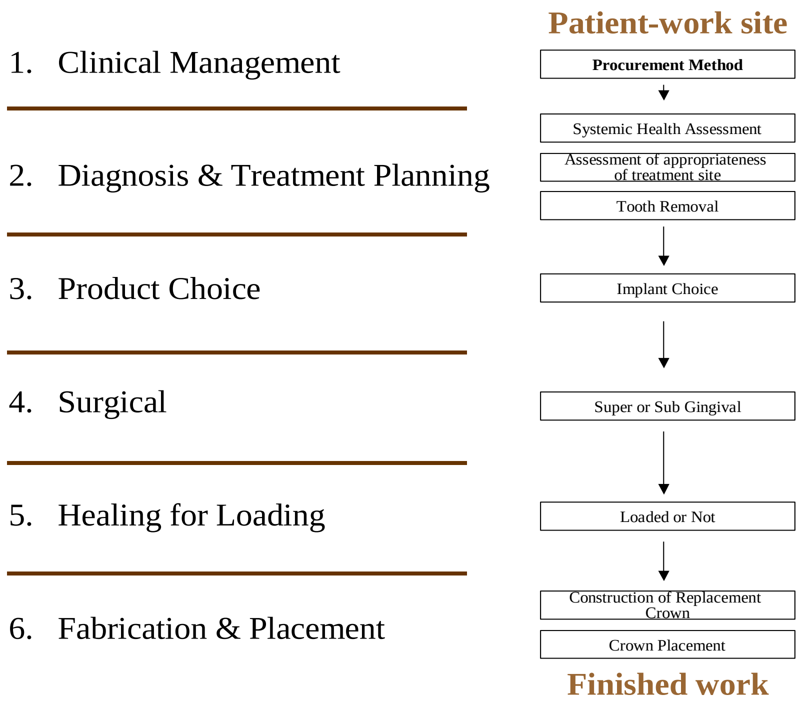

Diagram 4. The generic work flow of the dental implant application technique

Each case will illustrate the work-flow specific to their specialization.

Each case (Ch. 6, 7, 8) identifies how the different types of dentists generate improvements in throughput in their operations. These are compared to identity commonalities and differences. While there is a relatively standard pattern, differences occur because of differences in the knowledge of each specialty about the technique.

1.6.5 Observations and conclusions, Chapter nine

Chapter nine provides a summary of the thesis as the research observations are brought together, that addresses the importance of economies of scale, learning and institutionalization.

The chapter highlights the importance of the functional integration of technical and organizational actors, to enable them to achieve the collective learning needed to generate higher levels of throughput within an institutionalized payments system.

The thesis concludes with a discussion of the strengths and weaknesses of the approach, contributions, implications for policy and potential future avenues of research in this area, as follows.

Contributions

This research is original in that it makes an empirical contribution to innovation studies, by introducing dentistry as an important sub-sector of medicine, to which patterns of innovation differ from medicine.

This research contributes to medical innovation knowledge, in that it, observed General Doctors do not use less advanced technologies than Specialists (c.f. Geljins & Rosenberg, 1994), suggesting policy aimed at shifting the mixes maybe counterproductive to medicine efficiency.

This research supports the methodological approach of focusing on one medical procedure, rather than on all of medicine, to understanding the mechanisms of action that underlie technical change, as in Gelijns & Rosenberg (1994).

Within that condition, this research supports the methodological approach that focuses on post-adoption constraints to understand mechanisms that enable innovation Rosenberg (1976, 1982), David (1986) and others Section 2.4.2.3 - Iterative learning between technology and the market.

The constraint to innovation in Dentistry is the financial system as it changes the direction of innovation. It is linked to institutional needs and to the institutionalized market that excludes responses to market demand, distorting the business functions of marketing and distribution. This prevents a full understanding of the transformation effects of new technology to dental care practice. Insofar, the mechanisms of action important to innovation in dental care, identified in this research are: higher throughput, as in "increasing speed of treatment at a given level of reimbursement" and the importance of the latter to capacity utilization of dentist's time – decrease dentist's time at the chair per treatment. These interrelationships are important to increase quality in dental care services and to the adoption of new technology. In this context, continuous dental education is the key enabler of innovation in practice. That is my contribution to innovation theory knowledge.

This research extended the Chandler (1990) "Economy of Scale" theory by adding field of dentistry.

Chandler developed theory for a semi-skilled production oriented manufacturing application. This research adapted the model to the highly skilled activities of professionals as part of the dental-care production function. A key insight taken from Chandler, is not the importance of scale, as in spreading fixed costs over large amounts of output by adding more dentist's chairs, but instead the importance of increasing speed of treatment at a given level of reimbursement and that is, the "capacity utilization" of the dentist's time, its influence on cost structures and how they can be improved by better coordination.

This research has advice for institutional system theory, which currently talks about supply of knowledge as means for trajectory change but does not take into account, at a disaggregated level, how institutions condition the knowledge firms can apply.

This research extended Granberg's innovation system data mapping technique, designed for industry, to map work-processes of highly skilled medical professionals. The key contribution to this mapping technique, and its success to this research, is that it was modified to collect data in real time, considered a contribution to this method.

Limitations

a) To make this research generalizable, more directly comparable data should be collected from others samples that could include, other regions in Canada and countries.
b) To make this research more generalizable, other complex dental procedures should be analyzed to see if the pressures on capacity utilization are as sharp.
c) Dentists are high paid professionals, and it maybe that there are other motivations that affect learning, that have not been brought out.

Generalizations

Generalizing is something that should be done with care until more comparative data are collected. Chapter one talks about how the implant technology is unique, as the learning by doing aspect, is particularly sharp. However, it is possible to generalize around the theoretical arguments of the thesis.

a) All cases support the modified Chandler (1977, 1990) application to understand how highly skilled professions, manage the throughput effect in their service firms.

b) All cases confirm learning is institutionalized. All cases confirm the application of Johnson's (2010) model assists in identifying institutionalized activities.

c) All cases support the "learning by doing" paradigm supported by innovation system theory (Arrow, 1962; Rosenberg, 1976, 1982; David, 1986). Medical innovation theory (Gelijns & Rosenberg, 1994; Nelson & Buterbaugh et al. 2011; Morlacchi & Nelson, 2011). Institutional theory (Johnson, 2010; Nelson and Winter, 1977).

d) All cases confirm the institutionalized effect of insurance, and how the insurance based financial model inhibits and/or molds innovation, as found in medical innovation supported by Gelijns & Rosenberg (1994).

e) All cases support, adoption is the beginning of the innovation process, which is the theoretical underpinning of the innovation theory (Ch. 2), supported by Marx (1858), Rosenberg (1976, 1982), Pavitt (1984) and Gelijns &Roserberg (1994) and in the medical literature, supported by Nelson et al. (2011) and Morlacchi et al. (2011).

Opportunities for further research

a) More innovation theory work is needed in relation to post adoption risks and constraints, associated with transformation of technique. Innovation risks are not only found in the science (upstream) end of the linear model widely used for medical innovation, risks of transformation of technique begin with adoption.

   Post adoption risk is an important consideration because it can change the direction of learning. From an innovation and economic policy consideration, it maybe that, transforming technology through technique is more important or equally as important to advance an economy, as iterating with science to advance technology. Such work could attempt to clarify the "do's and don'ts" of the innovation.

b) This research observed a very strong connection (casual) between continuing professional education and changes in practice, suggesting potential policy concerns that justifies further testing for two reasons: a) it is mostly large firms that provide that function in the dental industry, and smaller firms outsource this function. The fact that Canada's firm structure composition, is mostly small firms, this may be an important topic for innovation and industrial policy, and b) it could relate to efficiency issues in medical health care that could be taken up by health care policy. In relation to possible efficacy concerns, **throughput this**

research, dentists' that practice dental-care have shown dedicated concern for the oral health of their patients, or this research would have not been possible.

d) Dentistry is one of many regulated professions. It would be valuable to apply the approach used to look at other professions to see if some or all of this research can be generalized to other professionals.

CHAPTER TWO
LITERATURE REVIEW and THEORY

2.1 Introduction

In seeking to explain innovation in dentistry, the thesis has chosen to focus on dental implant technology. The dental-implant tooth-replacement technique is complex and involves many steps, technologies, dental specialties and organizations. Therefore, its diffusion, raises questions about how knowledge flows influence innovation, particularly given the substantial variance found between countries in its uptake, suggesting particular (national) organizational structures influence these flows.

In seeking to address the main research question related to how innovation takes place in dentistry, it seeks to understand how institutions influence innovation and in particular the articulation of demand. The introduction briefly highlighted two other features of dental innovation that were found to be important in the pilot study: firstly the importance of throughput as a key economic factor in dental practice, and secondly, the importance of "learning by doing" (Ch. 3).

This chapter reviews previous work in this area. It is structured in 5 sections. Section 2.2 presents the literature review. Section 2.3 provides an overview of the dental industry in Canada, and its historical evolution. It stresses the economic importance of throughput and economies of scale that are achieved by speeding up procedures at a given level of reimbursement. Given the importance of throughput, Section 2.4 briefly reviews Chandler's theory on the growth of the large firm in mass production industries. While dental practices are obviously not large firms, Chandler's insights into the interplay between new technology and new organizational arrangements, are argued to be insightful in this setting. A brief historical overview of innovation theory links this to Johnson's Institutional model. Section 2.5 identifies theoretical gaps and how the case study might address them.

The literature review therefore contains both the literature that was used to frame the initial research and also the theory that was selected to interpret the empirical findings. This division was important as the initial literature used in the study was found not to be as useful as hoped for understanding the important roles played by demand and institutional set ups found in the empirical work.

This introduction concludes with some definitions.

Definitions

Despite its importance to innovation studies, technology is only rarely defined. In this thesis, "technology" is defined as a process Bucciarelli (1994), with the ability to carry out productive transformation (Metcalfe, 1995). "It is an ability to act, a competence to perform, translating material, energy and information in one set of states into another, more highly valued set of states" (Ibid.: 34). It has three interacting forms that are explored in this thesis: knowledge, skills and artifacts (Layton, 1974). Their application typically involves a wider set of institutions, with variance in institutions between sectors, affecting decisions to try out new technology (Nelson and Winter, 1977: 61).

When "technology" is used in the thesis it typically relates to *techniques* Pavitt (1987b), Rosenberg (1976b, 1982), Nelson (2008) with "artifacts" having imposed functions so that the same artifact can have multiple functions, as supported by Nightingale (2008: 562-3). Although artifacts can be used as technologies, their functions are imposed by the technique, rather than intrinsic (Ibid.: 563). "Technique" relates to how the function is generated (i.e. how a production process is achieved in practice) using configurations of artifacts, knowledge and skills. These skills often have a large tacit element. "Innovation" is distinguished from "invention" – coming up with a new idea – and is understood as the first, successful (commercial) introduction of new and improved products and processes (Freeman & Soete, 1997).

2.2 Literature Review

Dentistry is a sub-category of medicine, for example, 'dentistry and surgery' are part of a broad medical field in the SPRU patent database.[16] Similarly, the "medical device category" of global trade statistics in Canada includes dentistry and medicine (confirmed by Fred Gault at Statistic Canada, 2009).[17] However, dentistry plays a relatively minor role in the medical innovation literature, and according to Dancer

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[16] This database is structured to reflect data on patenting in the United States, supported by (Carlsson, 1997: 33).
[17] www.ic.gc.ca-MedicalDeviceIndustryprofile_Oct26_2009.pdf.

(2010) is smaller, under-funded and dentists are less well linked to the larger traditional medical organizations. In the wider medical innovation literature Gelijns and Rosenberg (1994) suggest the focus on technological innovation, which is so important for the production of goods and services, is less applicable in medical settings. Cost reduction pressures in health care settings rarely specify the directions in which cost reduction should be sought while in industrial settings they often direct innovation towards changes in technology (Rosenberg, 1982: 123; Gelijns & Rosenberg, 1994). However, as noted in the introduction, two key features of medical innovation are highlighted in this work. First, the high levels of uncertainty about new technologies that continues long after introduction. Second, the importance of iterative feedback between producers and users. Research on dental innovation, is limited, but highlights a similar pattern.

Dancer (2010)'s doctoral research also highlighted the importance of professionalization in dentistry. The research explored the social construction of professional roles and compared theoretical models of professionalization, by testing for changing perceptions relating to deprofessionalization (removal of diagnostic power) of medical/nurses to the dentists. Yacyshyn (2002)'s research highlighted the role of economic factors in comparing information management systems. The research gathered real-time data on the financial earnings of dental care firms, and showed how they could be improved with ICT.

With dental implant technology, there is a body of literature as follows. On its opportunities Scarf & Tarnow (1993), Ring (1995), Albrektsson & Wennerberg (2005), Tosto (2006), and Hahn (2007) and on its efficacy which highlights the importance of subsequent innovation Zarb, Smith, Levant, Graham, & Staatsexamen (1979), Zarb & Schmitt (1990a, 1990b) and Albrektsson & Wennerberg (2005). Jönsson & Karlsson (1990) explored cost/benefit effects on scheduling. Fleming & Flood (2008) found that users' knowledge and economic factors influenced scheduling.

Albrektsson & Wennerberg (2005) explored the history of the implant technology and highlighted the role of Canadian researchers in bringing widespread recognition to Dr. Brånemark's scientific discovery of osseointegration. This history highlights the importance of bringing the research community together at a conference Sullivan (2001), and building databanks (Bryant, 2001). This generated publications Zarb (1983) and Brånemark, Zarb, Albrektsson, & Lekholm (1985) at a time when there were no publications in American journals of any successful attempts to place implants anchored in bone (Albrektsson & Wennerberg, 2005: 327a).

The emphasis on publications is important because technology diffusion has been linked to the cognitive and behavioural characteristics of dentists (Chapko, 2007; Parashos & Messer, 2006). Other studies stress the importance of access relationships to insurance status (Litaker & Cebul, 2003; Cooper, Manski, & Pepper, 2012); service supply elasticity to price and/or procedure (Rice, 1983; Grembowski, Conrad, Weaver, & Milgrom, 1988; Grembowski & Milgrom, 1988) and establishing quality of national dental care programs based on dentate population (Gilbert, Shelton, Chavers, & Bradford, 2003; Jones, Boehmer, Berlowitz, & Christiansen, 2003). Schnitman (1990) looked at efficacy of implants, over other modalities, and found that while there are advantages, costs are a major constraint on diffusion.

The importance of interactions between producers and users in dental innovation is suggestive of a link to von Hippel's (1976, 1988) -dominant innovation pattern, found in the development of scientific instruments. Rosenberg (1992) highlighted the importance of users as sources of innovation in scientific instruments (see also Shimshoni, 1966; Utterback, 1971; Achilladelis, Robertson, & Jervis, 1971). For both major and minor innovations von Hippel (1976) found:

> It is almost always the user, not the instrument manufacturer, who recognizes the need, solves the problem via an invention, builds a prototype and proves the prototype's value in use. Furthermore, it is the user who encourages and enables the diffusion of his invention by publishing information on its utility and instructions sufficient for its replication by others users – and by instrument manufacturers (: 227).

He goes on to note that:

> …we suspect that this pattern is also characteristic of medical and dental innovations (e.g. new dental equipment is usually invented, first used and perhaps discussed in journals by dentists prior to commercial manufacture being undertaken by a dental equipment firm (: 231).

The titanium dental implant technology doesn't entirely fit this pattern, as the underlying science, was generated by an academic researcher.

Rosenberg (1992: 386, 1994) found the development of scientific instruments have a symbiotic relationship that runs upstream to the development of basic science. When usefulness is apparent, the instrument finds application in other scientific areas in academia or in industry, but often after substantial modification or redesign. This is similar to the famous case of the capital goods industry, where machine tools originally designed to meet specifications of textile or locomotive or musket manufacturers were later transferred to manufacturers of sewing machines, bicycles, typewriters and automobiles (: 251). The post-market modification of instruments in consultation with academic researchers, helped build fabrication and design skills that expanded the capacity of academic researchers to conduct research. In medical settings, while expanded diagnostic capabilities may outrun the possible therapeutic interventions, they can improve the search for effective therapies.

In the development of medical technologies, Gelijns and Rosenberg (1994) found similar complex feedback loops between clinical physician users and producer firms. As with scientific instruments, when a technology is adopted it often requires substantial modification or redesign. During that process, physicians in consultation with producer firms, can innovate to a) increase the intensity of use in practice, b) expand indications of use, and c) introduce new or modified technologies to practice (: 40, 42) culminating in increased costs to medical practice.

Hence the emphasis on the high degree of post-adoption uncertainty, and the importance of close interaction between developers and physicians in the medical innovation literature (Gelijns & Rosenberg, 1994: 32; Ramlogan, Mina, Tampubolon, & Metcalfe, 2007; Morlacchi & Nelson, 2011). This literature highlights the importance of clinical research hospitals and the tacit knowledge of physician-users to the adoption and intergenerational diffusion of knowledge. Ramlogan et al. (2007) found globally distributed scientific networks where medical innovation emerges through multiple interactions between firms that sponsor clinical studies, clinicians and academic scientists. The relationship is so tight that the “supply chain interdependence of the medical service economy and the medical manufacturing industry are effectively one” (Ramlogan et al.,: 487).

Implant producer firms Nobel Biocare and Straumann also have infrastructure investments (for example in Canada). These investments, described as “private research and learning-by-doing schools”, offer courses that are required as part of dentists continuing license to operate.[18] So while user-producer interactions are important they are situated within a more complex institutional setting.

This contrasts with more typical situations where consumers and suppliers are clearly separated (Nelson & Winter, 1977). In such settings the innovator's profits and the losses experienced by the laggards stimulate imitation (Ibid.: 64). In non-market settings, organizations that do not compete have less incentive to prevent others from adopting their successful innovations, and can play more complex roles in innovation.

For example, Nelson & Buterbaugh et al. (2011) find medical know-how progresses along three pathways: the first involves basic scientific research into disease pathologies to generate deeper scientific understanding of disease; the second involves technologies that enable the development of new modalities of treatment and diagnosis that are not necessarily related to deeper understanding of disease, such as electronics and new materials; while the third involves learning in clinical practice. The second pathway supports the discussion on scientific instruments wherein development in one field leads to new technological capabilities in others (Rosenberg, 1992). The third pathway, highlighted as critical but undervalued, involves downstream "learning in practice" where a physician refines and extends the use of new innovations Nelson & Buterbaugh et al., (2011: 1342) supported by Gelijns & Rosenberg (1994) and Morlacchi & Nelson (2011). These three pathways will obviously interact making the lines between "observation, evaluation and experimentation blurry" (Nelson & Buterbaugh et al., 2011: 1342).

2.3 Dental Industry in Canada

Dental-care involves a different work environment than other forms of medicine, reflecting their different historical roots.[19] This makes the innovation capacity of clinical dentists different from clinical medical doctors, who (in Canada) work in public hospitals as part of the nation-wide clinical research system. Dentists, by contrast, operate in the private sector, with only about three percent working in academia or in public health (Papadopoulos, 2010; CDA, 2013). Physician-dentists working in private

[18] In support, //.nobelbiocare.com (2007); and for Straumann, //.tdlc.ca (2010).
[19] When dentistry competed for professional recognition with medical doctors, medical doctors considered "medicine" and "surgery" separate, with the latter looked upon as a trade or handicraft Chauliac (1778); Billings (1895) and supported by Weinberger (1940); Weinberger (1948); American College of Dentists (2002).

practice therefore have less access to the “learning by doing and using” from the clinical trials taking place within the public medical system in Canada.

This lack of integration is important in this context as Canada places 3rd in clinical study publication authorship rates after the United States and Germany, Hoekman, Frenken, de Zeeuw, & Heerspink (2012), and rates second or third, depending on the publication source, within the global standards for share of clinical trials (Boudreau, 2007). Roughly 25% of the total 74,526 public clinical physicians (2013) are involved in clinical trials and of those, only about 1 to 2% are dentists (2010) (Tyrrell & Palmer, 2009: 35; Leclerc, Laberge, & Marion, 2012; Canadian Dental Association; Canadian Medical Association).[20]

Throughput is an important factor for dental-care firms and is embedded in dentist education. Procedures are covered by public and private insurance systems, with the regulated insurance market playing a key role in structuring the economic incentives within the dental system. In the Alberta dental care system, where the case studies are found, the dental regulation agencies and insurance firms regard dentists as the key gatekeepers responsible for the adoption of new technology.

Canada has instituted mandatory continual dental education (CDE) for dentists, which takes place in both Schools of Dentistry in Canada and private schools of dentistry in the United States. A range of Schools of Dentistry, private implant training institutes, national and provincial governance associations, dental societies, study clubs, supplier clubs, other clinical dental service clinics and producer firms all play key roles in communicating with dentists and training them to work with new technologies and procedures.

2.4 Theory

This section outlines Chandler’s theory of the large mass production firm, which emphasizes the importance of economies of scale generated by combining new technology and organizational structures and practices. It then reviews the innovation theory literature from early linear models to an institutional learning model.

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[20] //.cda.ca; //cma.ca.

2.4.1 Chandler – Economies of scale and throughput

Chandler (1990) explored the emergence and risk of the large firm, and the process of industrialization in late nineteenth century America. While economic growth in pre-industrial economies typically involved adding labour, for industrial growth Chandler argues a radically different approach. It involves increasing the scale, internal specialization and co-ordination of a business (Marshall, 1890; Lazonick, 2005: 31). A three-pronged strategy of investment in high-cost production equipment, distribution and management allowed large firms to generate economies of scale and scope (Chandler, 1977: Ch. 8; Lazonick, 2005: 39-40).

To exploit scale economies Smith (1776) and Babbage (1832) that could result in competitive advantage, the firm required managerial structures and systems to interrelate planning, coordinating and control. Capital investment was a key requirement to expanded output. The expanded output came about by improving (complementary technologies) and rearranging input (standardization, etc.) resulting in increases in volume and velocity (speed) of throughput rather than growth is size of factory.

Investment in higher-cost capital goods that allow reductions in the cost of production only become economically viable when their higher fixed costs are spread over a larger amount of output. Hence, it was only when they were combined with managerial practices and organizational structures that allowed high rates of throughput, that they became more profitable and allowed larger firms to outcompete smaller firms with cheaper production equipment. This created an emphasis on increasing throughput and the utilization of higher capacity production processes, which typically required more sophisticated managerial practices than had been found in smaller firms, with their simpler production processes.

Large-scale mass-production created the need for mass marketing and distribution. Increased fixed costs created pressures to achieve high labour and equipment utilization that creates the need to control raw and semi-finished material, marketing and distribution and to integrate industrial structures. Firms adopting Chandler’s three-pronged strategy of investment and structural change could shape, not just react, to market forces (Chandler, 1990). Firms with the required managerial structures and systems for planning, coordination and control could exploit economies of scale and scope to increase output and profits without proportionate increases in labour inputs.

As Chandler (1990: Ch. 2) notes, scale is captured by the "potential rated capacity" of the physical characteristics of production facilities which defines how much output they could potentially generate over a given period of time. Throughput is a function of this scale (rated capacity), the extent to which it is utilized and the speed of production (which captures how intensely capacity is used). High levels of throughput require organizations to integrate, coordinate and control the flow of materials through production processes. Increased throughput was often achieved by increasing speed, rather than increases in plant size and workforce (Chandler, 1977: 244).

While the Chandlerian framework is focused on large firms, as already noted, the same economic influences can be at work in smaller firms. One might expect a dentist's clinical practice, for example, that uses high cost equipment and labour to utilize implant technology, would benefit from using reliable routines, interchangeable tools and instruments, and compatible processing equipment to increase throughput. In fact, specialization and routinization are observed regularly in the dental industry. The process a dentist follows to replace a diseased tooth with a dental implant, includes division of labour between specialists, and the techniques employed are intended to achieve higher throughput.

The benefits achieved in this way make firms "organizational successes rather than market failures" (Lazonick, 1991: 13). Firms are understood as organized divisions of labour and technology that are able to produce goods and services more effectively than markets (Pavitt, 1998). A more dynamic view associated with Lazonick (1990: Ch. 7, 8) and Chandler, Amatori, & Hikino (1998) highlights that achieving high throughput or speed, requires an effective division of labour and functional integration of both technical and organizational factors, to enable collective and cumulative learning Lazonick (2005: 40-41), supported by Dosi & Teece (1993) and Patel & Pavitt (2000). These activities may be expected to be more difficult in settings, like dentistry where managerial co-ordination is less extensive.

As previously noted dentistry is typically carried out in small private firms, with 93% of dentists working in groups of five or less and 54% in solo practice. While the Chandlerian framework is focused on large firms, the same economic influences may be at work in smaller firms where production is more frequency rather than flow based. However, dentists use high-cost equipment, and invest significantly in their own expensive professional education. The more that this can be utilized, at a given level of reimbursement, the more procedures they can undertake in a given period of time and the higher their profits will be. The process a dentist follows to replace a diseased tooth with a dental implant, involves a complex division of labour between specialists, and techniques and one may expect a degree of co-ordination would be needed to increase throughput. The key insight taken from Chandler (1977) is not the importance of scale but instead the importance capacity utilization, its influence on cost structures, and how they can be improved by better co-ordination.

Chandler's approach can potentially provide insights into the economic drivers of innovation in the dental industry, however it needs additional dimensions to address the nature of technological innovation and iterative learning in a professional service firm. In particular, one needs to pay attention to how co-ordination takes place beyond the firm. Because dentistry isn't integrated within large firms, and is instead typically distributed across small firms, the opportunities for managed co-ordination are less extensive, which may make organizational adaptation more difficult, particularly if organizational practices are structured by institutions in a highly regulated market. The economic benefits to the adoption of new technology may well require simultaneous organizational innovations, and networks of dental practitioners will lack the centralized managerial co-ordination available to larger firms. Instead, external co-ordination is structured by a heavily regulated market. It may well be the case that innovation will be constrained, even (as is the case with dental implants) if the technology is superior. To understand the potential conflicts it is necessary to explore innovation theory in more detail.

2.4.2 Innovation theory, from linear to distributed models

The previous sub-section has argued that economic incentives related to the role that increased throughput plays in improving profitability may act as a demand factor that influences technical change. However, rather than co-ordination being achieved through managerial hierarchies, as Chandler found in large firms, co-ordination in dentistry is mediated through institutionalized markets. This sub-section explores what insights can be drawn from innovation theory to understand technical change in such a setting. It explores the literature from early linear models, which remain insightful in some regards for understanding modern dental innovation, to more systemic frameworks that draw on research on organizational learning. As the body of theory has evolved it now incorporates more players and their interactions, increasingly recognizing the diversity of innovative activity.

2.4.2.1 From linear to interactive models

The early science-push model developed after WWII suggested innovation emerges from prior scientific research (Brooks, 1994: 477).[21] It implies a clear distinction between research and development, and adoption, with the early research and development phase being the most uncertain (Gelijns & Rosenberg, 1994). The advances in science that drive innovation are largely seen as autonomous responses to internal forces, rather than external social and economic influences as suggested by (Bernal, 1939; Bernal, 1971; Rosenberg, 1982: 29). R&D was treated as a “black box” (Rosenberg, 1982, 1994; Brooks, 1994: 478). Its preoccupation with “technical originality” reflects Schumpeter (1939) and Schumpeter (1942)’s view of the importance of radical innovations to generate perennial gales of creative destruction (cf. Rosenberg, 1982).[22]

In a medical setting the linear model would suggest innovation begins with biomedical scientists generating a new idea, which then moves from the laboratory to animal models and to selected populations, then to the bedside (Gelijns & Rosenberg, 1994: 30, Figure 2). While this may be a reasonably accurate picture of pharmaceutical innovation it is misleading to suggest that all the uncertainties are resolved by the time the product has been introduced into clinical practice.

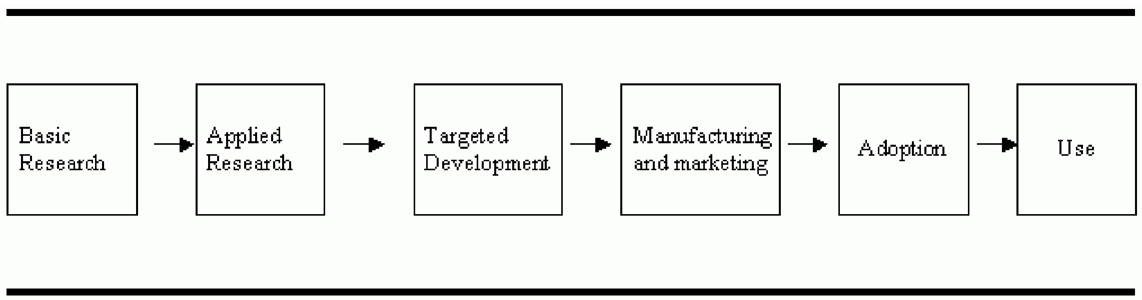


Figure 2. Linear model of innovation (Gelijns & Rosenberg, 1994: 30)

[21] It was legitimized by the influential Bush (1945), report ‘*Science, the Endless Frontier*’, who built on the military success of War II, suggesting the main retarder of economic growth, in the post-war United States, was low levels of academic research Brooks (1986: 124), even though Bush took a more systemic view that recognized the importance of R&D departments in firms for economic growth, it was the linear view that was widely adopted and applied (Calvert, 2002: 151).

[22] Suggesting Schumpeter’s work was more about understanding the nature of capitalism and the associated competitive process and less about understanding the process of innovation, at the firm level, as generally old and new technologies co-exist for long periods of time.

The science-push linear model applies in some exceptional cases, such as biotechnology, but remains over-emphasized in STI policy (Tassey, 2007). It fails to explain why or how innovation processes respond to market and social signals (Pavitt, 1987b). Moreover, addressing customer requirements seems to have more influence on innovation success than technical superiority (Rothwell, Freeman, Horlsey, Jervis, Robertson, & Townsend, 1974).

An alternative market-pull linear model treats the supply-side as subordinate and passive (Rosenberg, 1974b: 93) and suggests that changes in patterns of demand, often measured by changes in volume of a particular class of patents, drive patterns of innovation (Schmookler, 1966; c.f. Rothwell & Freeman et al., 1974; c.f. Mowery & Rosenberg, 1979). Mowery & Rosenberg (1979) critiqued the methods Schmookler (1966) used to measure demand. They noted, “to explain the historical sequence in which different categories of wants have been satisfied, via the inventive process, attention must be paid to the supply side variable: the growing stock of useful knowledge as most patents never reach commercial exploitation and many commercially successful innovations are never patented” (Rosenberg, 1982: 232), see also Patel & Pavitt (1995). Historical evidence confirms that inventions are rarely equally possible in all commodity classes (Rosenberg, 1976b: 268-9).[23]

The market-pull model consequently fails to address the uneven development of different technologies, which can be partly attributed to the degree to which they exploit the science base, and the institutional and organizational influences that are different across firms, sectors, and countries (Dosi, 1982; Rosenberg, 1976b; Nelson & Winter, 1977; Martin & Nightingale, 2000). Users and industries are not homogeneous in the inventive activity they can draw on, or in the knowledge they can consider as potential substitutes in the inventive process (Rosenberg, 1976b: 279; David, 1986). For example, in the medical industry, practitioners have different perceptions about what diseases are solvable (Gelijns & Rosenberg, 1994; Mina, Ramlogan, Tampubolon, & Metcalfe, 2007).

2.4.2.2 Technological trajectories and paradigms

Given these problems with linear models in the 1970s and 1980s more sophisticated models of innovation emerged which stressed the way in which organizational problem

[23] The investigation of pre-existing innovations ‘reads history backwards’ and always finds the educational component of innovation already in place (Freeman, 1997; Nightingale, 1997).

solving routines mediated between the research base and the market. Nelson & Winter (1977) evolutionary theory reformulated the push-pull debate in terms of technological trajectories that emerge from the synthesis of supply and demand factors. Technology advances along a trajectory, reflecting path-dependent, firm-specific know-how about how to advance practice Nelson (2008: 486), as can be seen in historical examples such as 19th century mechanization, scale economies in continuous flow production and more recently, the decreasing size of circuits on microprocessors.

Dosi (1982) took the idea of scientific paradigms and applied it to technology. Paradigms consist of sets of procedures, definitions of relevant problems, and details of the specific knowledge related to their solution (Dosi, 1982). Paradigms have a powerful exclusion effect Metcalfe (1995) and can blind engineers and organizations to other technological possibilities. In this regard they are similar to Nelson & Winter's (1977) technological trajectories and Rosenberg's (1976) focusing devices (: 117). They provide routines for trading-off between scientific and technological inputs, economic incentives (such as cost and labor savings), and institutional and social factors.

As noted earlier, in relation to dentistry and medicine, one key way that knowledge production and use is structured is through occupations and professions (Nelson & Winter, 1977). "The systematic knowledge base of professions is thought to have four essential properties. It is specialized, firmy bounded, scientific and standardized" (Schön, 1991: 23, 307).

At a more aggregate level, these paradigms and trajectories cause factories that produce similar products to have similar production processes (Nelson, 2005: 161; Nelson, Peck, & Kalachek, 1967). Willingness and ability to adopt an innovation are based on degrees of uncertainty and available information (Rogers, 2003). Awareness and interest motivate a potential adopter to seek subjective evaluations about choices from near-peers (Rogers & Kincaid, 1981). Mutual understanding results in common choices for trial and adoption. Rogers (1962) asserts that diffusion, among connected members of a social system, follows an s-shaped curve representing the cumulative conversion of adopters over time (Rogers, 1983; Rogers, 2003). Techniques and knowledge tend to become associated with particular sectors Malerba (2005), which in turn can be associated with particular occupations and professions (Nelson 1967, 2005; Nelson and Winter, 1977).

The increased emphasis in this work on uncertainty, problem solving, learning and path dependency led to the chain-link model of innovation (Kline & Rosenberg, 1986: 289, Figure 3). This incorporated feedback processes and iterations between the stages of the development process, paying attention to stocks as well as flow of knowledge, and how learning could reduce uncertainty (Ibid.: 289). Critically, these feedback loops enabled market considerations to influence science (Rosenberg, 1974b; Rosenberg, 1974a; Pavitt, 1984; Nightingale, 2008).

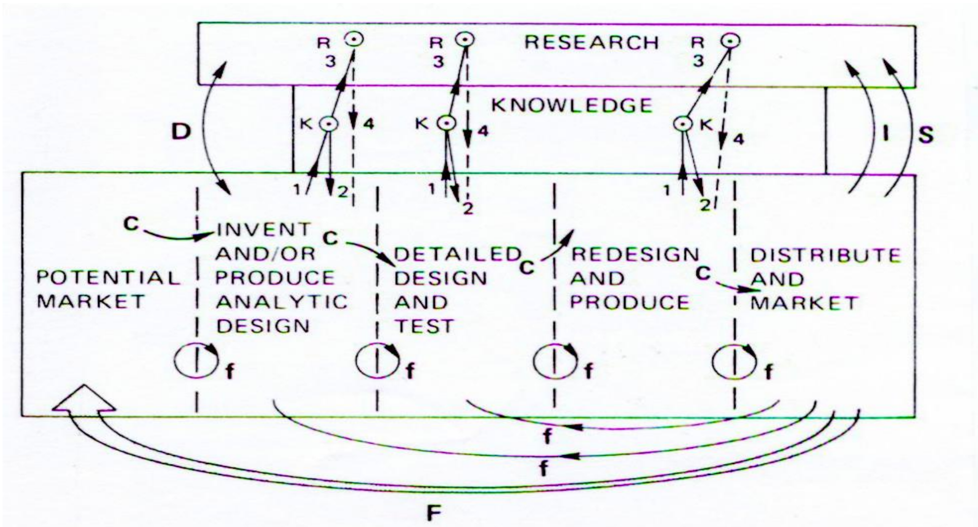


Figure 3. Chain link model of innovation (Kline & Rosenberg, 1986: 286)

More recent work has extended these ideas beyond the product development process and hence beyond the boundaries of the innovating firm. Iteration between a technology and the market inevitably exposes technical imbalances that impact diffusion and provide opportunities for further innovation. For example, in the development of medical technologies, Gelijns and Rosenberg (1999) found iterative feedback effects between clinical physician users, producer firms and a technology used for a clinical condition. Physician users help direct technological development, advance scientific and engineering knowledge and articulate demand.

These iterative effects are important because of two forms of learning (and their associated technology transfer mechanisms) - “learning by doing” Arrow (1962) and “learning by using” Rosenberg (1982) in David (1986: 384). The iterative learning between learning by doing and using, can be considered as “learning curves of experience”. The accumulation of experience in production and use, helps sustain a continuing flow of incremental innovation along a trajectory. This lowers the costs of successive vintages of technology and extends penetration into new markets and areas of application (David, 1986: 384).

2.4.2.3 Iterative learning between technology and the market

Research highlights a number of important iterative interactions that influence innovation (Rosenberg, 1976a; Rosenberg, 1982: Ch. 5, 6, 7, 10). Learning between user and producers is a key interaction. Better integration of product development and adoption by users, provides opportunities for firms to create second-generation products (Rosenberg, 1982). Often empirically acquired and accumulated knowledge of practice is needed, that cannot be generated in R&D laboratories (Rosenberg, 1982:444; Dosi, 1982; Brooks 1994). For example, the techniques, methods, and artifacts used in industry vary considerably and it may not be possible to explain, "why they perform the way they do" (Rosenberg, 1982: 144). Blast furnaces and coal-fired electric power generating plants were operated with limited understanding of their combustion processes. Similarly, aircraft design was achieved before the theory of turbulence or compressibility was understood and used to determine optimal design configurations (Rosenberg, 1982: 143; 1994: 12). In dentistry, user need led to the development of allogenic tooth-transplantation techniques before science understood bone dynamics (Loma Linda University School of Dentistry, The American College of Prosthodontist, Academy of Osseointegration, & The American Academy of Implant Dentistry, 2003). Interactions with users can therefore provide important inputs into future innovation that are not available within the innovating firm.

Many materials are subject to a host of practical maintenance difficulties that may be difficult to articulate prior to product launch. For example, degradation, fracturing, contamination, aging, corrosion, and brittleness. Scientific understanding assists engineers in knowing where to look when a problem occurs. In dentistry, increasing the osseointegration (bone integration) of tooth-implant technology is based on an understanding of the biology of bone growth.[24] Innovation, whether pertaining to the physical shape, material, or coating of the implant, involves increasing or maintaining

[24] It is important to understand the term "osseo" as it is used often in the thesis. The response from the forces of 'bone to dental implant' is different from the force response from 'bone to bone' (natural tooth-root bone to jaw bone). The latter are the forces exerted with the normal clasp of upper and lower teeth when the jaws are closed. Bone to bone (tooth root to alveolar bone/jaw bone) exhibits a biological response of bone resorption or 'bone uptake' rather than 'bone build-up', which is the biologic response from the forces of alveolar bone (jaw bone) to implant. The bone build-up secures the implant to the jaw-bone, analogous to a fence post secured by concrete adhering to the post. The process of increasing osseointegration enhances bone integration by fibrous growth locking the implant more securely into the jaw and/or sinus bone.

the turnover rate of the living bone next to the prosthetic implant device. Understanding the biological mechanisms that produce a more rapid and continuous bone response to the implant is therefore helpful to the dental technologist when problems occur (Garetto, Chen, Parr, & Roberts, 1995; Boyne, 2003).

Learning from users can also identify research directions. Technology has shaped science in important ways because it provides observations and data that scientists then explain at a deeper level (Rosenberg, 1982: 147). Even in scientific fields such as electricity and chemistry, practical experience with new technologies has often led to major discoveries such as crystal growth or knowledge of the ionosphere (Rosenberg, 1982: 144-46).

Interactions and iterations can also help capture knowledge about how artifacts and technologies might better fit into systems. Technologies and techniques are typically embedded in interrelated activities, so that changes in one component can have repercussions on other components in the system (David, 1975: 83; Rosenberg, 1976b: 125). As a result, internal pressures in complex technologies can initiate exploratory activity in particular directions – what Rosenberg refers to as “compulsive sequences” – that help identify areas for further improvement and focus subsequent research (Nelson & Winter, 1977: 73; Rosenberg, 1982: 147; Dosi, 1982).

For example, Kay's Flying Shuttle led to the need for speeding up spinning operations because it created a shortage of weaving capacity in the English cotton textile industry. This encouraged Cartwright's introduction of the power loom (Rosenberg, 1976: 112). Similarly, in dentistry, during the sixteen and seventeenth centuries the demand for replacing diseased teeth with healthy human teeth resulted in a growing black market in teeth. To store them in the absence of refrigeration, John Hunter (mid 1700s) introduced a technique in which teeth were extracted, boiled and replanted in a cock’s comb (Tsukiboshi, 2001).

Links and interactions within a system of actors involved in innovation therefore not only allows better understanding of how a technology performs, but also helps guide future development. These interactions are important as the initial versions of new products or processes often suffer from numerous flaws. Identification and remedy of these defects depends on accumulated feedback information from users – what Rosenberg (1982), calls “learning by using”. As the new technology and its microeconomic environment co-evolve, the extent of profitable application will often broaden (David, 1986: 379). This is Mansfield's diffusion effect: it is generated by the gradual dissemination of information on the technology, and the gradual increase in the extent of an innovation's application (Perez, 1983). Across the economy it appears as an adjustment process as learning-by-doing resolves inefficiencies and encourages production efficiency.

The potential existence of irreversible, dynamic scale economies, under conditions of increasing returns, can in theory become cumulative. This creates the potential for a particular product, process or system design to potentially lockout rival technologies, and become locked in (David, 1986: 385).

Any decision to introduce a new technology often requires discontinuing the operation of an existing facility or technology. It takes time to supplant old technologies particularly if they are embedded in wider systems David (1986: 382) and knowledge needed to use them is costly to acquire (Teece, 1976; Mansfield, 1977). If the relevant operational information is held by others, if specialized equipment, product or services, are needed, and if interrelated complementary assets are required, displacement is more difficult. For example, name-brand dental implants each require specialized training, and complementary tools. The division of labour in dental care means that if a surgeon dental firm uses a particular brand, the referring dentist will need the tools to complete the procedure or lose the customer. New technologies may therefore be at a disadvantage if they disrupt existing procedures and have high switching costs (Monteverde & Teece, 1982; Nightingale, 2008). The use of dental implants to replace other dental services can be perceived, as putting some high cost professional knowledge at risk and thereby the viability of some dental-service firms.

Understanding the process of innovation and diffusion in dental techniques therefore requires an understanding of how demand is articulated, and how that demand is mediated by economic requirements to increase profitability, which in this case, will often be related to the ability of a procedure to reduce treatment times, and hence increase the number of patients that can be treated with a fixed level of costly equipment and people. However, understanding how these economic and organizational influences interact requires understanding about how they are positioned within an institutional setting.

2.4.3 Institutions

Institutions play important roles in determining regularities in firm behaviours that influence how firms innovate and adopt and transform techniques. However, Nelson (2005) suggests weaving institutions into a coherent theory of the determinants of economic performance will not be easy, as there are so many variations in the use of the term, however “institutions clearly have a certain stability” (Nelson, 2008b: 4). This is the case, regardless if the distinction between institutions and organizations are fuzzied (the way firms tend to be organized and managed) or understood as a “basic rules of the game”, “institutions define or mold the way economic agents interact to get things done” (Williamson, 1975, 1985; North, 1990a, Nelson, 2005: 153; 2008b).

This section is not about unpacking the concept of institutions, or discussing institutions as social technology Nelson (2008b), its about understanding their function, as being stable contributors of their function. This research followed knowledge at the level of technique to understand the transformative effects of technology Pavitt (1987a, 1987c), Rosenberg (1976b, 1982), Nightingale (2008: 562) in terms of techniques that provide the medical services, doctor’s perform in their practices. This sheds light on how dentists do things in particular economic contexts, where the interactions and activities are functionally linked to a number of institutions and other private organizations that have the ability to mold or determine what is economically feasible for dentists to achieve in their practice.

The historical division of labour between different types of dentists (and their respective categories of knowledge) is protected by their professional bodies (established 1867), dental societies (established 1906) and dental regulating authorities (established 1902) and sustained by the financial managers of the dental care service and disseminated by dental teaching schools. This makes the distinction between governance of the profession and the organizational principles employed by dentist’s to organize the private practices of their firms, not clean.

However, the knowledge specialization of dentists influences how a technology is used and how it diffuses. Thus, the notion of institutions as exhibiting certain stability, “can only exist if people have particular beliefs, have collective intentionality”, hence, an “institution is a special type of social structure that involves potentially codifiable rules of interpretation and behavior” Searle (2005), as supported by Hodgson (2006: 5).

Institutions play a key role in generating the rules and routines that provide structure to economic activity, in firms and create the conditions for collective action in the following ways (Johnson, 2010: 34-38). Within a firm, the learning by doing is often a routinized activity (Arrow, 1962). This is the complementary internal learning important for dental firms to utilize external knowledge. Similarly, between firms, learning by using can become routinized. The iterative learning between learning by doing and using, increases the learning curve of experience incrementally along a trajectory, lowering costs and penetrating into new markets and areas of application Rosenberg (1982) and David (1986), and can exhibit exclusion effects to other technological possibilities (Dosi, 1982; Metcalfe, 1995). Learning by interacting or searching is the systematic search for new knowledge and generally connected to organizations that do basic science (Lundvall, 1985, 1988, 2005).

As dental firms take time to update practices, “a successful competitive firm has to anticipate changes, suggesting that dynamic capabilities are shaped by markets and technologies and direct its capabilities to the present and future capabilities of consumers and suppliers” von Tunzelmann (2009: 442), as supported by Helfat, Finkelstein, Mitchell, Petraf, & Singh (2007). Learning from the markets is an essential complement to drive innovation (Baumol, Litan, & Schramm, 2007; Edquist & Hommem, 2008; Foster, 2010; Dodgson, Hughes, Foster, & Metcalfe, 2011: 1154). Absorptive capacity and routinized activities are important Cohen & Levinthal (1990) and Cohen, Burkhart, Dosi, Egidi, & Marengo (1996) if links to specific resources of knowledge within the supply chain (suppliers and customers) are to be relevant for innovation (Fitjar & Rodriguez-Pose, 2013; Berg Jensen, Johnson, Lorenz, & Lundvall, 2007; Tether & Tajar, 2008).

These activities can sometimes be difficult to capture in terms of market interactions as they will often reflect non-economic motivations and use non-market forms of governance. Early theorizing about the market exhibited a clear separation of firms, consumers and regulators. Firms are viewed as bidding, and competing for consumer purchases, and the market is judged as working well or poorly based on the extent to which the profitability of a firm relies on its ability to meet consumer demands, as well or better than its rivals (Nelson & Winter, 1977: 67). For example, in dentistry, values related to working in the public interest and expectations about how public agencies behave play important roles in structuring behaviour. In the absence of market, Nelson & Winter (1977) identify expectations about how legitimate values in these environments are determined. Public agencies play key roles in articulating values in medical services, creating enforced normative expectations that doctors' decisions are not influenced by personal gain and medical staff are suppose to more informed than the customer. Institutions need not therefore be politically neutral, optimal or efficient, they simply need to exhibit reasonably consistent behaviour (Douglas, 1987).

Johnson (2010: 32) positions institutions into economic activity through within and between firm interactions and activities, building on the innovation systems theory of Lundvall (2007), providing a framework for understanding institutionalized activities. Johnson argues, "modern firms search systematically and in organized ways for new knowledge to be used in the production of new products. The regularities in their learning become institutionalized. At an aggregate level, the learning regularities embedded within the organizational structure of the firm, and the organized markets between firms, affect the communication and interaction patterns in the economy, and thus, learning is thought to be instituted at the national level (Johnson, 2010: 35).

How the within and between firm communication and interaction patterns are established and change through time will be influenced by both organizational structures and institutional rules. For example, policy mechanisms related to the distribution of benefits, costs and risks through tax rules, capital markets, competition frameworks, ownership rules, trade barriers, and or associations of knowledge generating actors (i.e. universities, basic research, government laboratories) (Johnson, 2010; Lundvall, 2007). Institutions and institutionalized behaviors can be characterized as stable, relative to the pace of innovative activities, and hence can be thought of as providing a framework or structure for directing the learning associated with technical change.

Collective behaviour therefore tends to be associated with institutions or institutionalized activity (Feldman, 2000; Zollo & Winter, 2002). Knowledge production for example, is central to economic theory (Gray, 1988: 352; Polanyi, 1962, 1967; Machlup, 1980, 1982, 1984; Gibbons, Limoges, Nowotny, Schwartzman, Scott, & Trow, 1994).

To understand this Johnson (2010: 35) suggests viewing an economy at different levels of aggregation to help clarify how communication is organized and the market and non-market interaction patterns between firms and other organizations. These institutional interactions help structure learning and direct it toward the production of new goods and services. Firms, then store this knowledge in organizational routines that are independent of individual knowledge holders (Zollo & Winter, 2002; Feldman, 2000).

As Abramovitz (1952) recognized, institutions can have both stimulating and retarding, supported by (Johnson, 2010: 25). Nelson & Sampat (2001) and Nelson (2005) for example, are concerned with the imbalance of technological advance, the motivations of publicly funded national institutions, and how behavior in public institutions may not be effective at advancing knowledge.

Institutions can either increase or decrease the uncertainty associated with innovation in dentistry and hence potentially constrain the diffusion of new techniques. Institutions do not necessarily therefore promote technical progress; they provide stability. Hence institutions and institutionalized behaviour are sometimes assumed to lie behind the poor macro-economic performance of nations. Rigid structures in firms, inflexible cooperation patterns between firms and within firms, and inadequate production of science and technology can all generate inefficiencies in the utilization of new technology, evoking the Veblen (1898),[25] institutional drag hypothesis (North, 1990a, 1990b, 2005; Landes, 1998; Mokyr, 2002; Filippetti & Archibugi, 2011: 179).

Institutional mismatches help explain the low-growth rates found in some OECD nations, as lack of effective institutional and organizational adaptation can constrain the translation of technical advances into productivity gains (Johnson, 2010: 24). In this context, a diversity of institutional structures can help enhance innovation (Ibid.: 39). As Nelson & Winter (1977) notes "…a major function of an effective institutional structure is that it screen innovations effectively, accepting and spreading the good, winnowing out the bad (: 47).

Institutions can help do this because they provide information that shapes understanding and action (Commons, 1931; Veblen, 1919; Hodgson, 1988; Feldman, 2000). How individuals recognize, classify, remember and forget is structured by their membership of an instituted community such as a profession, firm or network (Douglas, 1987). Changing these configurations within and between firms can therefore have profound influences on learning (Johnson, 2010: 28).

Within the institutionalist tradition regularities in behaviour are often seen to lessen uncertainty by reducing the amount of information needed for individual and collective

[25] Cf. Johnson (2010).

action. Thus, institutionalized behaviour acts as signposts, for relations between and among, people making other peoples' and organizations' actions more predictable and actually provide information (Lachmann, 1978; Johnson, 2010: 25).

For an institution, to function as an "information signpost", they need to hold images long enough for communication to be possible, making inertia, a basic feature of institutions. Similarly, innovation follows trajectories with the associated 'information signposts' that help organized education and make more rapid progress possible (supported by the paradigm and trajectory literature in this chapter). This often requires continual reinvestment, while knowledge that is not institutionally supported, (for example, if it doesn't fit into the cultural context of an occupation or firm), tends to be forgotten (Douglas, 1987: 29).

Theories of institutions therefore help understand the regularities that influence firms to innovate. Understanding how communication is organized and the market and non-market interaction patterns between firms and other organizations, assists institutions to help structure learning and direct it toward the production of new goods and services.

Learning is viewed an important element for understanding regularities. Johnson's (2010: 31) work builds on the iterative learning models, previous mentioned in his chapter. This includes routinized "learning by producing" within firms. "Learning by exploring" and "learning by searching" are between firm – Table3, as in Johnson (2010: 30-38). The terms learning by doing, learning by using, and learning by interacting Arrow (1962), Rosenberg (1982), Lundvall (1985) respectively, refer to activities that can be placed on a similar scale of interaction, represented in Table 3.

Table 3. Techniques to assess if learning is institutionalized

Type of action	**Type of learning, Johnson provides similarities to:**	**Knowledge configurations**
Producing	Learning by Doing (Arrow, 1962).	Within firm, increased quality, reduction of uncertainty, is a by-product of experience.
Exploring (feedback from others)	Learning by Using (Rosenberg, 1982). Are tight, knowledge configurations used to analyze the market.	Between technology and the market.
Searching	Learning by interacting (Lundvall,1985, 1988, 2005- STI).	Systematic and organized search for new knowledge (universities, research organizations, R&D departments – involvement with basic science (Lundvall, 1985). Considered as less bound by established paradigms and trajectories).

If learning in dental firms, "partly emanates from routine activities in economic production, innovation must also be rooted in the prevailing economic structure of technological opportunities and income elasticities" (Johnson, 2010: 35). Learning by producing influences searching and exploring. Learning by producing, involves routinized activities, typically related to an existing trajectory and involves normal communications within and between firms rather than the generation of knowledge. Learning by exploring (feedback) from users and producers, is influenced by the commodity logic of the enterprise, and is susceptible to rigidities. "Routines and habits of thought are important elements in research. They can be organized in ways that increase their learning potential" (Dosi, 1988; Johnson, 2010: 33). Learning by searching involves systematic and organized search for new knowledge, typically through engaging with universities, research organizations, R&D departments and through involvement with basic science, who are less bound by existing trajectories. Research projects are based on forward, backward, and horizontal links (Lundvall, 1988).

2.5 Towards a framework for analysis

The existing literature and pilot work suggest a number of key features that are helpful for understanding innovation in dentistry. From the medical innovation literature the emphasis on uncertainty, learning by doing, links to basic research and company R&D, high levels of regulation, professionalization and concerns to minimize risk as much as possible, a greater emphasis on co-operation and important economic effects from the separation of final user and payers.

For dentistry, as a subset of medical care, these features may need to be modified because dentistry tends to be undertaken in smaller institutions that lack the scale to directly influence innovation, and possibly have a greater emphasis on continuing professional education as an institutionalized requirement for dentists to practice, which will influence how they learn about new techniques. There may also be greater emphasis on profitability as most dentists are private operators.

In understanding how this economic incentive operates, the Chandlerian framework suggests paying attention to throughput - and how innovations in technique might increase the number of patients that can be treated in a given period time. As this increases, the high fixed costs of equipment and professional education can be spread and profitability increased. However, the fragmented nature of the dental market, and its lack of integration with scale intensive firms means that the co-ordination needed to achieve this throughput is not generated by Chandler's managerial hierarchies. Instead it involves complex interactions between dental specialties and other organizations, which in a medical setting are heavily institutionalized and regulated.

Hence, the final part of the theoretical framework looks at how learning is influenced by institutions. The institutional approach helps makes sense of the stability and structure of collective action in this hybrid market-non-market setting. This allows attention to different kinds of learning, through different mechanisms at different levels of aggregation.

CHAPTER THREE

RESEARCH APPROACH and METHODOLOGY

3.1 Introduction

Dentistry is a socially important, science-intensive sector that remains under-researched. As the introduction and literature review highlighted, it shares many features with medical innovation, but also important differences, that may well limit the extent to which concepts and frameworks from medical innovation can be extended.

The high-level research question this thesis addresses relates to how innovation takes place in dentistry, as a sub-set of medical innovation. A particular focus, relates to the relatively slow diffusion of techniques despite their benefits, which is suggestive of organizational and other constraints on innovation.

This research is exploratory. It aims to understand how innovation occurs in dentistry that can be challenged and/or extended by future research, by exploring post-adoption constraints to understand how institutions alter demand for new technology.

This chapter discusses the research issues, and the research design and methods employed, followed by a more detailed discussion of the epistemology and the theoretical stance adopted to justify the methodology.

3.2 Research issues and design

The field of dentistry only has a small body of published research and other materials on patterns of innovation. This limits the use of secondary sources or archival records. While more work has been done on medical innovation, it is not clear this would correctly describe the situation in Canada where public health care, other than dentistry[26] is provided at public expense, has different forms of regulation and professionalization, and innovation is likely to be significantly different. Particularly, dental innovation is characterized by global linkages (rather than the close connections to the national research system found in hospital settings). However, these linkages

[26] Except for the disadvantaged and First Nations people (Canadian Dental Association).

are not well understood so identifying targets for surveys or similar approaches presents difficulties.

The research setting is therefore characterised by both a lack of existing data and studies, and a lack of well-developed theoretical approaches and clearly defined categories that can be tested. Given the limited extent of previous studies to guide data collection and interpretation there is clearly a danger of generating unrobust results. There are an infinite number of possible explanations, many of which will be contradictory, that are consistent with any empirical evidence and hence a research design is needed that will generate robust and meaningful findings, and move beyond a simple descriptive study.

Given the focus on a "how" question, the early stage of the research and the relative lack of existing data and robustly tested theories, the research design involves a case study approach.

A wide range of methodologies were considered. Table 4 summarizes social science research methodologies and their appropriateness for use in the analysis of dental implant technologies.

As Ragin (2008) highlights, cases are "meaningful but complex configurations of events and structures". They are single, purposefully chosen examples that are empirically explored, in parallel with concept formation and elaboration. Hence they contrast with variance approaches, where homogeneous observations are chosen at random from a pool of equally plausible selections and tested using well-established theories and well-defined concepts. With cases, the concepts themselves and their appropriateness to the case, being studied, are uncertain and flexible.

To generate a degree of variance the study explores three distinct settings, where it was initially assumed that the innovation process would be similar enough to make comparisons meaningful (Bryan & Ragin, 2008). This ended up being the case.

As Morgan (2012) has highlighted, case studies involve open-ended investigations of a bounded object in all the complexity of a real-life setting to generate a complex, narrated account. Case studies allow for clarification of weaknesses of existing explanations (i.e. by highlighting how dentistry differs from medicine and how these differences make models of medical innovation inappropriate), because as Popper highlighted single falsifications can be applied to universal statements.

Cases also allow for explanation development where complex events generate a range of points in which an explanation can be tested for internal validity. This is particularly important when researchers are faced with a situation where there is no large body of well-articulated, properly validated theory that can be statistically tested against a pre-existing sample of relevant observations. The “relevant population” is generated by a theory laden, concept intensive process of defining what is meant by a sample of cases in a particular setting. During such case studies, internal validity is generated by the three requirements that explanations from cases are: consistent with all the evidence, coherent and provide explanations that are credible in the light of other things that are robustly known, and mesh with robust explanations from other fields and settings.

A key element involves avoiding *ad hoc* explanations, and ensuring that the final explanation that is reached at the point of data-saturation fits all the evidence. A key part of the research process therefore involves exploring the boundaries of where theories do and do not fit the evidence. This involves working through implicit assumptions against a range of settings to see where weaknesses lie and how explanations can be modified. The final outcome is an explanation that is both valid (the premises imply the conclusion) and sound (the premises are trustworthy). It should involve a complex chain of argument containing causal claims about the phenomena in question that fit both the evidence and (possibly modified) theory. In this particular study the initial assumptions about the appropriateness of one framework, from Granberg (1997), were found to be weak and a new body of theory was drawn on to better explain the empirical evidence. However, Granberg’s (1997) functional decomposition methodology was found to be useful to capture the innovation process at work in a structured way.

The research study was conducted in overlapping phases. During the initial validation phase, the literature review was completed in parallel with pilot interviews. Dentists associated with academia and/or private practice, provided insights about the current situation through semi-structured one-on-one discussions with telephone phone follow-up, as required. These discussions were specific to the functionality of the implant, in its current state.

After the case study data were collected and organized, concerns with the selected methodology approach became apparent. It became obvious that, the theory to real world data fit, considered important Van de Ven & Poole (2007) when engaging practical knowledge, was better suited to analytical frameworks incorporating throughput and institutionalized activities that closely related to the real world of dental-care firms. While the need for throughput was implicit, it was not as pronounced as it should be in the case outcomes, and, while institutions were identified, institutionalized activities were not generally addressed. The issue arose because the real-time data collection process structured relationships between technology, techniques and the dental-care service firms differently, than the orientation of actors required in the innovation systems approach (see section 3.4).

Methodologies	Description	Strengths	Weakness	Appropriateness	Applied
Case Study	An exploration of a bounded system by time, place, an event, an activity or individuals often through multiple methodological tools and data sources to achieve its aims.	Preferred to examining contemporary events and useful to understand complex social phenomena where contextual conditions are pertinent.	Difficult to make causal connections and data comparisons.	An acceptable approach to examining a contemporary event in real-time, given the complex issues.	☐
Derived from primary sources					
Phenomenology	Structures of conscious experience from the first-person point of view gathered through open-ended questions and dialogue. The aim is to determine what the experience means for the people who have had the experience.	Regards the data of experience as imperative in understanding human behaviour and as evidence for scientific investigations.	Difficult to understand an experience based on the assumption that one can be totally unbiased and without presupposition.	The testing and extending existing of innovation theories is more factual and requires objectivity than an emotionally based output.	X
Ethnoscience	It assumes that knowledge can be classified into subjects or into taxonomic categories and interviewee's will respond or rate the phenomena accordingly.	It can be used to build knowledge based on existing categories. The output can lead to building more taxonomies.	Assumes that interviewee's will respond to phenomena similarly and will produce similar results.	Suitable to use in the dental industry where dentists have similar socialization through education and business experience.	☐
Ethnography	Direct observation of the activities of a certain group as well as communication and interaction with the group members. The result is a written description of a particular culture – the customs, beliefs, and behaviour based on information from data collection.	Provides detailed analysis of what characterizes the group.	Requires a large amount of time to be spent with group's involved and pre-existing knowledge of observed behaviour.	A required approach to contribute to complex issues and given that time spent with dental professionals is limited, time spent has to be well organized.	☐
Grounded theory	The data is collected first and the theory and hypotheses are derived from data.	Good for building theory.	Difficult to guarantee theoretical contribution as a new theory may not emerge from the study.	More difficult to fulfill the requirement of testing and extending existing theories	X
Semi-structured interviews	Used to collect qualitative data by asking identical questions that allows the respondent to talk about opinions on a particular subject and allows the interviewer to use open-ended questions to probe the new and unexpected issues that may arise.	An efficient way to gather data with little direction from the interviewer and to collect data of which the interviewer had no prior knowledge.	Outcome depends on skill of the interviewer to effectively probe for higher levels of knowledge. Process is time consuming and expensive. It is difficult to exactly repeat a focused interview.	This is a suitable tool to explore theory guided data collection questions.	☐
Structured interview	Survey – Asking identical questions of a representative sample of the population.	Can deal with phenomenon and context and useful to gather large samples of data over large geographical areas.	Ability to investigate context is limited. The survey designer has to limit variables in order to stay within a representative sample. Even then response can be low, as researcher has no influence over interviewees.	Even though my research has a fairly homogenous population, the context is complex and requires the researchers influence.	X
	Experiment – A quantitative analysis that holds as many variables as constant as possible to focus only on a few variables.	The researcher can manipulate the remaining variables to provide strong causal evidence.	Assumes that context can be separated from the phenomenon of the study. Has limited application with complex social issues.	The context of the dental implant implementation technique is vital to understanding the phenomenon.	X
Derived from secondary sources					
Archival records	Using existing literatures to produce a history and derive evidence to support contemporary theories.	Is precise and quantitative as it has a long span of time, many events and many settings.	Retrievability can be low. Represents a biased selectivity if collection is incomplete. Reflects unknown bias of author.	Although invaluable knowledge, will not identify the current institutional structures that affect technological learning.	X

Table 4. Summary of social science methodologies and choices for the thesis (Yin et. Al., 1983, 1994; Ragin, 1987; Oppenheim, 1997).

3.3 Overview of research process

3.3.1 Phase 1 – Validation and Preliminary Research

The study began, by engaging a small number, knowledgeable members of the dental industry (research scientist, professor of dentistry, dean emeritus, clinical dentist) and completing an investigative research report to validate and clarify the functional and utilization claims associated with dental implant technology (Appendix A, five page report).

Initial validation and Phase 1 preliminary research was based on exploratory, semi-structured, open-ended interviews and oriented toward the dental and utilization opportunities and constraints, involving mostly primary sources. This work was supplemented by a review of academic and professional literature.

The key interviewees comprised:
Dentist, research scientist, Past President of a Dental Society
Dentist, Director Continuing Dental Education, Department of Dentistry, UofA
Dentist, Professor of Orthodontics and Dean Emeritus, Department of Dentistry, UBC
Dentist, Emeritus Professor of Dentistry, Department of Dentistry, UofA
Executive Director, Public-private Research Institute
Executive Director, ADAC
Advisor, Health Protection Branch
Vice President and Chief Information Officer, Alberta Blue Cross
Specialist, Past President of Canadian Academy of Periodontists
Specialist and Private Training Clinic and Clinical Practice – Dr. Herald Bergman
Dental-care service firms – three owned by General Dentists and four by Specialists

One of those interviewed had been engaged with the transformation of the original Nobel Biocare technique to lower the price of the modality to patients in Canada. It was evident that this involved applying techniques associated with achieving economies of scale and the interview evolved into discussions of throughput. Another interviewee involved with research provided insight into the current institutional and industry involvement with implantology research and diffusion, including university/implant producer firm relationships and the private learning-by-doing, infrastructure located in Canada. Another interviewee presented insight into the dental society environment, its accreditation and educating roles and the overall organizational influence that lies within their membership. All interviewees provided the researcher with insight into the close industry – practice – academia relationships and industry strategies for product accreditation at public institutions.

This work satisfied the condition that the dental implant would be an interesting research project for innovation studies, and confirmed that the dental-care sector was reachable, but not easily. It also raised questions about how the technology would be transformed into regular practice.

The data from this phase lead to the wider engagement of other players, with refined questions leading to more in-depth understanding of systemic constraints to technology application in practice and linkages to institutions and industry.

3.3.2 Phase 2 – Semi-Structured Interviews

In addition to general dentistry, there are nine recognized dental specialties, some of which can place and maintain dental implants as a result of their degree, and some who take additional accreditation to qualify. The dentists most likely to engage in implantology are Prosthodontists, Periodontists, Oral Surgeons and General dentists.

Phase 2 of the research, engaged 39 individuals in the dental-care sector, or associated with it, and involved with dental implant and complementary technologies, including industry, in a semi-structured interview approach. Semi-structured interviews were used to allow interviewees to express in their own language what they felt was driving innovation and hence to avoid imposing frameworks on them in an inappropriate way. The interviewees’ responses were then triangulated against each other and other material. Some industry players were identified by dentist interviewees. The 39 interviewees were:

Dentists - Specialists in implant research (1)
Dentists - Dental-service firms - General Dentist (3)
Dentists - Dental-care service firms - Specialists (8)
Dentists - Post-Dean of Dentistry (2)
Dentists - Executive Management of Dentistry-related Associations (5)
Insurance firms – Management level (4)
Research Scientists Nano-bio tissue materials (1)

Implant Producer Firms (4) and affiliated clinical dental firms as regional trainers (2)
Producer Firms of complementary products (6)
National Regulating Agencies of medical device products (3)

Most interviewees requested anonymity; consequently the data are cited by code (1 to 39) and interviewees are identified as “Interviewee 1 to 39”, rather than by name. References are discreet unless anonymity was not requested. Care was taken to observe the appropriate protocol to maintain confidentiality. The interviews were typically recorded, with permission, and transcribed using Dragon Naturally-Speaking voice recognition software.

This phase was to understand a) what corrective action the technology was to provide, b) what technology was used before, c) what factors would influence technical change, and d) who controls the factors. The results of this phase raised important concerns about factors that needed to be further explored. For example, throughput, as reflected by a dentist’s time at chair, and mode of delivery issues related to insurance eligibility, reimbursement and patient coverage, kept surfacing.

3.3.3 Multi-Case Study

A multi-case study of three dental firm dentist practitioners was undertaken to follow the progress of knowledge at the technology (dental implant) level, using a modified Granberg (1997) analytical framework, to identify the actors involved and how they perform. The selected dentists were all owner-operators of dental-service firms, as are 93% of all Canadian dentists (solo or small-group practice firms). To collect the data, two specialties were observed in real time: Oral and Maxillofacial Surgery Dental-care Service (Ch. 8), Prosthodontic Dental-care Service (Ch. 7), as well as a General Dentist Dental-care Service (Ch. 6). The structure of the empirical case chapters reflects the generic sketched dental implementation process (Diagram 5 & 6).

The case method was supported with semi-structured interviews and semi-ethnographic methodologies oriented toward the dental specialities and utilization opportunities and constraints, involving primary sources. For consistency, common interview questions were used to begin the interviews. For effective control, case study observations were limited to dentists and work they do that is explicitly associated with installing and maintaining dental implants. Supplementary interviews supported case data collection and written case descriptions.

Implant technology is almost three decades old and still not fully diffused. The notion was to collect data, in real time, based on the dental implant installation technique, and at technological intervals, question who the dentists turn to solve problems associated with the technique, as technologies do not just get inserted into practice, they are transformed and that transformation involves other technologies Chandler (1977), Nightingale (2000) and Lazonick (2005), thereby identifying the industry actors and reasons for association. This would also identify the competence centre, so it could be further analyzed for opportunities and constraints. The initial and on-going data were collected through semi-structured interviews, involving actors of common membership to the implant technology. The data collection was a long process. The researcher observed one patient, for almost a year at one firm. Data obtained were supplemented by additional telephone conversations with Phase 2 participants as required.

The mapping data tool to decompose the technique used by dentists in applying the dental implant technology, originated in the technology innovation systems literature (Granberg, 1997). Research theory has concluded that quality specifications emerge from integrator firms and that adding quality increases throughput. Granberg (1997) developed an idea for defining and decomposing a system in which system components, interact around integrator firms, who then communicate the quality specifications for new technical knowledge to the producer industry and the developers of science and technology. In Granberg, the actors of the technology system functionally align and link their activities around a bottleneck in the production process or technique, forming a problem solving competence centre. To show this, he progressively decomposed a factory production process of specialized goods, into technological knowledge components (cad/cam, sensors), that related to specific knowledge fields at the university level and to specific production processes of producer firms – thus he created a problem solving competence centre for specific national industrial actors. The national industry actors would communicate the performance requirements to the national research centres which could then advance knowledge that would transform the techniques and thus, alter the technological trajectory of the firm.

While Granberg’s effort was not fully successful in his specific application, it appeared to offer potential for assessing the integration of a new technology, such as the dental implant, into an established process and was the initial basis for developing the research framework used in this study. Granberg (1997)’s decomposition approach was applied to this research in a modified form in an effort to illustrate how a new technology transforms techniques or production processes in firms.

The dental-implant tooth-replacement technique is a complex, non-linear routine, involving many steps and stages and involving many other technologies and multiple dentist specialties and firms. The implementation process needed to be decomposed, to be used as a template for real-time data collection. The decomposition is similar to Nelson's (1967) seminal cake baking recipe where the technique involves numerous other technologies, in each of which, the knowledge to operate is tacit. It must follow the application of technological knowledge, at the process level, to see how firms respond, to the appearance of a technology that provides a new way to perform functions. The application of a dental implant generally requires services from other specializations, a division of labour that encompasses other firms. There are functionally linked interdependent industry and institutional structures, around implant technology, that the decomposition and accordingly the collection of data, were intended to expose.

The initial decomposition was based on the Loma Linda University School of Dentistry training CD authorized by the University of Alberta as a source to certify dentists for implant dentistry. The researcher then held two interviews to ensure accuracy, with Dr. James Yacyshyn, Department of Dentistry, UofA. The six validated techniques are mapped as – Subsystem 1, "Work up the Patient" and Subsystem 2, "Procedural" (Diagrams 5 and 6, respectively, as follows.

Diagram 5. Data collection mapping tool, subsystem one – Work Up The Patient

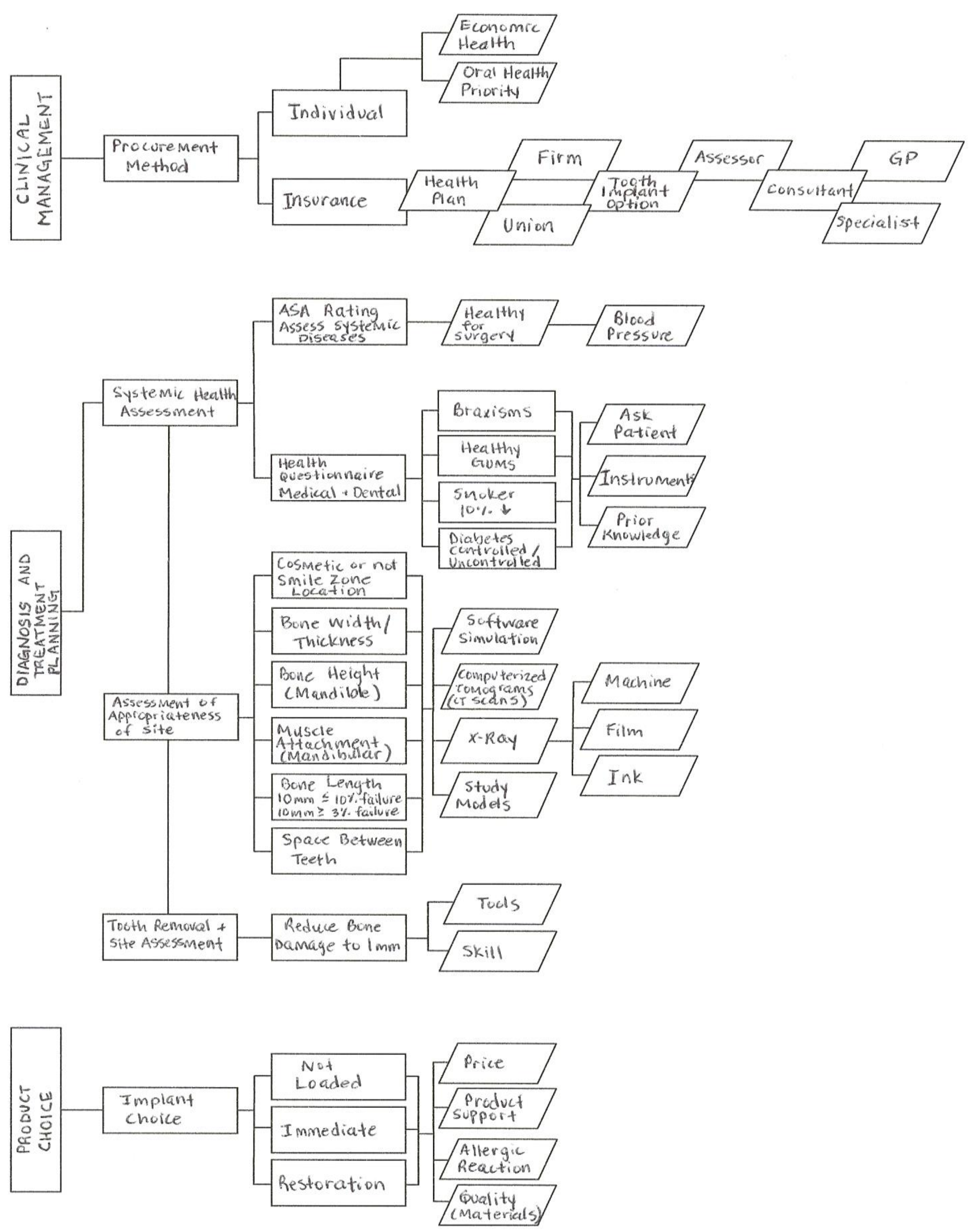
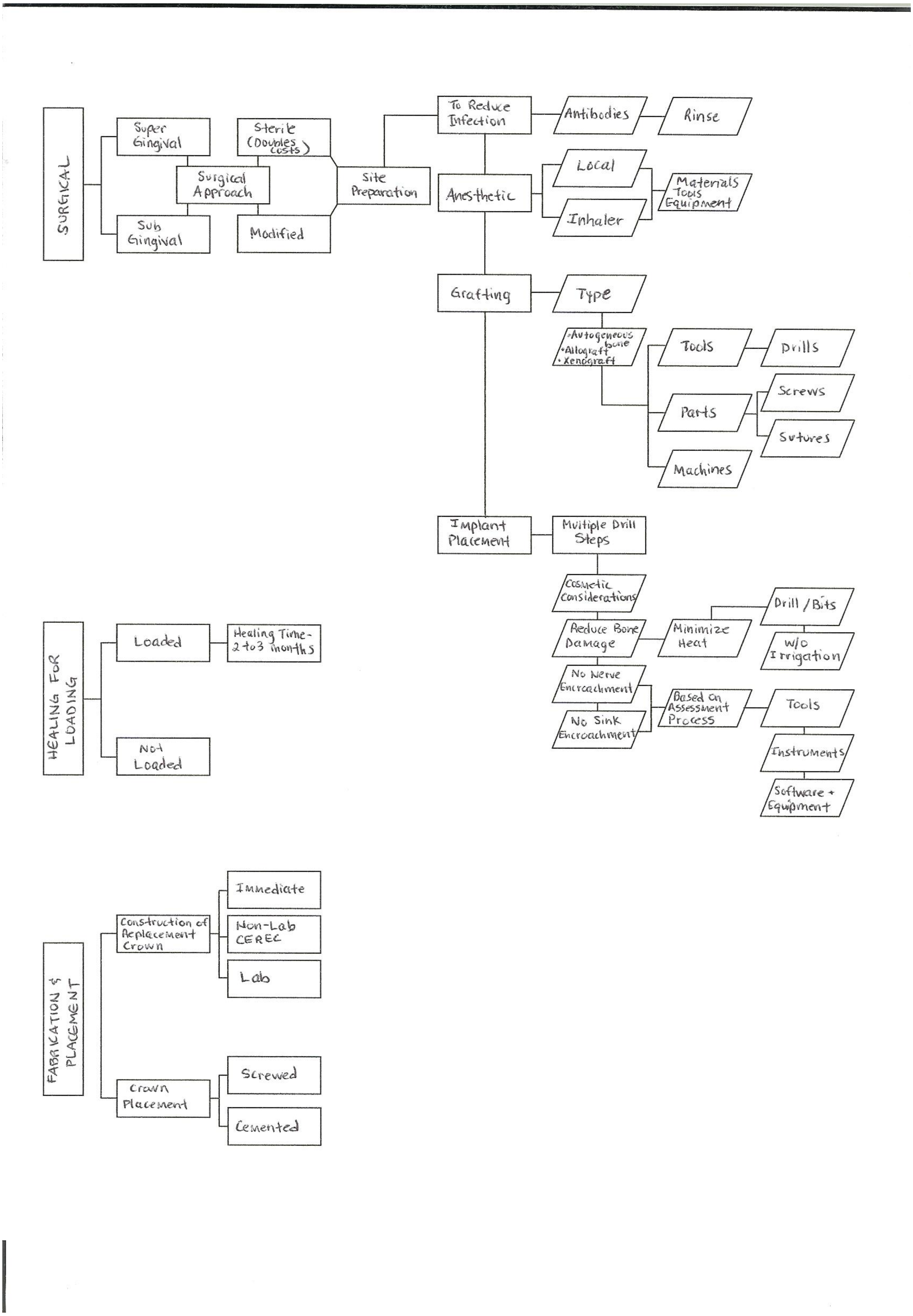


Diagram 6. Data Collecting Mapping Tool, Subsystem Two – Procedural



The decomposition does not codify the dentists' tacit medical skill or even suggest that is codifiable i.e. the activity in deciphering x-rays. The codification applies to the operational routines, that include technological components but the researcher does not suggest that even then, all minor sub-routines are codified or even codifiable. The researcher is, however, particularly qualified to understand the organization of work environments, having twenty plus years of practical experience in executive management roles with complementary degrees. This supports, that while the researcher is not a dentist, understands the interrelationship of business processes and to the market. As previously mentioned, the work flow undertaken by dentists in this study, was prepared from the Loma Linda University School of Dentistry training CD authorized by the University of Alberta as a source to certify dentists for implant dentistry. Prior to data collection, the data flow illustrated, in Diagrams 5 and 6 was reviewed for accuracy by two dentists, with one change suggested. The work-flow was also approved by each case dentist prior to data collection, and all agreed it reflected the overall generic process. However, as data collection proceeded, it became apparent the application of the dental implant was not a linear process. Each dentist had adopted a pattern that varied slightly in the order, the subsystem-techniques were executed. The cases reflect this detail.

The data for each case (Ch. 6, 7, 8) are collected as a set of subsystems linked to the division of labour of the dental specializations, and their functional role in the overall implementation technique. Each case presents the time-line of the functionally linked steps the patient goes through until the work process, is completed by the dentist. Six validated techniques are mapped as – Subsystem 1, “Work up the Patient” and Subsystem 2, “Procedural” (Diagrams 5 and 6, respectively). The data per case are collected as a subsystem of techniques, specified by the operating principles (the dentist's specialties and the associated techniques). The results of the case studies are analyzed individually and collectively. Analyzing one technique with multiple operating principles, each with associated subsystems and components, increases the reliability of the results and allows for comparison between cases and is also reflective of how each dental practice organizes the knowledge components systemically within the technique. The data collection process reflects this.

To map a technological system, the first step is to decompose the technological system and prepare a work-breakdown structure of the dental-implant tooth-replacement technique based on its operating principles. This leads to a process, which is the time-line of what happens to the patient when having a dental implant technology installed, involving many stages, dentists (their firms) and techniques. For example, Section 3.3.4 illustrates the decomposition of the six sub-techniques (Diagram 7) represented in the patient-work site is further decomposed (Diagram 8). To ensure the data collected are reliable and the results are comparable, the study is restricted to implant technology used in tooth replacement and not restorative facial surgery. [27]

To collect the data for the three cases, previously featured Diagram 5 and 6 were sketched on 22” x 17" sheets of paper. They guided the data-collection and were used to write on during the real-time data collection.

3.3.4 Decomposition of the dental implant installation technique

A dynamic system can be described and identified in terms of objects such as (a) the system, (b) its subsystems, and (c) their components (Simon, 1998). The workflow of the dental implant technique, has two main subsystems and six components. This partial decomposition shows the six steps followed after the patient comes into the dental office (see Diagram 7). The terminology, such as “work up the patient” is not the choice of the researcher - it is unique to the dental sub-sector.

The Dental Implant Technique and Sub-techniques

Subsystem Two - Procedural

Fabrication & Placement of the crown **Step 6**

Healing for Loading w or w/o abutment **Step 5**

Surgical - drop the implant **Step 4**

Subsystem One - Work up the patient

Product Choice **Step 3**

Diagnosis & Treatment Planning **Step 2**

Clinical Management **Step 1**

Diagram 7. The dental implant technique and sub-techniques

[27] The scope of analysis does not include other dental professionals such as dental assistants.

Similar to the production of goods and services, "*the patient"* enters into the *implementation production process*, with the dentists as operators, and goes through many steps, and surfaces as a "*finished product"*.

For data collection, further decomposition and specification of the system must occur. Diagram 8 illustrates the patient, going through a staged process involving numerous techniques that generate a *patient-work site.* From the time of initial consultation, Steps 1-4 take about 6-8 weeks. Once the implant is surgically placed (Step 4), there is a healing period for 4-6 months (Step 5) for the implant to osseointegrate sufficiently to take the load of a prosthetic device such as a crown. The prosthetic reconstruction occurs in the Fabrication and Placement Process (Step 6). The total clinical treatment process generally takes place over a period of 6-12 months.

The rectangular boxes represent techniques. The arrows represent stages to another step with different functional requirements, which in some instances requires a change of dental specialty. This is a generic process, as each dental implant brand follows a similar implementation process. The techniques are distributed among several dental specialists who, despite being in separate firms, are functionally connected to the entire implementation technique. This division of labour is reflected in the data collection described in each case study - General Dentist Dental-care Service (Ch. 6), Prosthodontic Dental-care Service (Ch. 7) and Oral and Maxillofacial Surgery Dental-care Service (Ch. 8).

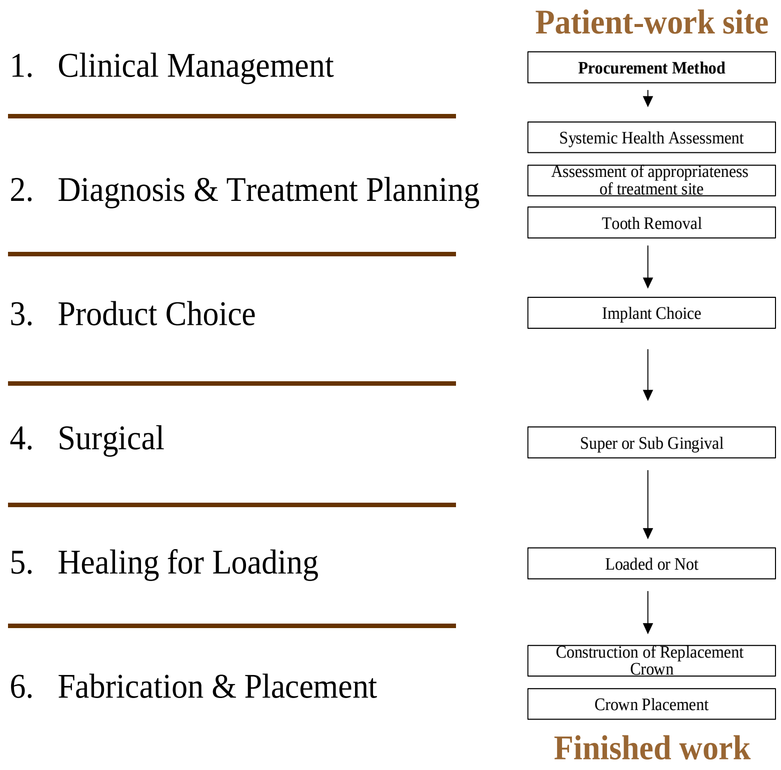


Diagram 8. Dental implant technique, patient-work site, beginning to completion

The data collection, in real time and at each level of specification, breaks the work-flow into knowledge components or techniques, and the artifact input to make the technique function. This is further specified into the firms that produce the technology and/or product (i.e. dental device, tool, instrument, material, chemical, software process or item of process equipment) and then, make up the industrial structure of the technique. At each technological component, the dentists identify who would solve problems for them, should a problem occur – making up the competence centre.

3.3.4.1 Knowledge components of the technique

To identify knowledge components of the dental implant system, further decomposition used the data collected and described cases. Using Ch.8 case as an example.

The Dental Implant Technique and Sub-techniques

Subsystem One - Work up the patient

Clinical Management **Step 1**

Diagnosis & Treatment Planning **Step 2**

Product Choice **Step 3**

Oral Surgeon

Subsystem Two - Procedural

Surgical - drop the implant **Step 4**

Healing for Loading w or w/o abutment **Step 5**

Fabrication & Placement of the crown **Step 6**

Diagram 9. The dental implant technique and the Oral Surgeon's sub-techniques

The subsystem component Surgery (Diagram 9, Step 4), applied by the Oral Surgeon is decomposed in Table 5 to identify knowledge components of the technique and then specified to an artifact level. Italics denote a subsystem **"technique (a function)"** and an underline denotes an "***artifact"*** **input that generates the function** (see definition section Ch. 2)**.** The *artifact* can be a dental device, tool, instrument, material, chemical, software process or item of process equipment. The artifact, when specified or decomposed, connects to an industrial producer; parts, material or equipment firm; and to a university research department to advance the science of the artifact – hence the industry and competence centre of the technique. Column 3 observes, potential **scale effects to technique.**

Table 5. Step 4, Surgical placement of implant and scale effects to technique

Technique (Function)	Artifact input that generates the function	Observed opportunities & constrains associated with increasing returns to scale
Super Gingival	***Two stage approach, Dental implant***, Vendor design specific.	If chosen, involves more steps, higher infection risks, more material costs and increases the hours spent by the surgeon.
Sub Gingival	***One stage Approach, Dental implant***, Vendor design specific.	Saves patient time and pain and reduces the required time of the surgeon
Modified infection control, Partially gowned,	***Masks, gloves***	Half the cost of fully gowned technique
Sterile Infection control – fully gowned	***Masks, gloves, patient and dentist and stuff gowned*** Vendor specific design and material	
Sedation – general sedation	***Anaesthetic machine,*** Vendor specific design	
	Inhaler, Vendor specific design	
	Sevoflurane, Vendor specific inhaler drug	
Local sedation – injection	***Ultracaine D-S,*** Vendor specific anaesthetic drug.	Lack of consistent reaction time per patient is considered to delay work-flow, add expense to the technique, by increasing the dentist's work day (Ch. 7).

3.4 Analysis

Understanding innovation in dentistry, required observation of real-time iteration effects and the dentist to identify problem solving actors and the reasons for the interaction.

The qualitative method was chosen to construct in-depth representations of phenomena; often addressing phenomena researchers feel have been misrepresented or not represented at all. The in-depth investigation focuses the researcher on a case, on the commonalities among separate instances of the same phenomenon, or on parallel phenomena identified through a deliberate strategy of theoretical sampling, within or among cases (Ragin, 1994).

A multi-method research approach is appropriate for a broad topic area and seeks to validate data through triangulation by combining a range of data sources, tools and methods to widen the scope of study to include contextual aspects of the situation (Yin, 1994: 91-93). If two case studies are shown to support the same theory, replication can be claimed as two-level inferences providing reasonable confidence to support policy and theory (Ibid.: 31).

To Ragin (1994), the strategy of theoretical sampling Glaser, Barney, & Strauss (1967) is not to capture all possible variations, but rather to aid the development of concepts and deepen the understanding of research subjects. A researcher's sampling strategy evolves as the understanding of the research topic matures (Ragin, 1994: 99). Triangulation provides a better fix on something that is only partially known; it can be a powerful tool to build analytic frames (: 100). However, Ragin (2008) claims, casual processes are best observed at the single case level, through in-depth research (Ragin, 2008; Ragin, 2009). Such research is considered successful even if it only succeeds in showing that the existing theory is inadequate (Bryan & Ragin, 2009).

There can be no sharp distinction between causal conditions and outcomes. Generally researchers examine causation holistically in terms of convergence of structures, actors and events (Ragin, 2008; Ragin, 2009). These researchers are centrally concerned with sequences and timing of events, with an eye toward path dependence, making case study research focused almost entirely within case patterns Ragin (2008), supported by Van de Ven & Poole (2007).

Cross case analysis is central to the process of constructing generalizations. Researchers are required to make strategic comparisons and thus need diverse cases, but at the same time need to maintain case homogeneity because their cases should be instances of, or candidates for, the same outcomes (Byrne & Ragin, 2009). The prime objective of comparative research is not theory testing, but concept formation, elaboration and gradual refinement.

Sharpening the definition of a set of relevant cases is often an important theoretical advance itself (Ragin, 2008). To sharpen qualitative research, a bracketed “string of words capturing basic elements of information” about a discrete event (unit of analysis) can be coded and classified as a theoretical event (Van de Ven & Poole, 2007: 218). The qualitative datum can then be used for separate incident comparison or later for time series comparative analysis. Ragin (2008)’s cross case generalizations involve set-theoretic relationships. This involves making cross-causal correlation symmetries. The key is to assess the sufficiency of a combination of conditions that satisfy the outcome.

Table 5 illustrates areas to which dental care service firms could apply throughput, to transform new technology into existing routines, economizing the dentists’-time, by innovating their techniques. The two mapping tools, Diagrams 5 and 6 provided a framework to guide the researcher’s observations of dental implant practise, and to identify and understand the opportunities and constraints associated with increasing returns from scale.

The wider group involved in Phase 2 of the study built on and verified the insight gained during validation by involving a broader range of interviewees, including dentists, regulating institutions, insurance, researchers and the producer industry. This allowed the researcher to progressively build a mental schema or Buzan (2002) mind map of the systemically linked incentives and constraints of the implant technology in relation to practice.

The regulating institutions and insurance firms helped the researcher verify the gatekeeper role of dentists in technology adoption and also added depth to understand reimbursement and billing procedures.

To draw out findings and conclusions, the end of each case (Ch. 6, 7, 8), identifies indicators that illustrate how specialties apply economies of scale. These indicators are compared to identify commonalities and differences. The researcher has also added the throughput provisions, to illustrate their application, at the end of each case chapter.

Chapter 9 illustrates, there is a pattern to the application of throughput, however the internal pressures or interrelatedness Chandler (1977), Rosenberg (1976, 1982) within the technique can largely be attributed to the specialized knowledge of each specialty Nelson & Winter (1977), Rosenberg (1982) and Dosi (1982) – the pattern changes according to the knowledge base of the technique. The knowledge is paradigmatic and transforms slightly with each technological change to the knowledge base. Thus the transformation of one technology progressively changes the performance criteria of the next and transformation of the next – change builds on previous technological achievements.

Chapter four will present the constraints, to the adoption of new technology, that were acquired through semi-structured interviews.

Chapter five applies the institutional framework, utilizing the data from interviews and case studies, to identify instituting factors that can be applied to Johnson's (2010) theoretical framework to triangulate and expose institutional effects and institutional actors, associated with learning by using.

Ch. 9 observes the institutional theory at the national level talks about supply of knowledge, but not how that knowledge is conditioned by institutional demand. Thus the combined throughput and institutionalized effects, observed suggests the cases support the same theory.

Observations revealed in the final chapter (Ch. 9) are used to understand the relationship between throughput effects and the institutionalized effects, on technological change in the dental-care sector.

CHAPTER FOUR
DENTAL CARE INDUSTRY, MARKET AND THROUGHPUT CONSIDERATIONS

4.1 Introduction

The search for economies of scale and scope that govern a firm's business capabilities, as applied to a large manufacturing Chander (1977, 1990) firm provides a potential framework for looking at economies of scale in other applications, such as the dental industry. The introduction to this chapter begins by exploring the structure of the dental industry in Canada and how it may be considered similar to large manufacturing firms to address economy of scale and throughput speed issues. The proposed structure is evaluated with respect to institutional impacts on flow of knowledge and learning to identify the constraints that, institutions impose on the diffusion of technology.

A visualization of the Chandler theoretical framework, outlined in Ch. 2 is illustrated in Diagram 10.

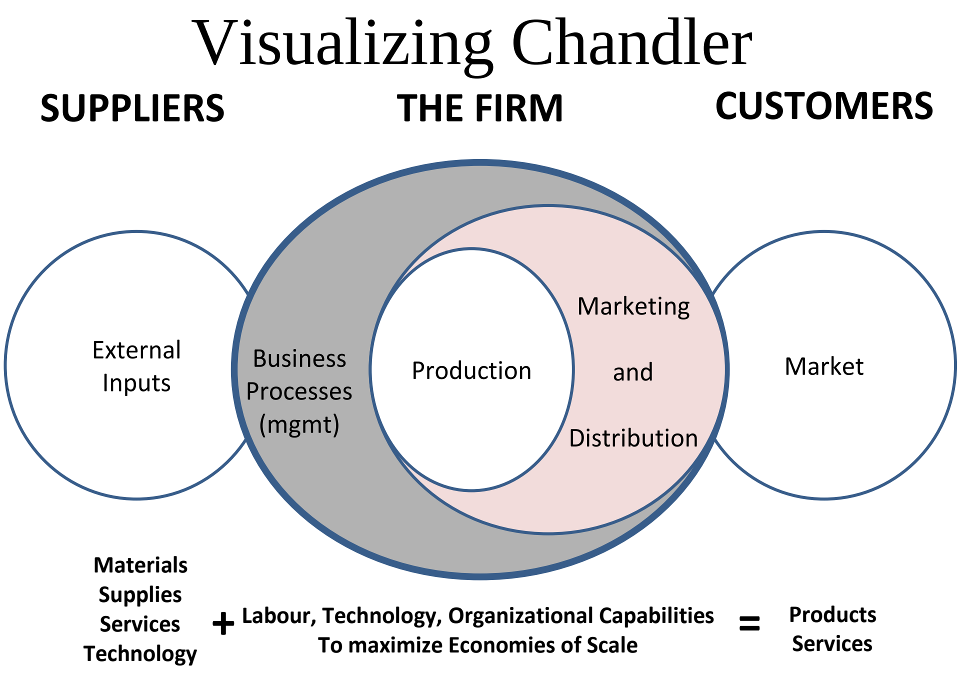


Diagram 10. Vizualizing Chandler

It reflects that a firm can supercede the hand of the market not only through capital investments and division of labour that result in lower cost of production, but also through marketing and distribution and critically by organizational design and business processes that exploit the potential of workers and machines/technology in all aspects of the business of the firm.

The dental industry has a unique structure and characteristics. In Canada, it emerged from a non-market construct of the late 1800s in which society allocated certain functions (education accreditations, admission criteria, quality of practice, ethics, fees) associated with highly educated professionals, to self-governing dental practitioners and their collectives, who in turn made various arrangements with educators, suppliers and institutions.[28]

The dental industry system appears to have evolved, in the aggregate, to fulfill a role similar to that of the large manufacturing firm, where the system within the dotted line

[28] The researcher drew on John R. McDougall Past President of Engineers Canada (equivalent to CDA) to define and characterize the societal associations of a self-governing profession.

square, performs functions encompassing strategic, organizational and managerial aspects as well as production, marketing and distribution (Diagram 11), that in a large firm would be done internally.

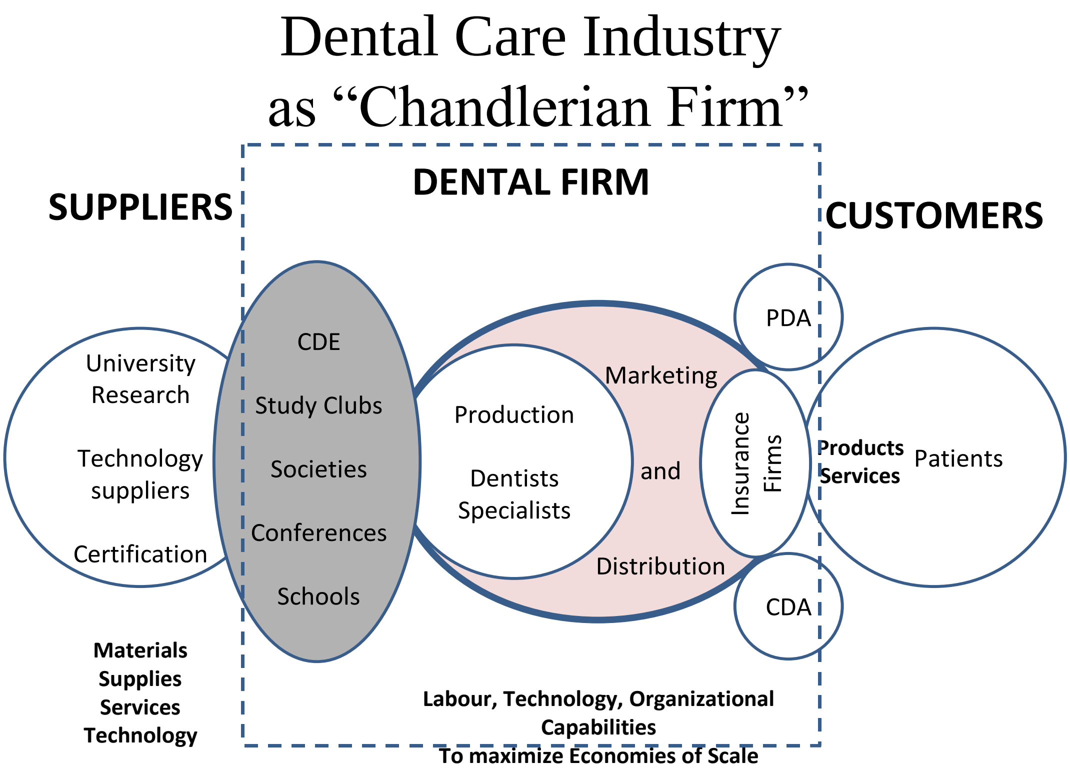


Diagram 11. Dental care industry as a Chandlerian Firm

The system of the dental care (within the dashed line square) appears to have been structured to achieve economies of scale and scope based on investment in technology, in organizational design (division of labour and specialization) and business processes such as standardization, financing, continuing education and planning, coordination and control to increase throughput and profitability for system participants.

The institutionalized planning, coordination and control in Dentistry, is historical (see Diagram 12 (Appendix B for references).

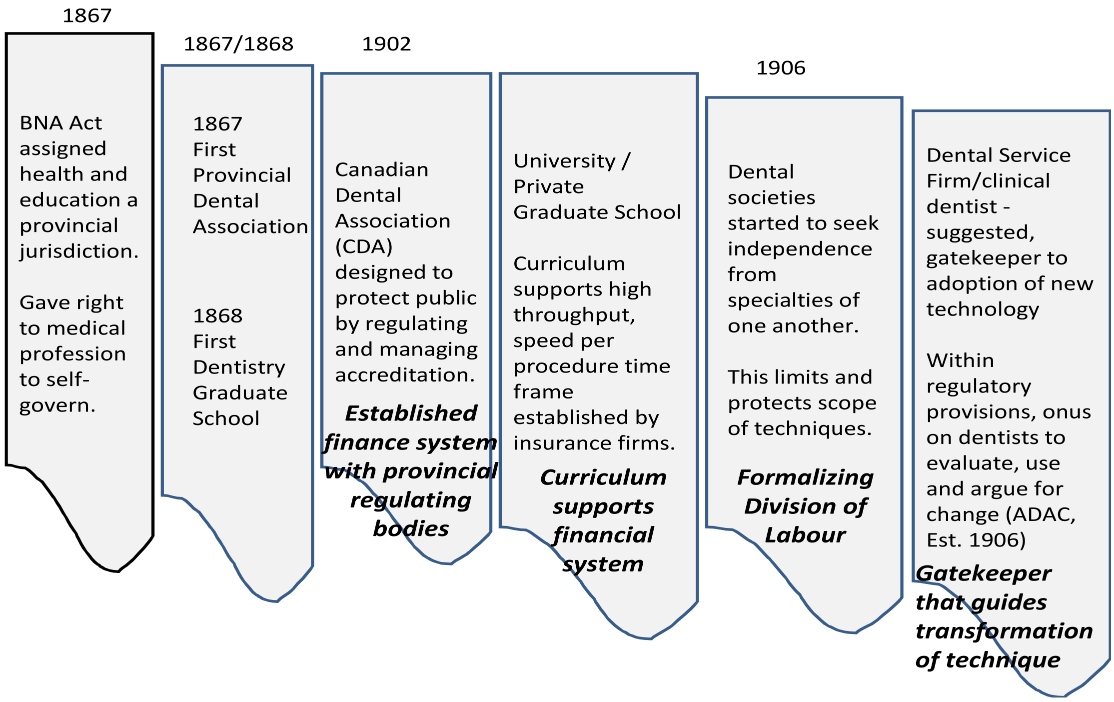


Diagram 12. Time-line to the institutionalization of Dentistry

The dental care industry emerged as a self-governing profession in 1867 when the first Provincial Dental Association (PDA) was formed in Ontario to carry out various functions and dental societies began to specialize (see Appendix A). The first dental graduate school was formed in 1868. In 1902, the Canadian Dental Association (CDA) was formed to "protect the public" by regulating standards and managing accreditation. Over time professional and business bodies emerged across Canada and assumed functions such as educational accreditation, admission criteria, quality of practice, ethics and fees and these institutions, in turn made arrangements with various educators, suppliers and other institutions.

A financial system, using insurance firms, was established in collaboration with provincial associations with fee schedules (payment to dentists for specific treatments for patients) based on prescribed units of work (speed per procedure). These fee schedules, are part of educational curricula, effectively making throughput a business practice approach for dental practice post-education, noting students are graded on quality of work.

This chapter **hypothesizes that particular institutional set ups, such as the financial managers that mediate the dental-care market, can obstruct the flow of**

information between users and supplier firms and hence constrain dental-care innovation.

This chapter begins by exploring the nature of innovation in the dental-service firm in Canada in Section 4.2. Section 4.3 discusses how division of labour between specialists is related to increasing throughput and profitability and how institutions influence their business practices through standards, specialization and continuing education. Section 4.4 considers the nature of the market and in particular, the influence of institutions on technology adoption and diffusion. This section talks about the importance of market size to assess the throughput requirement of new technology, implicit in Chandler and Lazonick (2005), highlights market distortions Gelijns & Rosenberg (1994), demonstrates the distortion of the “market-based fee schedule” and how these distortions separate the business function of finance from the production function, associated with dental-care service delivery. This section concludes in a non-market environment where the articulation of demand is distorted and where revenue is largely controlled by others by attributing specific time to a procedure, high throughput or speed, becomes an important surrogate marker for dentists in the adoption of specialized machinery and instruments. As shown in sub-section 4.5, reliable routines, interchangeable tools and instruments and compatible processing equipment can spread the cost and contribute to profitability, however in dentistry, insurance firms alter the articulation of demand. Section 4.5 explores throughput in the dental-care business, and provides a modified Chandler framework for the dental care industry.

4.2 Dental care firms and innovation in Canada

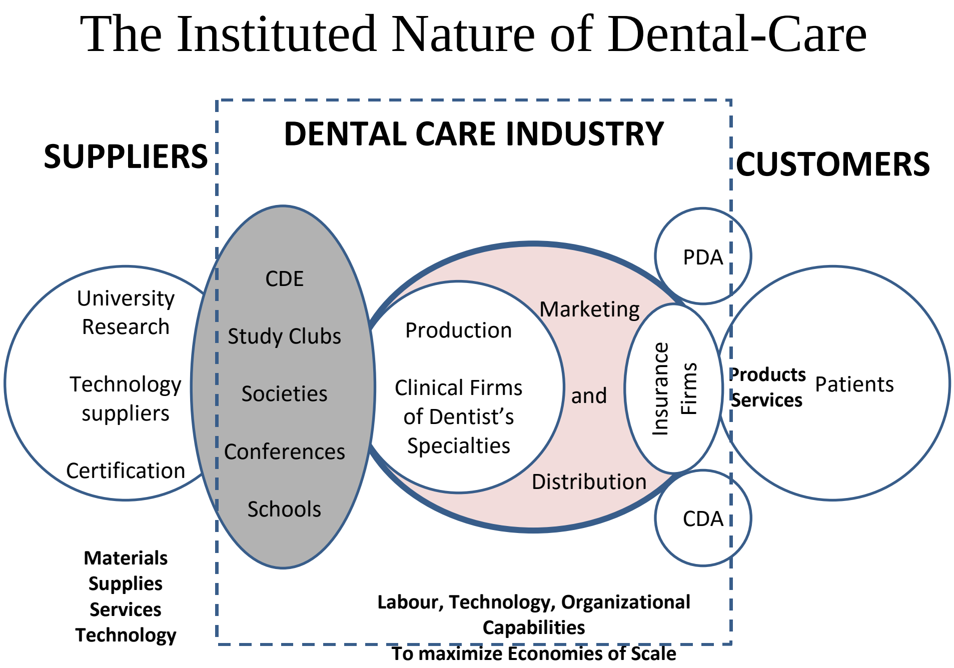


Diagram 13. The instituted nature of dental care service

Diagram 13 illustrates the functionalities provided by the range of actors involved with the dental-care firm, with those directly associated with or mediating the implementation of a new technology included within the dashed line square.

Dentists operate largely as independent or small group practitioners in a fundamentally non-market business model and rely on external institutions, third party organizations and cooperative activities for information, financial management, access to specialized skills, technology and strategic direction. Yet they remain entrepreneurs providing the production function, and are the key interface with the customers. As highly educated professionals, they are one of the high unit cost elements in service delivery and also have the power to make decisions about adopting new technology.

Dental firms are corporations, and the dentists involved are free to run their businesses as they see fit. The firms interact with other firms, organizations and institutions. Table 4 observes the major actors involved and their functions, in Diagram 13.

Each entity is responsible for a key function involving the activities involved in delivery that function. The primary linkages from each actor to other key actors are also identified. A review of the table demonstrates the interconnectedness of the players that reinforce the idea to consider the industry collectively in terms of throughput and economy of scale considerations, in reference to Diagram 13. (note Ch. 5, the analysis chapter provides a filtered version of this table).

Table 6. Long list of Dental-care industry, entities and functional links

Entity	Function	Functions/mechanism	Links with
Patient	User (customer)	Direct pay for services	Dentist, insurance firms
Dentist	Service provider, business manager, capacity, service quality, efficiency, throughput	Sales, patient interface, insurance claims, investment	Patient, insurance firms, PDA, CDA, education, technology supplier
Specialist	Service provider business manager, service quality, efficiency	Expert services, patient interface, insurance claims, investment	Dental society, patient, dentist, insurance, technology supplier
Clinical researcher	Research	Research services, clinical trials	Clinical hospital, government, technology suppliers
Provincial Government	Regulation, consumer protection	Oversee PDA	Public, PDA
Federal Government	Funding, Consumer protection	Research, product certification	University, technology suppliers
Provincial Dental Association (PDA)	Governance, standards,	Admission, ethics, discipline, regulated training	Provincial government, CDA
Canadian Dental Association (CDA)	Business practice, standards	Accreditation	Dentist, provincial dental associations
Dental Societies	Specialized body of knowledge	Education	Specialist
Assoc of Dental Meetings and Conferences	Education and upgrading	Conferences, product certification	Dentists, specialists, technology suppliers, researchers
University	Education, research	Upgrading, continuing education, research	Dentist, Researcher, Technology supplier
Private School of dentistry	Training	Continuing education	Dentist, Technology supplier
Study Clubs	Education, promoting	Upgrading, information	Dentists, specialist, industry
Technology supplier	Equipment, materials, supplies	Production, promotion, sales and maintenance, research, training	Dentist, specialist
Insurance firms	Financing	Claims processing and evaluation	Dentist, specialist, patient

The view of the dental industry as a collective, assists this chapter to frame, identify and understand market distortions and post adoption constraints that affect throughput and that arise of the result of the industry structure that affect the techniques used by dentists to do their work, drawing on Gelijns & Rosenberg (1994)'s distortions to innovation in the medical sector.

The dental sector seeks increased profitability through economies of scale and scope from investment in technology, organization design (division of labour and specialization) and business processes such as standardization, financing, continuing education, and planning, coordination and control to increase throughput and profitability.

The businesses are highly leveraged. This lessens the dental-care firms' ability to internalize a high number of transactions, utilizing high priced technology, within a firm Chandler (1977: 236), decreasing their learning ability. They may use advanced, high-priced medical technology but require a return on investment, in less than one year.

Dental-care service firms can achieve, high throughput or profitability either through economies of speed (time) or economies of volume that expand the scope of the clinical practice (Chandler, 1977: 281; Nightingale, 2000; Interviewee 2).

> In a business model based on profitability, the simpler and faster the treatment, the less expensive the procedure itself will be. Inherent material and labour costs are less. It does not matter whether the dentist uses a throughput model or expands the business with more procedures the less maintenance and follow-up time invested in problematic procedures, the greater the return.
>
> It's like owning a car that is always in the shop. You can make a lot of money on it if you own that shop, but you are left holding the bag if the dealer says we have to support that car. Then we take the punch every time it comes in for warranty work and you can see why reliability becomes an issue (Interviewee 2).

Cost in dentistry relates to the "amount of time the patient spends in the dental chair". Faster, easier implementation reduces material, labour and infrastructure costs in all dental procedures with less risk to the patient (Interviewees 2, 7, 8). The *rated capacity* of the technique (work process), throughput volume, is associated with the dentists – the most expensive intellectual capital. Students of dentistry are encouraged to perform oral-health procedures within a certain time frame (University of Alberta Faculty of Medicine and Dentistry, 2007-08). However assessment is based on quality of outcome (Interviewee 2).

Changes that raise capacity utilization, increase volume by increasing throughput speed. For example, reduced failure rates, due to increased problem solving skills, gave the perception of increased R&D productivity, in pharmaceuticals (Nightingale, 2000). Learning has the effect of reducing labour costs, by increasing performance per unit of output, which can be thought of as reduced cost of products (Arrow, 1962; Rosenberg, 1982; David, 1986; Section 2.4). This initiates two responses: a) learning guided by trajectories that constrain and also provide opportunities Dosi (1982), and b) the institutionalized effect of professional specializations, as in Nelson (2005) and Johnson (2010).

"A model based on high throughput or profitability and reliability or longer term prognosis is not exclusive" (Interviewee 2). In dentistry, the profitability and throughput are affected by the reliability of a clinical procedure. A very large factor in performing high-quality work is cumulative learning, post-dentist-degree, resulting in irreversible dynamic scale economies, based on increasing quality and reduction of uncertainty of routines (cases, Ch. 5,6,7; Section 2.4.2.3).

This is reinforced by the dental-care financing model, as time for maintenance is limited by the billing system and insurance will not pay for a dentist's mistakes. Leonard-Barton (1983) found mistakes are not easy for a patient to detect.

Throughout this research, dentists referred to the time-consuming nature of dental-implant work, and how it takes continuous practice to get high-quality results (Interviewee 2). Interviewee 21, a Periodontist, quit placing implants. Because of the hand-intensive work and the cumulative nature of learning, he had to make a decision "between the heavy work-load to keep gums healthy (the root of periodontal work) or implant work".

The CDA and ADAC (Alberta Dental Association and College), both dental regulatory associations (Interviewees 14 and 15), and the dental health-care financial managers (insurers – Interviewee 19) expect clinical dentists to adopt new technology. Dentist-owners of clinical dental firms are the gatekeepers of practical technological knowledge (Interviewee 3 and 8) and are free to modify demand for new technology as long as they operate with Canadian dental regulatory provisions.

> With regard to new technology the onus is on the dentist to evaluate and with proper training use, and argue a new technology should be part of the scope of practice. Clinical dentists are free to modify demand for new technology, as long as they operate within the Canadian dental regulatory

> provisions (Interviewee 27, David Miller, VP & Chief Operating Officer, Alberta Blue Cross, 2009).

However, clinical dental firms may not look at a new technology that does not produce a better clinical result, and even then, it has to be efficient. As in Lazonick (2005) and Nightingale (2005), there is the need to functionally integrate *organizational factors* and *technical factors*, to achieve competitive advantage *through* opportunities from *new technologies* that functionally link interdependent structures.

> When I think about what creates the desire for new technology, it really comes down to the dentist more than anything else. They really enjoy trying new things that make life easier. I've always loved watching anything that develops that is a better way of doing something. It's about the only thing that I can come up with that's really a driver (Interviewee 8 – dental-care service owner)

Dental-care service firms adopt new technology to innovate their techniques, in ways that illustrate learning to achieve economies of scale or scope, supporting the findings of Gelijns and Rosenberg (1994), that physician-users increase demand. Clinical dental firms modify demand for technology by:

a) Adopting technology and then innovating the technique – example, modified Nobel Biocare implant-denture system in 1985/86 to lower cost of a high priced technology and increase scope of the practice (Interviewee 24 supported by Interviewee 3).

   Scaling effects of learning by *performance improvement in the technique - example, decreased use of implants* from six to two (decreasing cost from $25,000 to about $4,000)[29] *giving the impression of reduced cost of product.*

b) Adopting a technology, that does not meet the technique's requirements and finding other uses for it – example, chairside crown CAD/CAM technology did not replace external laboratory, as advertised, but expanded the scope of dental services (Interviewee 8).

   Expanded capacity utilization, of a large fixed cost, results in cheaper per unit costs, typical of the mass production technologies (Babbage, 1832); Rosenberg, 1994: 26; Jackson, 1998: 81).

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[29] Dr Bergman, DDS, Dipl.OS&A, MScD(Path), MRCD(C), Dental Interviewee 24 is an Oral and Maxillofacial Surgeon. He owns a clinical practice and an implant training centre in British Columbia. He is the inventor and developer of Anchor Dental Implant System, the first Canadian dental implant system approved in Canada, USA, and Europe. He has operated for 36 years as a specialist, accumulating over 34 years experience in the placement and restoration of dental implants, and authored over 50 scientific and technical publications and articles (email 3 June 2010 and phone contact).

c) Adopting a technology, that does not work as advertised, and “parking it in the back room”.

In most cases, dental-care service firms, adopt technology and products developed for particular techniques, thus, producer and supplier firms have adopted a technology-push innovation model.

4.3 Specialization, institutional influence and division of labour

The transformative effects of technology are understood in terms of the technique (Pavitt, 1987c, 1987a; Rosenberg, 1976b, 1982; Nightingale, 2008: 562). To understand how new technology diffuses through dentistry, specialization that results in division of labour, must be functionally linked to a technique.

Nightingale (2000), building on Rosenberg (1992: 384-89)’s observation of a systemic relationship between technical-instrumentation tools and scientific advance, applied Chandler’s economies of scale framework to understand the high cost intangible capital - throughput relationship to drug development, observing that tacit knowledge is required to solve complex technical problems. Since it is embodied in people and embedded in firms, the relationship is “highly inter-dependent” (Chandler, 1977). “Economic advantages can be obtained from the division of labour to ensure that high cost activities are exploited to the full” (Nightingale, 2000: 317).

Technique and knowledge tend to become associated with sectors Malerba (2005), occupations and professions (Nelson 1967, 2005; Nelson & Winter, 1977). Professional knowledge is thought to be highly standardized, scientific and systemic (Schön, 1991). Paradigmatic knowledge has cognitive frameworks Dosi (1982) similar to regimes, which affect diffusion of knowledge in a highly standardized way (Nelson & Winter, 1977). Shared knowledge implicitly speeds up problem solving, creates a trade-off between speed of problem solving, and the depth of analysis gives structure to academic fields (Nightingale, 2000).

Throughput requires a) division of labour, and b) functional relationships between components of a technique or process. “Innovation requires learning about how to transform technologies and access markets in ways that generate higher quality, lowering cost of products” (Lazonick, 2005: 30). This occurs by transferring capabilities generated from development of one product to another Mowery & Rosenberg (1989/1994: Ch.4), generally accumulating trajectories of competence development

Teece, Pisano, & Shuen (1997: 516, 524) and Nelson (2008) and paradigmatic cognitive frameworks, that define technological boundaries, limitations and thus, opportunities (Dosi, 1982).

Learning associated with scale economies relates to a) speed or efficiency, b) reliability of routine, and c) increased quality to increase performance. These can occur by decreasing learning-by-doing time, specialized equipment, interchangeable tools and instruments, or more compatible processing equipment.

Specialization in dentistry is historic. This research observed division of labour through specialization and learning through close coupling of technical and organizational activities by virtue of firm ownership and numerous learning mechanisms between the technology supplier and dentist service firm such as continuing education, study clubs, conferences, etc. This is reinforced by the development of specialties in dentistry and the requirement for continuing dental education imposed by professional associations on the practice of dentistry

Specialization creates opportunity for industry. The developer of implant technology, Nobel Biocare, initially entered the market by teaching and marketing only to dentist-specialists. Around 2005, when this market became saturated, the company began to target General Dentists (Interviewee 24, supported by Merrill Lynch Report – 27 March 2007). This precipitated a trajectory of secondary innovations with higher levels of embedded knowledge to allow General Dentists to do more. Examples are dental implant placement simulation software (case, Ch. 6) and CAD/CAM crowns from materials that allow more forgiving placement of the titanium implant (case, Ch. 5).

Dentists with less depth of skill appear to provide technological opportunities for producer firms. This aligns with Gelijns & Rosenberg (1994) observation that “medical generalists” use less high technology than specialists. However, producer firms recognize dental implant technology diffuses in a distributed manner among dental specialties, suggesting that Gelijns & Rosenberg’s (1994) suggestion, of adjusting the specialist/generalist mix to reduce costs to the American health care system may, open up avenues to technical change, that in the long run, result in cost increases.

This also suggests quality could suffer with an overly diverse service mix, for a specialist. Division of labour is instrumental to providing high-quality dental service, as it decreases learning by doing. However, responsibility for referral lies with the practicing dentist. If dental schools do not teach skill limitations, lack of referral to specialists could increase implant failure (Interviewee 12) due to reduced reliability of routines.

> If it's better but takes twice as long, economic reality comes in and I can't afford to do it because the fee structure is based on how much time it takes to do it right now…so it has to be a significant improvement in about the same timeframe…A lot of the technology developed or offered for dentistry allows for increased savings in time (Interviewee 8 – dental-care firm).

Supported by all dentist's interviewed and Rice (1983), reimbursement rates are important to physician-induced demand, not only in relation to technology but also to the selection of services they choose to provide.

4.4 The nature of the instituted market of dental-care firms

Dental service firms are private corporations. The market in which dental care firms compete is cooperative and firms have little incentive to prevent others from adopting their successful innovations. The lack of profit driven innovation and imitation by competitors makes the stylized Schumpeterian competitive environment hard to maintain (Nelson & Winter, 1977: 65).

In Canada, many business and government employers, support prepaid dental plans, at little or no charge to employees. Canadians do not pay taxes on prepaid dental-health benefits. Although employers pay for most dental plans,[30] life insurance and health insurance firms manage the dental-care financing system. It is a profitable business for the insurance firms.[31] Speed-per-procedure time frames are established by insurance firms through their dental consultants, in consultation with the appropriate dental bodies that regulate dentists and their scope of their work.

As illustrated by the billing system, the mode of delivery for dentistry is reinforced by the insurance firms that manage the dental-care financing system. This mode of delivery distorts the market in these ways:

---

[30] And are really the insurers of the Canadian dental health care industry (Dr Sperber).

[31] On average, only 60% of total paid benefits are utilized. For example, the unused portion of the benefit paid by an Alberta government research organization of 515 employees was about $25,000 for 2010 (Interviewee 7, 21, verified by Interviewee 26).

a) The structure limiting usage based on waiting time and preauthorized procedures of insurance coverage, influences the number of potential customers for the dentist (as previously described),

b) Dental procedures covered by insurance are often seen by customers as a proxy for what is required to maintain good oral health (Interviewees 2, 8, 12, 21; dental implants are beyond the reach of most (Schnitman, 1990), and

c) Insurance coverage is a cause for not seeking dental care in Canada Grignon, Hurley, Wang, & Allin (2010), supported by Litaker& Cebul (2003), for the United States.

Although employers (business firms and governments) pay for most dental plans in Canada,[32] the life-insurance and health-insurance firms sell packages that limit usage based on waiting time and preauthorized procedures. This system rewards use (perhaps overuse) of preauthorized procedures and their underlying technologies and limits use of higher-tech, higher-priced equipment, such as radiographs and crowns.

Causes for variation in use of a technology are the continual potential conflicts between the dentist's belief about what is best for the patient and what the insurer interprets as best for the patient, and in some cases, ignoring the more intense demands of oral specialists patients. Another cause for variation is the distorted use of technology. One such example is filling posterior teeth with a white composite that has a 30-40% higher failure rate than an amalgam filling but is an insurable procedure in Alberta (Interviewee 8). A short-term approach that encourages use of less-costly technology.

This approach is similar to managed-care organizations[33] in the US, where the insurance arrangements decrease costs by lowering hospital-utilization rates (Gelijns and Rosenberg, 1994). Distortion arises because technology is treated solely as a cost-reduction effect, and technological change is seen as the introduction of new processes that reduce the cost of an essentially unchanged product (Rosenberg, 1982: 4; Gelijns and Rosenberg, 1994).

When a mode of delivery lowers cost by decreasing services, it affects both the quantity of dental/medical interventions and their price, and thus the aggregate costs to the insurance firm. However, as a change in cost cannot be attributed to an underlying

[32] Are insurers of the Canadian dental health care industry (Dr Sperber, Interviewee 4).
[33] Such as HMOs and PPOs (Health Maintenance Orgs and Preferred Provider Orgs).

technology, the message to the developers of science and technology is distorted. If adoption appears to concerned only with cost reduction, development of more costly, higher-quality technologies such as the dental implant, which improves health but does not lower short term costs, will be inhibited.

Interviewees 2, 7, 8, 21 and 22 note:

> The dental-care financing system (insurance) is not responsible for the long-term health of the person receiving the treatment. This is because insurance contracts that finance the dental-health-care system are short-term, and thus negates the value of creating medical technologies that improve the long-term health of the individual, such as dental implants that can lower costs in the long run.

In Canada, clinical dentists are free to adopt technology and expand their scope of business as long as they operate within the Canadian dental regulatory provisions. The third-party payment system does not totally insulate the patient or dentist from financial implications. This information asymmetry has a limited effect on the adoption of higher-priced, higher-quality dental health-care technology. It has a somewhat greater effect in promoting technology to the self-paying end-user. The superior quality of dental implant technology, over other procedures suggests connection between the dentist and patient is essential for higher-quality, higher-priced, health-related technological interventions.

The scale of market size, implicit in Chandler, is important to assess the throughput requirement of new technology. The financial managers of dental-care, obstruct the actual *market share,* of potential customers and the employers (business firms and governments) that pay for most dental plans, therefore, distort the message to the suppliers of innovation, that may assist the dental-care firms with innovation. Dentist interviewees believe that insurance companies will not support a new technology, such as the dental implant, based on its quality or longevity.

The requirement of “efficiency in terms of time” could encourage scientists and technology producers to focus on the high-throughput requirement of the business of dentistry (i.e., ICT has been very successful in dentistry, Interviewees 2 & 3), rather than health-related technology like the implant technology that is more expensive in the short term. These types of *operating distortions* affect articulation of technological demand and are attributable to a mode of delivery reinforced by the dental-care financing system (insurance firms). The operational distortions of the dental-health-care financing system encourage the technological advance of process technologies, but, based on implant technology, these distortions may limit or constrain higher-quality, health-related technologies that improve health at increased cost. The notion of financial managers obstructing the markets, initiates two responses:

a) "Cost" in relation to "speed" at which a technique is accomplished, becomes an important indicator to measure financial returns, and defines the quality performance criteria, and
b) The learning, internal to the firm, to achieve economies of scale and scope is not related directly to the dynamics of the market but instead to the dynamics of institutional specializations and to the constraints of a mode of delivery reinforced by the financial managers of dental care.

Allowable laboratory costs can vary between patient plans (Interviewee 8). Interviewees describe – it is not uncommon for the same insurer to accept a procedure for one patient but reject the same procedure for another with the same clinical condition. Efforts to keep costs down may result in the insurers' consultants discounting the opinion of the dental medical professional (Interviewee 7, supported by 2, 8, 21).

Insurance firms reimburse dentists based on a procedure code for each task. A patient's plan will reimburse a set number of units (15 minutes = 1 unit) per year per procedure. The technology cost, material, labour, and other operating costs are all included in the procedure code. The allowable *billable units per procedure* and laboratory costs, are outlined in an approved fee schedule such as "*Fee Schedule, Patient services and clinical protocol manual"* (University of Alberta Faculty of Medicine and Dentistry, 2007-08); Interviewee 8).

The constraints of the "market-based fee schedule" could lead to price setting among dentists. More so, it leads firms to adopt a business model in which innovation relates to high throughput. A dental clinical practice, that uses high capital cost equipment and labour, and is highly leveraged, depends on innovation. "Throughput" or "speed per procedure" become important. Throughput and profitability are important factors for both the insurers and the dental-service firms. Although the main driver is reduced cost, it overlooks the fact that lower cost associated with longevity can potentially be more profitable, if long term economies of scale arising from more reliable technology are considered.

The operating distortion is the formula, for the *dental fee* or *billing amount* per unit, a market-determined rate based on the 70th percentile. The formula is based on the notion that, "70% of Alberta dentists' bills are at or below this level". Assessment is carried out by Alberta Blue Cross, the largest consumer group dental insurance plan, in Alberta. This firm believes their large market share places them in a unique position to accurately assess billing rates for Alberta (Interviewee 18).[34]

However, the oral disease of a specialist patient is substantially advanced compared to the severity of a General Dentist's patient (see cases) and is perhaps not as well addressed by a market-determined rate. For example, laser technology, accepted by insurers to replace the curette and the probe, was to make teeth cleaning easier and faster, but it does not work for the level of periodontal disease the specialist addresses. Interviewee 21, Periodontist explains, "The laser is substantially more expensive than curette and probe technology without *health benefits* for the patient or *throughput benefits* for him and simply drives up costs for the patient", also distorting the message to the developers of science and technology.

It appears that these distortions may result from separation of business functions such as finance from the production function associated with service delivery and the researcher hypothesizes that this particular institutional set-up can obstruct the flow of information between users and supplier firms and hence constrain dental-care innovation.

In dentistry, variations in technology intervention are less about professional uncertainty as observed by Gelijns and Rosenberg's (1994). The operational distortions appear to be attributed to:

a) The requirement for cumulative learning,
b) Uncertainty of insurance acceptance,
c) Insurance focus on keeping costs down,
d) Timeline for return on investments in new medical operational technologies, and
e) Limitations associated with approved procedures leading to increase return visits.

In a non-market environment, where the articulation of demand is distorted and where revenue is largely controlled by others by attributing specific time to a procedure, high throughput or speed, becomes an important surrogate marker for dentists in the

[34] The dental-provider groups, excluded from a market-based fee schedule, are the provincial and federal government departments that provide oral health care for select disadvantaged groups.

adoption of specialized machinery and instruments. As will be shown in the next sub-section, reliable routines, interchangeable tools and instruments and compatible processing equipment can spread the costs and contribute to profitability. However, in dentistry, insurance firms alter the articulation of demand.

4.5 Economies of scale and throughput

As previously shown, dental care is a partly non-market sector operating in an institutional setting where many activities are distributed between organizations. In other sectors similar activities might be internal to the firm. Hence dentists tend to adopt specialized machinery, techniques and instruments associated with higher throughput.

The Chandlerian framework suggests paying attention to throughput - and how innovations in technique might increase the number of patients that can be treated in a given period time. With this increase, the high fixed costs of equipment and professional education can be spread and profitability will rise. However, the fragmented nature of the dental market, and its lack of integration in scale intensive firms means that the co-ordination needed to achieve this throughput is not generated by Chandler's managerial hierarchies. Instead it involves complex interactions between dental specialties and other organizations, which in a medical setting are heavily institutionalized and regulated. Dentistry differs from the industries studied by Chandler (1990) and Hughes (1987) by the extent to which institutions structure demand, particularly the insurance firms that manage the dental care financing system.

Throughput is the primary source of economic advantage for a dental practitioner. Dentists instinctively apply *throughput,* profitability based on speed, to the processes they use to repair diseased teeth. A dentist's clinical practice generally uses high capital cost equipment and labour that build economies of scale from reliable routines, interchangeable tools and instruments, and compatible processing equipment. Innovation relies on implementing business practices that result in economies of scale, permitting the high throughput required of highly leveraged profession.

Without high-level sales, high fixed costs of developing technology would result in losses (Lazonick, 2005). High throughput requires, investment in high capital cost equipment, labour, and complementary organizational assets (i.e. specialized services of dental care firms) to build on the economies of scale and scope, arising from standardized processes, precision instruments and interchangeable tools Chandler (1977: Ch. 8), supported by Lazonick (2005: 39-40).

To Chandler (1990), “the way a firm was organized was an essential constraint on, and key facilitator of, what it could do” (Dosi, Nelson, & Winter, 2000: 17). The complex interaction of the dental specialties and other organizations and the institutionalized market are factors that allow a firm to capture the scale and scope of the market (Ch. 8). The efficiency gains of “learning by doing” lead to the refinement of existing production processes or application techniques. Generally, this learning is iterated with performance feedbacks from the market (Teece et al., 1997; Tripsas, 1997; Helfat, 1997; Helfat and Peteraf, 2003; Winter, 2003); “learning by using” (Section 2.3.4).

Understanding throughput requires a) division of labour, and b) functional relationships between components of a technique or process. The learning associated with scale economies relates to: a) speed or efficiency, b) increasing the reliability of the routine, and c) increasing quality, reducing uncertainty by increasing performance. This can occur by investment in specialized equipment and instruments, interchangeable tools and equipment, the adoption of technology or using referrals to other dentists to increase implant success, decreasing learning time, reducing maintenance and return visits, reducing material costs and by extending the scope of practice.

Scale, as a form of governance of business capabilities, is expected to channel innovation and learning, in dental-care service firms, along these lines:

a) Scale is measured by *potential rated capacity* of *physical characteristics* of production facilities – the reason why Hughes (1982) was able to measure load factors of his technical system, and Nightingale (2000) could not (: 352).
b) Measurement of scale is dependent on both "volume (rated capacity)" and "speed (intensity)" (Chandler, 1990: 24).
c) *Size* as in *rated capacity* and *speed* as in the "intensity that capacity is used", *thereby* the actual measurement of scale and scope is in "*throughput*".
d) *Speed* factors in “rated capacity”, link to *volume*. For example: a) maintenance, decreases speed by extending the working day of the dentist, and b) infection-control procedures add fifteen minutes extra to an Oral Surgeon’s time to place an implant (case Ch. 5; interviewee 24, Dr. Bergman).

e) The “*rated capacity”* of the dental implant implementation technique/work process, in dental-service care firms, is “amount of time the patient spends in the dentist’s chair” – a per day measurement of volume, of the most expensive intellectual capital.

The Chandler framework, helped to understand how new technology diffuses through the dental care system of innovation, and how institutions mediate pre and post-adoption constraints to innovation. The process a dentist follows to replace a diseased tooth with a dental implant involves a complex division of labour between specialists, and techniques and one may expect a degree of coordination would be needed to increase throughput. The key insight taken from Chandler is not the importance of scale (size), as in spreading the cost over large amounts of output by adding more dentist’s chairs, but instead the importance of increasing speed of treatment at a given level of reimbursement and that is the capacity utilization of the dentist’s time, its influence on cost structures and how they can be improved by better coordination.

From this work, *to utilize implant technology*, a dentist’s clinical practice would be expected to use of high capital cost equipment and labour, that builds on the economies of scale arising from reliable routines, that may increase speed and throughput. To increase the reliability of routines, to reduce the uncertainties associated with implant failure and other technologies, while sustaining the rated capacity (time in chair), possible quality improvements the cases may reveal, include:

a) Specialized diagnostic equipment and instruments,
b) Compatible processing equipment,
c) Technologies relating to implant success,
d) Reducing maintenance and return visits,
e) Decreasing learning-by-doing time, and/or
f) Expanding the scope of practice.

To facilitate comparisons and generalizations between case studies, the boundary of the cases are drawn around the functions/techniques generated by each dental-firm specialty. Previously mentioned, the technique is a ‘function’, and an ‘artifact’ denotes ‘input that generates the function’. The identified *artifacts*, will be italicized. The case is organized in terms of these functional links. However, as mentioned in the methodology, the written description relating to the techniques, is supported by other data gathered through the semi-structured interviews, generally identified in the footnotes.

Each case identifies how each dentist, generates improvements in throughput in the practices associated with their specialization and their firm.

To reiterate, as cases do not follow directly after this chapter, cases explore role of economies of scale and throughput to understand how it takes place, and how demand is articulated within a dental medical innovation system. A multi-case, comparative study of the specialties was undertaken to follow the progress of knowledge at the technology (dental implant) level. This allowed for a degree of variance. Following Granberg (1997) the dental implant system was decomposed into its components and interactions, to explore how the actors in the technology system functionally align and link their activities around a production process or technique. Because dentists' require services from other specializations and firms, the cases illustrate these **functionally linked industry and institutional structures.** Each case captures a map that provides insight into the processes involved, specialties distribution within the system and how they relate to knowledge flows.

Each case provides varying level of medical detail about procedures, based on their specialized knowledge. Such, as suggested reading order is to start with Ch. 8, then Ch. 7 to fully appreciate how the General Dentist relies on the referral system (division-of-labour) to achieve economies of scale by executing only high-quality procedures in her practice.

Each case identifies how the different types of dentists generate improvements in throughput in their operations. These are compared to identity commonalities and differences (Table 8, Ch. 5). Cases employ division of labour between specialties and technique to increase throughput. While there is a relatively standard pattern, differences occur because of differences in the knowledge of each specialty about the technique.

CHAPTER FIVE
INSTITUTIONALIZATION OF DENTISTRY

5.1 Introduction and objective

This chapter based on observations, describes the institutionalization of dental care. It builds on Ch. 4 and the cases. To summarize, Ch. 4, for one, built the case to understand how dentist’s overcome market distortions and presents the modified Chanderlian framework for the dental care industry. The cases (Ch. 6, 7, 8) observed a number of mechanisms associated with increasing returns to scale that are used by the three dental firms involved with the dental implant and the functionally linked external entities that these dentist’s use to solve technological problems, associated with the implant placement technique.

This chapter has four sub-sections.
5.1 Introduction and objective.

5.2 Professional organizations and the institutionalization of dentistry - describes the institutionalization of dental care.

5.3 Learning techniques of the dental-care service firms - demonstrate how dentist specialties associated with dental implants, in this study, are conditioned by institutions.

Section 5.4 Case study regularities and learning categories, concludes by showing how linkages to learning approaches emerged from the case results and the learning regularities they exposed, related to the implant technique.

It concludes with demonstrating how similarities and differences were found among the cases with final observations in Ch. 9.

5.1 Introduction, suggests it is helpful to visualize the institutionalization of dentistry to understand how institutions alter market demand, in contrast to the Chandlerian firm (Ch. 4, Diagram 10) where internal business functions plan, coordinate and control their activities according to the market demand, the dental care industry relies on external organizations, such as dental associations, producer firms, and insurance companies to plan, coordinate and control their activity as illustrated in the following illustration.

The Instituted Nature of Dental-Care

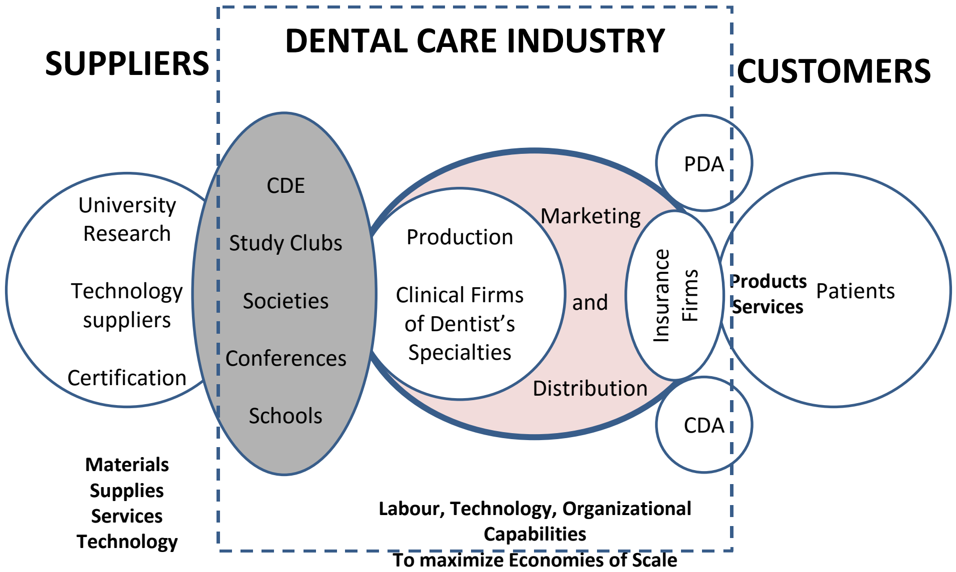

Diagram 14. The dental care industry

Diagram 14 is helpful to visualize how the Dental Care Industry is institutionalized. The elements of this table, was developed from a core list of entities associated with dental care, that influence communication and interaction patterns, in dental-care service firms, as identified or observed in the cases and interviews. The initial long list (Table 4, Ch. 4) is not presented here as it was evaluated and reduced to a list of the primary entities and groups of entities in Table 5 with knowledgeable professionals. The bolded entries are considered to influence dental-care service firms. Non-bolded entities interact predominantly with producer-firms.

This chapter describes the role and pattern of interaction of the dental-care service firms with the entities listed in the Table 7, to assist in assessing communication and interaction patterns.

Following the table, Section 5.2 Professional organizations and the institutionalization of dentistry - addresses how these functionally-linked entities and others influence dentist and possibly innovation. Each bolded entity represents the observations of this study, described in detail with some entities grouped i.e. Professional organizations include CDA, ADAC, Dental Societies and Study Clubs.

Table 7. Dental-care industry, entities and functional links

Canadian Dental Association, CDA, and equivalent
Clinical Dental Practitioner
Clinical Research Hospitals
Dental Society
Health Authorities and Nat. Medical Association, CIHR and affiliates
Health Canada, Health Protection Board, HPB
Insurance Firms, Consultants, Employers, Customer
Private Policy Organizations
Private Training and Research Institutes (in Canada)
Producer Firms
Provincial Governance Associations, ADAC, BCDA
Study Clubs
Supplier Firms, promotional
University R&D, direct
University R&D, indirect
University/Private School of Dentistry

5.2 Professional organizations and the institutionalization of dentistry

Canadian Dental Association (CDA), regulating association
Province Governance Associations (ADAC), regulating association
Dental Society, facilitates the accreditation boards
Study Clubs

The evolution of dentistry has been strongly shaped by professionalization of dental practice, with dental associations established to protect the public, regulating who may operate as dentists and how they are accredited (Canadian Dental Association, 2002: II-2; Dyck & Sperber, 2007). The CDA (1902) is an oral-health advocate for Canadian dentists and for the business of dentistry, noted for its role as an advocate for tax-reduction (1920) - a 32.5% tariff tax dropped on certain imported dental goods (Canadian Dental Association, 2002: XI-1 to XI-6). The CDA also led the movement for a financial management system of prepaid dental plans[35] (1950) as a mode for delivery of dentistry. It established bodies that aided the careers of the dentists,[36] advocated for reforms to assist the profession,[37] and developed funds for research and education.[38]

Each dentist in Canada must belong to two dental associations in order to practice. One must be a provincial jurisdiction, such as the Alberta Dental Association and College (ADAC), and the other is the national jurisdiction – Canadian Dental Association (CDA), generally, with the executive roles staffed by dentists. In Alberta, ADAC is two separate bodies in one organization - the association and the college. One manages the interest of the public and the other manages the interest of the profession. For the profession, ADAC sets and regulates parameters for appropriate practice and training. For the public, it also sets admission and practice standards. From external observation, it is not entirely clear whether the standards are erected to protect the profession or to promote the profession and the industry that serves it (Interviewee 2, 4). The distribution of knowledge among dental specialties is protected by dental societies[39] - associated with the accreditation boards and with the ability to officially certify products, and dental regulating authorities - the associations, and disseminated by dental graduate, teaching schools. Dentists operate in a stable institutional context (Schön, 1991).

These institutions and the institutionalization of the financial management of dentistry evolved early in an interrelated and (layered) self-enforcing cycle, set out in Chapter 4.

The dentist's organizational influence extends to membership in dental societies. A society is a group of dentists with similar interests. Canada, like the United States, has instituted mandatory continuing dental education (CDE) and professional or similar bodies sponsor certified CDE courses and conferences approved by ADAC.

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[35] There are currently 150 prepaid dental plans in Canada that are paid for by employers as a tax free benefit to its employees.

[36] The Canadian Dental Service Plans Inc. (CDSPI) was jointly (CDA-federal and provincial-association) established in 1959 to focus on insurance and investment plans i.e. the registered retirement savings investment plan (CDA RSP). By 1990, CDSPI had 90% of dentists participating.

[37] In the 1980s, a "Third Party Dental Plans Committee" was formed to raise funds from its members for an active campaign against "capitation" or 'closed-panel dentistry'. This resulted in the patient, rather than the insurance firm (like in the US), having the right to choose a dentist. In the 1990s, "CDAnet", an electronic data interchange (EDI) between the dentists and the insurers of the patient's dental plan, was formed to expedite the dentist's billing process.

[38] CDF continues today as the charitable foundation for the dental profession to attract funding for research and education (Dental Historian, 2007, V45; CDA's series, Century of service; Dr Sperber – Interviewee 4).

[39] For example, it is the specialists in the UK and the USA that are developing public awareness campaigns warning the General Dentists' of their legal liability for improper placement of implants (Merrill Lynch, 2006 report).

"Approved" activities gain credit toward the CDE requirements of Canadian dental-regulating agencies. The 2009 accredited study club list for the Province of Alberta, is presented in Table 6 (ADAC; Interviewee 2).

Study clubs are organized by interest or geographical location. They may be specific to a dentist-specialty, research topic, or equipment (i.e. concerns with computers in dentistry). Speakers can be sponsored by club membership fees or by industry. Generally, speakers are recruited from dentistry by industry and are often dentists who speak about the specific equipment or services they use. They are typically paid an honorarium. Study club presentations are a way for dental firms to market indirectly to dentists, Interviewee 8, 12, 24, and also provide a venue for specialists to attract referrals (Interviewee 24, Dr. Bergman).

Table 8. Accredited study clubs in Alberta

Alberta Gnathological Society
Calgary and District Gnathological Society – two sites
Calgary Bioaesthetics Study Club
Calgary Society for Advanced Dentistry
Canadian Forces Dental Service Study Club
Computerized Dentistry of Northern Alberta
Edmonton Implant Study Club
Edmonton ITI Dental Implant Study Club
Edmonton Multidisciplinary Study Club
Edmonton Society for Periodontal Studies
Lethbridge Association for Progressive Dentistry
Multidisciplinary Association for the Study of Cranio-Cervical Pain
Orthodontics Study Club – Calgary
Parkland Orthodontic Study Club
Parkland Study Club
Red Deer and District Multidisciplinary Study Club
Alberta Dental Implant Academy
Alberta Implant Seminar Study Club
Calgary Prosthodontic Study Club
Edmonton District Dental Society[40]

[40]The *Edmonton District Dental Society* is sponsored by manufacturers and suppliers of dental consumables and equipment. The members pay a yearly fee and the society brings in speakers every six weeks. The fees mainly cover the food, and the speakers are paid an honorarium in addition to travel, hotels, etc. by the sponsoring firm. The speakers are mostly dentists from clinical practice. They have a moral obligation to provide a list of any type of corporate sponsorship they have, to disclose the speaker's bias, "All dentists in Alberta expect this" (Interviewee 8). The interviewee also stated that "Alberta has ten times fewer dentists than MDs and it would be found out if a speaker was deceiving them".

The cases and discussion with dentists and persons associated with universities, found that CDE courses and study club meetings might partially or completely support an industry-based curriculum promoting certain brands of technology or fields of science-based technologies for patient care. Over time, as the recruited medical speakers become more specialized, they are certified as “experts” in the industry, and the dental societies, through their associated conferences and study clubs become a means for communication between the developers of technology and the clinical dental firms.

Clinical Dental Firms

While some private training qualifies for CDE, dental implant training does not. Implant producer firms like Nobel Biocare, Straumann and Zimmer, use regionally located, private teaching, clinical care firms to train and promote their products to other clinical dental firms. The curriculum for these courses is built around the industry implant brands. Instruction is provided for a fee, at dental-service offices by dentists viewed as having “expert” knowledge, who become “local champions”, because they market and train other dentists, within a geographic region for the producer firm. It was observed, close proximity of professional training, to dental-care service firms, is viewed favorably.

Insurance Firms

The financial system modifies the direction of learning of clinical dental firms by conditioning what new knowledge the dental-care service firm can absorb. There is continuing potential for conflict between the dentist’s belief about what is best for the patient and what the insurer, based on their consultant, interprets as best for the patient. It is not uncommon for the same insurer to accept a procedure for one patient but reject the same procedure for another patient with the same clinical condition. Attempts by insurance firms to keep costs down may result in their consultants discounting what the dental medical professional believes to be appropriate for the patient (Interviewees 2, 7, 8 and 21), and thus, distorting the message to the suppliers of the science and technology knowledge, who are responsible for future inventions (see Ch. 4).

The institutionalized process of insurance and its affect on dental-care services firms. The “financial management of dentistry” is institutionalized in an important way – insurance firms take “deposits – they hold the funds contributed for prepaid dental plans" and manage "withdrawals" – requiring justification of their use, by the clinical dental firms, for dental-patient care per patient. They also adjudicate the claims. These third party firms must abide by formal rules for claim reimbursement, maintain reserves (for liquidity) to assure solvency, and respect the norms for "pre-authorizing funds" and "payment of obligation to the clinical firms" through the organization of the capital markets managed by the insurance firms. The market of the insurance firms differs from the market of the dental-care firms. In the case of implants, insurance does not cover the full cost (Supported by all cases).

Private Training and Research Infrastructure in Canada

Dr Yen, Professor of Orthodontics and Dean Emeritus, Faculty of Dentistry, University of British Columbia,[41] considers the dentist as the gatekeeper or the buyer of implant technology. The goal of the implant producer firms is to "train the gatekeepers and get them to train yet more gatekeepers". The approach is to train dental students, as they will be the future gatekeepers, once they are employed as clinical dentists.

To access and train students, the dental implant firms build (or offer donations to build) university clinical teaching operatories supplied with their technologies. Students, who become familiar with the brand-name implants during their education, can subsequently be hired by the dental-implant producer firms to deliver courses to train other clinical dentist-gatekeepers. To attract the practitioners, the implant producers build their own continuing-education sites and hire practicing dentists to provide leading-edge instruction.

There are several examples of this approach in Canada. Nobel Biocare provided a donation of $5m over five years to build the Nobel Biocare Oral Health Centre at the University of British Columbia Faculty of Dentistry.[42] One of the main reasons for this donation was to gain access to Chinese universities and the Chinese market through UBC's dental graduates (Dr Yen).

To train future gatekeepers (other dentists), Nobel Biocare built the Nobel Biocare Toronto Training Institute Centre, with fully equipped surgical suites. The Centre is not

[41] Dr Edwin Yen; Interviewee 5 and 22.
[42] Built in 2007, there are 144 clinical operatories equipped with advanced instrument systems and chairside software providing the infrastructure for the clinical-practice component that is required for the completion of Doctor of Dental Medicine (DMD) requirements and graduate programmes.

a dental school, but a ”learning-by-doing” centre, targeting clinical dental firms that require continual dental education (CDE).[43]

Straumann has established the Training Dental Learning Centre in Oakville, Ontario, fully equipped with state-of-the-art non-competitor products that compliment Straumann products used for aesthetics, implant and restorative dentistry, i.e. CAD/CAM crown milling machines, Cone Beam CT x-ray scanners.

Producer Firms

Producer firms sell directly to clinical dental firms who expect the producer firms, to impart what is new in tissue-repair and regeneration, related to the dental implant that could impact current practice techniques. In this sense, the producer firms become the indirect contacts, to institutions that advance basic science.

It is notable to recall that producer firms seek to gain accreditation for their products in “university dental schools” and dental societies, and that dental-care service firms are observed to buy, products officially certified and promoted by their graduate dental school, dental society, and specialized dental study clubs.

Supplier Firms, promotional CDE

Producer firms are aware that offering CDE related to their products, directly or through affiliated supplier firms is effective. In some cases, they cover the CDE costs for the dental-care service firms.

University R&D, indirect (producer firms, publications)

Publications are referenced, as a source of more general external knowledge, not directly related to current practice, but still within the dental specialties (Interviewee 24, 12).

University/Private Schools of Dentistry – official product certification, graduate specializations.

Industry programme support may include unconditional grants, canned courses, material support, or other. Some universities have exclusive agreements with only one

[43] //.nobelbiocare.com/en/education-and-events; //.1.nobelbiocare.com/en/education-and-events/training-centers/default.aspx. These sights were recommended by Nobel-Biocare’s regional manager for Alberta, Interviewee 22.

type of implant brand, such as Nobel Biocare (Interviewee 2, 3).[44] Others, such as the dentistry department at the University of Alberta, work with a number of implant providers – Nobel Biocare, Straumann and Astra – and do not have deals of exclusivity. The University of Alberta has guidelines for corporate relationships with faculty courses. They are always declared to participants, and course objectives are clearly outlined, no matter what system of collaboration may apply (Interviewee 2, Director CDE, UofA).

Producer firms gain accreditation for their technology/product from schools of dentistry and dental societies. The official recognition of product, is widely sought by producer firms, and is a motivating factor to technical change and the bulk of these conferences are offered in association with dental societies.

When they provide official product certification, it changes the communication and interaction patterns among firms involved with the advancement of those technologies. It has been observed that dental-care service firms may make purchases of new tools, designed specifically for a specialization and their associated applications in practice, when they are "officially certified" by their graduate dental schools, dental societies and promoted in study clubs.

The next section, 5.3, demonstrates how dentists' learning, in this study that are associated with implant technology, based on the observations in section 5.2, are conditioned by institutional influence. These demand-conditions influence dentist's ability to be receptive to new technology (David, 1986).

5.3 Learning techniques of the dental-care service firms

Dental-care service firms are all conditioned by the same mechanisms that alter their learning. They are:

a) Their specialization societies, including education acquired in graduate school,
b) The required scale of throughput, and
c) Market distortions, caused by the dental-care financing system.

[44] University of British Columbia and University of Toronto (Dr. Yacyshyn); supported by Dr. Yen, Interviewee 3.

By applying Johnson (2010) economic logic to learning by doing and using Rosenberg (1982) and searching Lundvall (1985, 1988, 2005) this study observes that their learning is related to the economic logic of the firm. This reveals the dental-care firm's access to knowledge within the institutionalized non-market structure they work within, noting Ch 4 already established that real-markets are obscured from the dentist. It is an institutionalized profession, with particularly important influences from:

- Canadian Dental Association (CDA), regulating association
- Province Governance Associations (ADAC), regulating association
- Dental Society, facilitates the accreditation boards
- Study Clubs/University/Private School of Dentistry, and
- Insurance firms, act as a bank

Justification

Learning by using – the purpose of this thesis was to illustrate post-adoption constraints to innovation associated with dental implant technology. The communication and patterns of interaction between the dental-care service firms and other *clinical dental firms*, that train within a region, for implant producer firms as "experts", would be considered as connected to the commodity logic of the enterprise. So would the *Private Training and Research Infrastructure in Canada*, comprising the *Producer Firms* that direct sell to clinical dental firms, and the *supplier firms that provide promotional CDE.* As implant training is not part of CDE, all the learning by using, with the exception of the suppler firms that provide promotional CDE, is directed toward the "the rival modality of the implant trajectory" but is still within the commodity logic of the firm.

As mentioned, learning by using can interact with learning by searching. However, the parameters by which it is established are not clear. The iterative learning models (Ch. 2) and medical literature, illustrate technological advance can evolve from identified stress points in existing trajectories.

Learning by searching occurs through connections to basic and applied sciences, at universities and R&D departments. This thesis illustrates, *Private Training and Research Infrastructure in Canada* and *Producer Firms* act like bridging institutions of "new technological knowledge" from *private firms to private firms*.[45] Learning by searching, as with Rosenberg's learning by using, may or may not be linked to the

[45] It is within the commodity logic of the enterprise and thus, maybe more efficient.

commodity logic of the existing trajectory. As mentioned in Chapter One, only one to two percent of dentists are involved in clinical trial forms of basic research. Observed interaction with a *university,* is through *publications*, as a source of external knowledge, unrelated to current practices, but still within the dental specialty.[46] The observed connections to implantology and basic science, were within the commodity logic of the firm, however not, the dental-care service firm.

The market of the insurance firms is not the market of the clinical dental firms. The effect of the distortion will be presented, in Chapter nine.

The following section 5.4 Case study regularities and learning categories – demonstrates how the researcher found similarities and differences among the cases, that emerged from the case results as the dentist's intended to increase returns to scale, from the adoption and use of high priced technology such as the implant technology.

5.4 Case Study Regularities and Learning Categories

This will now show how the researcher found similarities and differences among the cases.

Learning associated with scale economies, is intended to increase returns to scale arising from:

a) Decreased in cost of one factor or another - (dentist labour) or (material-capital cost), generally by increasing quality and decreasing uncertainty.
b) Changes that increase capacity utilization, that is the volume during a set period of time, by increasing throughput speed or reducing failure rates.
c) Decreases in process costs that give the impression of a decreased cost of the final product and can be thought of as means of penetration into new markets and/or areas of application.

The case studies (Ch. 6, 7, and 8) observed a number of mechanisms associated with increasing returns from scale and throughput that are used by the three dental firms

[46] Interviewee 24, 12.

involved with dental implant technology. They are summarized in Table 9, which provided the basis for triangulating observations among and between cases.

The mechanisms focused on learning by doing are all associated with the production process itself and do not reflect marketing and distribution or other business processes to a significant degree. This would seem to relate to the non-market nature of the sub-sector in which costs beyond throughput improvements are mediated by non-market actors such as dental associations and insurance. Regularities in learning by doing are associated with division of labour through referral leading to specialization, reducing complexity through technology and increasing speed and or reliability through technology (all cases do this).

Table 9. Triangulation of the Case mechanisms affecting throughput

Throughput Factors	Case Ch. 8, Surgeon	Case Ch. 7 Prosthodontist	Case Ch. 6, General Dentist
Learning by Doing/Producing			
Division of labour	Specialize on implant installation only All work by referral	Specialize on crown and restorative Refer implant to Surgeon	Specialize on simple cases Refer complex cases
Eliminate steps	Knowledge reduces steps required (i.e. stent)		
Decrease complexity	Bone regeneration	Semi-sterile approach	Simulation +3D X-Rays CAD/CAM chairside crown milling
Inter-changeable equipment	YES – install one brand	NO – 3 brands – 3 kits	YES - Install one brand
Standardization	Install one brand	Works on multiple (3) brands	Install one brand
Increase Speed		Internal lab	External lab
	High end diagnostics – 3D, X-ray	High end diagnostics – X-ray	High end diagnostics – X-ray
	Advanced coatings for osseointegration	Impression plates	Reliable anaesthesia
	Tools for bone harvesting	In-house lab – custom work	Multiple kits for multi-maintenance
Reduce uncertainty - (failures, maintenance)	Screen for osteo issues before implant installed	Screen patients for health issues (ie smoking)	Screen out patients with complexity
	Reduce speed to reduce failures		
	Fully sterile infection control (regulated)	Modified infection control In-house lab – high quality,	Switch to “one” more reliable brand

		low cost	
Learning by Using			
Increase Speed – upgrade skills to reduce "learning by doing"	CDE (university), conferences, specialist society	CDE (university), supplier training, conferences, specialist society, study club	CDE (regional university providers), supplier training, conferences, society meetings
Uncertain insurance coverage	Insurance eligibility pre-screened by referring professional	Prescreen for insurance eligibility	Prescreen for insurance eligibility
	Enable user "direct pay"	Enable user "direct pay" Use materials acceptable to insurer	Enable user "direct pay".
		Leadership in Dental and Specialist organizations	
Expand scope	Hi end equipment (Simulation+3D X-Rays)	Multiple kits (3) to service multiple brands = more patients.	Multiple kits (3) to service multiple brands = more patients. (CAD/CAM chairside crown milling) threatens specialist market
Learning by Searching			
Bypass institutional constraints	Direct interface with basic science	Interface with basic science, lecture in graduate school	Incidental interface with basic science (local)

A key difference is that the more highly skilled professional is more likely to rely on personal skill for throughput improvement and technology to reduce uncertainty of performance while the lesser specialized professional relied on technology to reduce complexity and skill and also standardized around a single reliable brand.

Learning by using is associated mainly with continuing education, a mandated and regulated requirement for continuing practice, and therefore a regularity. Incidental benefits from CDE include learning about new technology and how it can be used.

Insurance imposes another external learning by using requirement on the dentists – how to work with the insurance industry – which is their primary financial connection with the market. Uncertainties in this aspect result in the three cases observed each taking some steps to improve predictability by pre-screening patients or choosing lower cost materials that will be accepted by the insurer. There appears to be minimal customer influence except to accept a user-pay option. All three cases enable that approach.

Learning by searching is possible, and all three maintain some level of connection with the scientific community, but it is unclear that any of the firms are employing a structured search process, perhaps a reflection of the non-market nature of dental care.

The final observations in Chapter 9, will be based on viewing learning at various levels of the economy. Learning is the result of routine activities in economic production of products, then, innovation must also be rooted in the prevailing economic structure of technological opportunities and income elasticities Johnson (2010: 35), supported by many others Ch.2.

What will be observed, is the institutionalized nature of the dental care industry, and how that lies beyond the scope of present theory related to economic efficiency in medical care and the dental care sub-sector in particular.

CHAPTER SIX
CASE - GENERAL DENTIST

6.1 Introduction

A general dentist is not considered a specialist in the dental industry, as all dental specialists have advanced graduate education in addition to general-dentistry degree. However, a general dentist can qualify to do implant placement with implant dentistry training.

The dental firm of the General Dentist

The General Dentist is one the owners of a small group practice started in the early 1990s. It functions as a dental-service firm in the province of Alberta, Canada. The General Dentist's education, in addition to the pre-requisite requirement, is a four-year general-dentistry degree. This firm is representative of the dental-service practice profile of Canada, as only 7 per cent of the total population of dentists do not work in owner-run (solo or small group practice) firms.

The demographics of the General Dentist:

a) She is a female General Dentist over the age of forty but under sixty. In comparison to the total population of dentists employed in Canada, she is part of the 49 per cent who are over the age of forty but under the age of sixty, and part of the 21 per cent of general dentists in Alberta who are female.
b) She is Canadian born and has taken her dental education in Canada. This makes her part of the 90 per cent of the total population of dentists operating in Canada who are also trained in Canada.
c) She has one associate, who is also a general dentist. Even though they are a husband-and-wife team, they are individual corporate entities. They operate their dental-service business as a corporate partnership. The dentist-owner of this study works only in one location; therefore, she is part of the 81 per cent of dentists who work in one location.
d) The General Dentist's patient load ranges from 15 to 20 per day. This places her clinical performance in the upper third of dentist performers (McCarthy & MacDonald, 2000).

The firm employs three full-time administrative employees. An office manager and one of the other two also doubles as a dental assistant. The firm also employs two full-time and two part-time dental assistants, and one full-time hygienist. This dental office is physically structured so that the co-owners work separately. Their areas are joined by a front office, where the office employees reside, facing the patient waiting room. There is also a shared dental-service support room, equipped with processing equipment and supplies.

The dental services provided by this firm include diagnosis (general check-ups), periodontics and dental hygiene (preventive maintenance), restorative dentistry (dental fillings), endodontics (root canals), fixed and removable prosthodontics (crown, bridge and denture work), and dental implant placement and restorative work.

6.1.2 How the General Dentist links to other dentist-specialties

The General Dentist of this dental firm executes all the steps required to replace a diseased tooth with a single dental implant, illustrated in Steps 1 through 6 of Diagram 15.

This leads to a process that is the time-line of what happens to the patient.

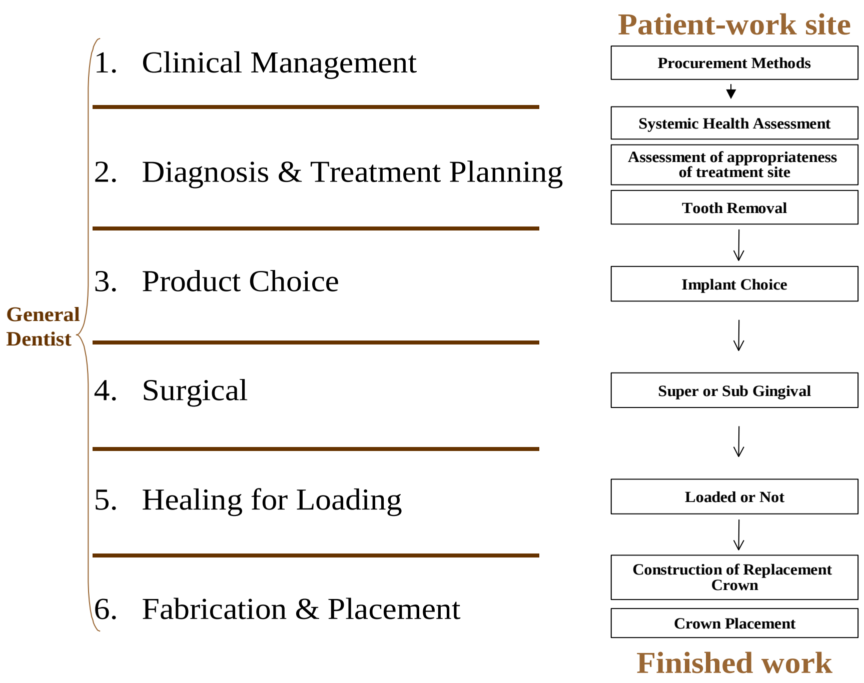

Diagram 15. The patient-work site of the General Dentist

In relation to the function provided by the General Dentist and her firm, a patient will experience a division of labour among dentist specialties only if the General Dentist deems the implant procedure for such a patient to be too complicated. If so, the General Dentist refers the patient to a Prosthodontist – the referral specialty of her choice, rather than an oral surgeon.

Setting specific guidelines for when a patient should be referred to a specialist is difficult (Hahn, 2007). The US National Institutes of Health (NIH) issued a statement (1989) recommending that edentulous patients missing one or more teeth should be offered a single-implant tooth replacement, and that general dentists could either perform or refer the service (Ibid.) During the 1980s, one doctor performed surgical implant placement, and the restorative (fabrication and placement of the crown) work was performed by another. The surgical modality of placing the implant (Step 4, Diagram 15) was initially claimed by the Oral Surgeons and the Periodontists. Fabrication and placement of the substructures, such as the crown, were claimed by the Prosthodontists. Implant dentistry in dental schools was offered only in specialty programmes, and the team approach was and is still taught that way (Interviewees 2, 3, 4).

Previous chapters pointed to the division of labour in implant dentistry as the result of the marketing strategies of producer firms. Another view is that the division of labour is the result of poor implant design, which requires dentists of higher skill levels to place the implant (Hahn, 2007). However, Dr Harold Bergman (Interviewee 24) states that general dentists were placing stainless-steel root-form implants for 40 to 50 years prior to Dr Brånemark's discovery of osseointegration (1952), which revolutionized the field in the mid-1980s. Dr Bergman also says that the stainless-steel implant was considered unreliable, and that implant dentistry "came out of the closet" when success using the titanium implant was predicted with a four-month healing period. It then became a specialist field.

As technology advanced, training courses became readily available, and clinical results improved, some Prosthodontists and a very small percentage of General Dentists started to carry out the surgical procedure of the implant. As almost all Prosthodontists and a majority of General Dentists already did restorative work, adding the surgical procedure to their practice brought in more patients (Christensen, 2000; Hahn, 2007).[47]

[47] Out of the dentist groups involved in dental implant installation or maintenance, it was the Prosthodontists that assumed leadership role in implant dentistry and stimulated numerous surgical and prosthetic technique advancements (Hahn, 2007).

Although official recognition is sought, status for implant dentistry among dentist specialties has not yet been obtained in the United States.[48] The researcher has found, the cumulative learning requirement to effectively place the implant at the speed required to be profitable, does influence the division of labour among dental doctors. Reference has already been made to Periodontist as one of the specialties initially laying claim to the modality of placing the implant. Interviewee 21, a Periodontist, quit placing implants five years ago, citing the lack of time.[49] He wanted to do high-quality implant work but “if not doing enough cannot really do well”, indicating that successful placing of implants at profitable speeds involves long hours of cumulative on-the-job learning. His views are supported by Dr Whitehouse DDS (2008) and Dr Christensen (2000) that believe that each successful implant placed leads to more confidence in placing the next one.

Dr Christensen advises general dentists to gain experience in implant surgery by practice-placing inexpensive educational implants, which implant companies supply, into fresh animal jaws obtained from a local slaughterhouse. To train for more complex cases, implant-placement-simulation software technology is available.[50] Dr Christensen also acknowledges that as more and more general dentists choose to place implants, a dilemma arises as to the complexity of which cases to do themselves and which to refer.

Some dentists view the division of labour within implant dentistry as no different from that found in other dental procedures. General dentists extract teeth in their office, but most refer their patients to a Surgeon for complicated extractions. They do Endodontic (root-canal) work, but when roots are twisted and convoluted they generally refer the patient to an Endodontist. In implant dentistry, patients who require bone grafts, sinus-cavity manipulation and nerve repositioning are generally referred to specialists such as Oral Surgeons, Periodontists or Prosthodontists (Interviewee 1,2,4,7, 8, 21), supported by Hahn (2007).

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[48] Historically Canada follows United States in medical regulations (Health Canada Interviewee 16).
[49] He claims, little technological advancement has been made in his field and he cites the reason is “a periodontist’s technological needs are more scientific than a manufacturer’s product push strategy can provide”.
[50] This software processes the CT scans and virtually places the implant according to the patient’s bone-tissue morphology. From this information a surgical stent can be produced that accurately directs the angle and depth of an osteotomy (surgical incision) for the implant placement.

The General Dentist views her education particularly suited to implant dentistry because of the undergraduate surgical and prosthetic training.[51] Other general dentists argue that they are the most suited to place implants because they are responsible for the total oral health of a patient, while specialists are not (Christensen, 2000; Hahn, 2007). Implant manufacturers such as Nobel Biocare recognize that general dentists have the first contact with a patient and target general dentists to increase market share. A 2007 survey reveals that 53% of general dentists do place implants, while 47% do not.[52] Some place only in ideal circumstances, a rule followed by the General Dentist of this case study. The General Dentist, to qualify for implant dentistry took certified courses from three implant manufacturing firms: Simpler (1994), Nobel Biocare (1999) and Straumann (2005) and has been surgically placing implants for 16 years.

If patient's treatment is too complicated, they are referred, generally to a Prosthodontist that is chosen by the referring doctor. The Prosthodontist, as represented in case Ch. 7, may or may not perform the surgical part of placing the implant. For example, Chapter 7 observes the Prosthodontist, after receiving the patient referral from the general dentist, assesses the complexity of the case and refers the implant patient to a Surgeon.[53] It should be noted that once the general dentist of this case study refers the patient to a Prosthodontist, the patient does not return. The patient becomes a patient of the Prosthodontist for the entire installation, and the general dentist loses the patient's business for the restorative work. If the patient requires major cosmetic changes, generally the patient will not return to the Prosthodontist either, as there are small group practices that provide complete cosmetic dental services.

The next section will link the General Dentist to the specific processes and the artefacts utilized to carry out the functions of the techniques. The final section will identify the institutional sources of the artefacts.

[51] The following lists how the University of Alberta General Dentistry programme curriculum qualifies a general dentist to perform (Step 4, Figure 14) the osteotomy (surgical incision into the gum-bone) for implant placement. There is no immediate post-extraction implant placement. There is one surgical case that includes working up the patient for implantation and doing the surgical step of implant dentistry (Figure 8.1, Steps 2 to 4), and a second case that involves only working up the patient but not doing the surgical step. Implant dentistry is taught separately from surgical tooth extraction, which is associated with the additional work of cutting the jaw or sinus bone (Dr James Yacyshym).

[52] Conducted on 4 June 2007, //.thewealthydentist.com/surveyresults/20_DentalImplants_results.htm.

[53] If the work is strictly for cosmetic purposes, such as enlarging or lengthening the teeth, there are only certain oral surgeons the Prosthodontists will use.

6.2 The techniques

The General Dentist executes the following six stages in the order presented.

1. Clinical management
2. Diagnosis and treatment planning
3. Product choice
4. Surgery – drop the implant
5. Healing for loading
6. Fabrication and placement of the crown

The patient will experience the following order of techniques over a minimum of six months, encompassing four or five appointments.

Appointment one – Stages One and Two:

Procurement method
Systemic health assessment
Assessment of appropriateness of site

Appointment two – Stages Two, Three, and Four

Tooth removal
Product choice
Surgical placement of the implant

Appointment three – Stages Five and Six

Healing time for loading
Construction of replacement crown

Appointment four – Stage Six

Crown placement

Guided by the data collection mapping tool of Diagrams 5 and 6 (Ch. 3), the following sections work through each appointment the patient goes through, commencing with the clinical management stage.

6.3 Clinical-management stage – patient's first appointment

As Diagram 5-Ch.3 indicates, the patient has two ways to provide payment for the service provided by this dental firm: direct payment and insurance claim. This patient will partially pay for the procedure, and the dentist's firm will claim some of the costs through the patient's *insurance firm*. The amount the dentist will be able to claim will depend on how the dentist divides the implementation work into sections. Some sections are claimable under the patient's insurance, i.e. crown work.

As previously mentioned, the insurance firms hire private dentist-consultants to advise them on what is considered an appropriate coverage. The General Dentist identifies another source who works with insurance firms to influence coverage. According to her, the *Alberta Dental Association and College* (ADAC), a policy and regulating organization,[54] is "working on health insurance firms to cover the use of two dental implants to accompany the placement of lower dentures". This would be an incremental coverage, as they are not arguing to use the implant as a single-tooth replacement technique but to include the placement of two implants to secure dentures. Research funded by the CIHR and Straumann, an implant manufacturer, confirms that even the use of two implants placed underneath dentures significantly improves nutritional status in edentulous patients (Hutton, Feine & Morais, 2002).

Although it is the dentists who are supposed to argue in support of technological change as part of the scope of practice, and ADAC's role is more about dealing with complaints when dentists are not operating within the established code of ethics rather than the scope of practice,[55] in this case, ADAC is negotiating for or with the dentist to promote technological advancement through insurance organizations. Therefore, both *ADAC* and *insurance firms*[56] are considered external sources of knowledge.

The next stage the patient goes through is diagnosis and treatment planning.

6.3.1 Diagnosis and treatment-planning stage – patient's first appointment

Diagram 5-Ch.3 shows that the General Dentist completes two steps in the first appointment. They are the systemic health assessment and an assessment of

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[54] ADAC's role is to protect the public by governing the regulated dentist members by establishing and maintaining and enforcing standards for registration and competence of the dentist professions to ensure the oral health of Albertan's is advanced through safe, available, affordable, quality and ethical dental service delivery (ADAC Interviewee14; Alberta Blue Cross, Interviewee 17).
[55] Interviewee 17.
[56] Insurance firms will not be listed individually as there are 105 Life and Health Insurers operating in Canada (Canadian Life and Health Insurance Association Inc., 2008).

appropriateness of site. The General Dentist will assess the location of the implant and the bone conditions to ascertain whether a referral to a Prosthodontist is warranted.

6.3.2 Techniques used in the systemic health assessment

During this first appointment, the patient completes a *health questionnaire* on their dental and medical condition. In addition to what the questionnaire discloses, Diagram 5-Ch.3 indicates the patient is examined for oral and systemic health diseases that may lead to less chance of implant success. The General Dentist indicated that this part of the examination requires no tools other than a questionnaire to assess whether the patient is healthy for surgery. Her reply is that if the patient is healthy enough to have a tooth removed, then they are healthy enough for the dental-implant procedure. Other than unhealthy gums, there was no indication that any of the other oral and systemic health diseases listed in Diagram 5-Ch.3 would be considered by the General Dentist as compromising the success of the implant procedure.

In addition to the techniques of the systemic health assessment, the patient will experience the General Dentist executing an oral examination. The outcome of this stage will result in making the referral decisions. The General Dentist refers patients based on the location of the edentulous site and bone conditions.

6.3.2.1 Techniques used in the assessment of appropriateness of site

The General Dentist goes through a number of steps to assess the appropriateness of the site, as illustrated in Diagram 5-Ch.3. The patient will experience the dentist and dental staff wearing *masks* and *gloves* to follow the protocol for the modified sterile surgical approach and using a *mirror* and *explorers,* in addition to other tools from the dental tool tray as required, to assess the location of the diseased tooth and the bone width/thickness, height, length, and space between the teeth.

If the diseased tooth is within the smile (aesthetic) zone, or part of the maxillary (upper jaw bone) zone, the General Dentist will refer the patient to a Prosthodontist. If the edentulous site is not located within those two zones, the General Dentist continues with the assessment to ascertain bone conditions. If the patient is deemed to have satisfactory bone conditions, the General Dentist will draw out a complete implant plan during this appointment.

To assess the foundation of the teeth, she takes a *radiograph PAN* or *PA x-ray* using *non-digital film* and processes the film using a *film radiography processor.* A periapical radiograph (PA) is taken to view only one or two teeth and the bone immediately surrounding the tip of the root of these teeth. The advantage is that the images are clear, and the cost is about 1/5 that of a full mouth series of X-rays: a disadvantage is that only one or two teeth are in view. A panoramic radiograph (PAN) exposes a single radiograph of all the teeth and much of the oral-facial complex. Whether the patient will experience a PAN or PA x-ray is case and dentist specific. Insurance firms do limit use of higher-tech illumination equipment based on wait times and circumstances surrounding the purpose of their use (Interviewee 11).[57]

The patient will then experience the dentist reading the x-rays. If there are bone width and height concerns, suggesting that grafting is required, regardless of the location of the edentulous site the patient will be referred to a Prosthodontist. The General Dentist does not do bone grafting.

If the patient passes the initial assessments, the General Dentist proceeds to draw out a complete implant plan. The patient will experience the General Dentist preparing *impression plates* to make an implant guide. To prepare the impressions, the patient will experience the dentist preparing *alginates impression plates* utilizing *metal trays* and *alginate* along with other tools from the *impression tray*. Once the impressions are taken they are poured in stone. This provides a gum-line measurement of the existing natural teeth, to assess whether there is space between the teeth for surgical access. If further diagnosis is required, the dentist will forward the prepared impression plates to a *laboratory* and they will prepare a *study model* if required.

Diagram 5-Ch.3 indicates that study models are always prepared, but this is not the case here. Study models can assist the General Dentist in assessing the patient's bite and how the teeth function or work together, but she typically prepares a study model only when it is required to assess the complexity of the implant installation. Such a model can serve as another check-point of her ability to place the implant. Diagram 5-Ch.3 also identifies that a dentist may use CT Scans for 3-D imaging, and software simulation as advanced problem-solving diagnostic tools. Neither 3-D imaging nor software simulations are utilized at the General Dentist's firm.

[57] Supported by //.ontla.on.ca/library/repository/mon/14000/261102.pdf.

What the patient experiences at the end of this appointment is based on the outcomes of the diagnosis. There are three options. If the General Dentist requires higher-level diagnosis and sends the impressions away to a laboratory, the patient will experience a delay until the laboratory results return to the General Dentist's office. Then the patient will return for the second appointment and further treatment assessment.

If the General Dentist finds that the bone conditions are such that grafting is required, or if for any other reason the dentist finds the case too complicated, the patient will experience a referral to a Prosthodontist. As the time-line of what the patient experiences during the next two appointments depends greatly on the diagnostic findings of the patient's first appointment, it may be that some of the techniques described as part of appointment one become part of appointment two, or vice versa. In the case described here, the dentist finds the diagnostic assessment of the patient's tooth replacement site as satisfactory and proceeds to set up a second appointment for tooth removal.

6.4 Diagnostic and treatment stage – patient's second appointment

6.4.1 Techniques used for tooth removal

During this stage the patient will go through a process in which the dentist will anaesthetize the patient by injection with *Septanest* or *Scandonest Plain* to cause loss of feeling before and during the dental procedure. The current anaesthetic technique lacks reliability in terms of accurate freezing response time per patient, which can increase the time in the chair by a factor of three. Since the dentist treats two to three patients at one time, it also disrupts other patient's work-site schedules.

After a short wait to ensure that the anaesthetic has taken effect, the General Dentist will remove the diseased tooth. During this process she will utilize *extracting forceps, root tip pic elevators,* and *pliers.* These tools and instruments are from the *dental tray kit.* Their use can overlap with other stages.

The steps in the tooth-removal process were described in detail in case Ch. 7 and Ch. 8 and will not be repeated here (note suggestions at the end of Ch. 4 to read Ch. 8, then Ch. 7 and then Ch. 6 to fully appreciate the complexity of the cases). If the process differs it will be noted.

This completes the process for tooth removal. Diagram 5-Ch.3 indicates that the next step the patient will go through is the dentist making an implant product choice. What the data collection tool does not illustrate is that the patient's time-line of events, post-extraction of the diseased tooth, depends on the location of the edentulous (toothless) site in which the implant is to be placed. If it is an anterior (front) placement, the root shape[58] is similar to the tapered implant shape, and the General Dentist can modify the extraction site for immediate placement. The General Dentist will then make a product choice and perform the surgical procedure to place the implant, Steps 3 and 4 of Diagram 15 presented in Section 6.1.2, during this second appointment.

If it is a rear placement (posterior tooth), the root shape[59] does not lend itself to immediate placement. The patient will go through a healing period of eight weeks, thus increasing the number of appointments and duration of the time-line required to complete the implementation process. The General Dentist did not specify how many patients require healing time before surgery. For the case study, an anterior, non-smile-zone implant placement is assumed, and it is further assumed that the General Dentist can execute the next stages during this appointment.

6.4.2 Product-choice and surgical stages

6.4.2.1 Techniques used in solving the product-choice stage

The product-choice decision lies with the dentist and not with the patient. This stage has two processes to carry out: the selection of the installation type and the implant brand choice.

The installation types were covered in detail in cases Ch. 7 and 8, where the Oral Surgeon (Ch. 8) placed the implant portion and the Prosthodontist (Ch. 7) executed the restorative work, respectively. In this case study, the General Dentist places the implant portion. The explanation will focus on why the General Dentist chooses an installation type and a particular product line.

The installation can be of three types: not loaded, immediate and restorative. Each type resolves a particular implant issue, and two of the three choices could have been made for this case study. The not-loaded, two-stage process could have been chosen.

[58] The front tooth has a single-root system.
[59] A rear tooth has a two- or three-legged root system.

If chosen, the patient would have required an eight-week healing period after tooth extraction. Some of the General Dentist's patients do require this option. For this case study, an immediate placement is chosen because the edentulous site has favourable bone conditions. It is clinically appropriate to place the implant immediately after tooth extraction. The General Dentist will commence the procedures required to do the surgical part of the installation (Stage 4, Diagram 15) once the brand choice is made.

Diagram 5-Ch.3 lists four steps the General Dentist will use to choose the implant brand: quality, patient allergic reactions, product support and price. The General Dentist was able to move through the product-choice stage by focusing only on quality. She recently switched from Nobel Biocare to Straumann. She stated that Nobel Biocare's implant has a flaw in the design that affects a patient's oral health. The visible abutment section is narrow, and when the crown is fabricated and installed it causes a food trap. Over time, a food trap can cause oral diseases that can compromise the efficacy of the procedure. The Straumann abutment has a wider upper part on which to build the crown. Not only does this resolve the food trap issue, the larger platform also increases the aesthetics. To conclude the product-choice section, the General Dentist opts for immediate placement of the *Straumann* implant.

The patient will now experience the General Dentist surgically inserting the Straumann implant. It is common practice to guide the surgery using a surgical stent instrument[60] prepared from the x-rays and impression results of the diagnosis and treatment planning stage. However, it is not common practice at this dental firm. If required, the stent will be fabricated by an external laboratory.[61] It is important to note that all complicated cases are referred to specialists.

6.4.2.2 Techniques used in the surgical stage

As shown by the time-line of Diagram 6-Ch. 3, in this stage the patient will experience the General Dentist engaged in a sub-gingival, modified sterile surgical approach. To stay within the sterile protocols and thus reduce the chance of infection, the dentist and

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[60] Just to reiterate, the surgical stent, when placed over the patient's existing teeth, acts as a drilling template, guiding the dentist to the exact drilling site and setting the angle at which to drill, thus maximizing the mechanical strength of the implant and reducing the risk of nerve damage, which can cause temporary or permanent numbness of the lip, chin or tongue. Using the surgical stent also reduces the risk of damaging the neighbouring tooth, which may result in the loss of the tooth during the site preparation to receive the implant.

[61] This led to an enquiry about is the frequency of stent use. The result was that some oral surgeons know the bone anatomy so well that from the patient's CT scans they can insert the implant at the desired angle and without nerve encroachment (Interviewee 2).

assistant wear *masks* and *gloves.* The patient will be provided with an *antimicrobial mouth rinse* – *Amoxicillin*. The patient will also experience the General Dentist administering the same *local anaesthetic (Septanest* or *Scandonest Plain)* used for the tooth extraction.

After a short wait to ensure that the anaesthetic has taken effect, the general dentist will perform the surgery using the instruments and tools that come with the *Straumann system* to place the implant. During this process, described in detail in Chapter 5, the General Dentist utilizes either a *Nobel Biocare* or *Straumann self-irrigating drill* and a *saline solution* to cool the drilling surface. The General Dentist inserts the implant (socket portion) into the jaw or sinus bone with the *healing collar* exposed, which saves the patient another surgical step. Once the *healing cap* is placed, the patient will experience the General Dentist placing *sutures* and *cyanoacrylate tissue glue* to close the site with the *healing screw* exposed.

The patient will now experience the General Dentist recommending a two- to three-month healing period. This places the patient at the healing for loading stage (Steps 5 of 6, Diagram 15).

6.5 Fabrication and placement stages – patient's third appointment

This appointment will see the General Dentist performing the procedural techniques to prepare the implant site for the installation of the abutment part, then building and placing the crown on top of the abutment.

6.5.1 Techniques of the healing for loading stage

The first step is for the dentist to confirm that the patient's gum tissues are adequately healed to proceed to the construction of the crown. To do this, the General Dentist uses the same tools and instruments from the *dental tray* as those listed previously in this case. If the patient is deemed to have healed, they are ready to proceed to the next step, constructing the crown.

6.5.2 Construction of replacement crown

The General Dentist's firm does not have an in-house laboratory and does not use chairside technology to manufacture crowns on site. The General Dentist commissions the fabrication of the crown to an *external laboratory*. She uses only well-known, name-brand abutments. This appointment is to accurately prepare the implant site to create impressions with precise measurements to be sent to a laboratory.

It should be noted that the while the General Dentist currently places Straumann implants, she continues to restore (maintain) other brands. This requires her dental firm to own the *instrument maintenance kits,* in addition to the *implant surgical kits,* for the *Straumann*, *Nobel Bio-Care* and *Simpler* brands. Straumann and Nobel Bio-Care are two of the three major implant suppliers to Canada. Simpler is a Canadian implant company.[62] The maintenance kits supply the tools and instruments for the procedures required to take impressions of the patient's implant site and surrounding teeth. The General Dentist will use these to gather information for the laboratory, described as follows.

The patient will first experience the General Dentist preparing the impression plates. To do this the General Dentist will use *Straumann* or *Nobel Biocare equipment* and the already mentioned dental tools and instruments, with the addition of *implant scalers,* to take the implant impression. The impression process follows the suggested Straumann method, as illustrated in Chart 1; case Ch. 7. This process is similar to the process described in detail in Chapter 7, using Straumann equipment such as the *impression tray, impression posts* and *guide screws*, except the General Dentist uses the following *impression materials: 3M ESP, PolySi* and *Regisi* or *putty material*, *Super Hydrophili*. Once the patient experiences the General Dentist performing the impression-taking techniques of this stage, the General Dentist will hand-thread the healing cap back into the implant's empty socket.

Before the dentist sends the impression to the lab with the fabricating-care requirements checked on the crown requisition, the patient's porcelain colour of the natural teeth is matched to the *porcelain material* colours displayed in the palette of the *Vita System Porcelain kit*. This information, together with the impression plate, is then sent to the *dental laboratory* for the crown to be fabricated. The patient will then experience the General Dentist's office booking another appointment for the dentist to place the fabricated crown. Once the crown is placed, the procedure is completed.

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[62] Simpler no longer sells under that name in Canada. It is marketed under an undisclosed European name.

6.6 Fabrication and placement stage – patient's fourth appointment

6.6.1 Techniques to the placement of the crown

Diagram 6-Ch. 3 presents two processes used to attach the crown to the exposed part of the abutment: cemented or screwed. The cemented option is associated with a one-piece abutment, and the screwed option uses a two-piece abutment complex. The cemented process is more economical in the short term for the patient, as this procedure requires a smaller investment in tools and time for the General Dentist. In the long run, however, it can be more expensive, because doing maintenance is difficult and costly.

The General Dentist no longer uses the one-step cemented process. She uses a two-step process involving a two-part abutment complex such as that described in detail in Chapter 8.[63]

To receive the crown, the patient enters the office and sits in the dental chair for the fourth appointment. The patient will go through a process of the General Dentist placing the crown by utilizing the following techniques to (a) place the abutment, (b) cement the crown, and (c) adjust the crown utilizing *implant scalers* and other tools that are part of the General Dentist's *dental tray.* She acquired these tools from her dental training at university. Additionally, to place and tighten the abutment into the implant socket, and the abutment screw into the abutment, the patient will experience the General Dentist utilizing implementation tools and bone-protocol instructions from the *Straumann surgical/tool kit*. To cement the crown atop the abutment screw, the patient will first experience the General Dentist performing two steps. One is to fill the top area of the abutment screw with a *Filtek Supreme composite resin* and then apply *Clearfil* as a bond to prepare the crown to accept the filling material. The second is to manually place the prepared crown on top the abutment screw. To adjust the crown, the patient will then experience the General Dentist measuring the bite, utilizing a *handle* with *articulating paper*. Depending on the results, the patient will then experience the General Dentist adjusting the bite of the new crown using *handpieces* and *drills* powered by a compressor and fitted with standard drill *burs.* During the adjustment, the

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[63] The difference in the processes used is the Prosthodontist (Case, Ch. 6) also tested the abutment once placed. It appears the General Dentist does not solve that step and in hindsight it may have to do with the fact that the General Dentist uses brand-name abutments and not customized abutments, or the testing techniques were overlooked during data collection. Either way, the same artefacts would have been used as in the diagnostic stage therefore the artifact/industrial-actor outcome is not affected.

utilization of the *air and distilled water syringe* will clear the patient's oral cavity of debris and water. Once the bite is adjusted, the General Dentist's work is finished.

This completes the patient-work site processes, to remove and replaced the diseased tooth with an implant, for artifacts see Appendix E.

6.7 The observed case applications of throughput

Transforming high fixed costs into *low unit costs*, during the dental implant implementation process/technique (as in the cases), is the result of the dentists' post-graduate education and the accumulated, learning by doing as of the result of scaling the technique to increase reliability and efficiencies within constraints of the technology and the market.

The learning associated with scale economies, has these characteristics.
Partial increasing returns to scale – arise from:

a) Decreased cost of one factor or the other - (dentist labour) or (material-capital cost), generally by increasing quality by decreasing uncertainty associated with the factors.
b) Changes that increase capacity utilization during a set period of time, by increasing throughput speed, i.e. reduced failure rates.
c) Decreasing cost in a process that gives the impression of decreased cost of final product and can be thought of as penetration into new markets and areas of application.

6.7.1 Achieving quality, for reliable routines

Part of quality control is to reduce the functional uncertainty of the dental implant technology.

Case one/General Dentist, retains high throughput in a number of ways:

a) **By increasing the reliability of routines through decreasing complexity with referrals to specialists.** This standardization process reduces work on patients' oral health conditions that may decrease the reliability of implant technology and require increased maintenance that affects the firm's efficiency and profitability

(Section 6.3.2.1). This dentist, to ensure less maintenance, will not only refer complex cases to specialists but also all cases within the smile zone, where aesthetic work takes more time, thus reducing the cumulative leaning time. This general dentist is highly dependent upon the division of labour, referral system (Section 6.3.2).

b) **By decreasing complexity through the use of capital equipment or rely on referrals.** Producer-firms are encouraging general dentists to undertake more complex procedures. They provide technology that replicates the skills of oral surgeons (using simulation software accompanied by 3-D x-rays to guide the surgical placement of implants) and laboratory technicians (CAD/CAM chairside crown-milling machines), and in this thesis, specialists were not observed as utilizing the technology.

c) **By increasing the reliability of problematic procedures.** Profits are increased by reduction in maintenance and follow-up time. Implants can add stability to dentures, lower long-term costs, make the procedure more reliable and improve patient health.[64] Reducing maintenance is important, because insurance companies reimburse a set number of units per year per procedure, regardless of the time the dentist takes to treat more complicated, higher maintenance, clinical conditions.[65]

d) **By switching the implant brand.** The design of the Nobel Biocare implant caused a food trap, which if not carefully maintained could compromise the efficacy of the implant. The switch to a Straumann implant increased reliability, and added aesthetic value (Section 6.4.2.1) and increased profitability by reducing maintenance.

e) **By improving complementary technologies.** There are other operating distortions that affect time constraints, decreased throughput, and add to the costs of the implant procedure. The current anaesthetic technology, for example, lacks accurate freezing response times and thus increases ‘time in the chair’ by a factor of three. This disrupts the dentist’s schedule and contributes to loss of productivity in treating other patients (Section 6.4.1). More reliable anaesthetic techniques

[64] Implants improve the chewing performance of dentures resulting in higher nutritional distribution.
[65] This dentist is already doing for patients what ADAC, a policy and regulating organization is working with insurance firms to cover. That is the use of two dental implants to accompany the placement of lower dentures. This would be an incremental coverage as they are not arguing to use the implant as a single tooth replacement technique but to include the placement of two implants into the jaw bone to secure dentures (Chapter 8, Section 8.3.1).

would therefore increase throughput. Similarly, infection-control procedures add costs to each dental procedure (i.e. fifteen minutes extra for an oral surgeon to place an implant).

f) **By using producer industry implant dentistry courses to reduce learning-by-doing.** The General Dentist took her implantology training at three regionally based, hands-on private teaching clinics (Section 6.7.2) that reduce the learning time leading up to higher throughput, supported by (Beazoglou, Heffley, Brown & Bailit, 2002). Dentists increase their output per unit through learning-by-doing.

g) **By relying on complementary equipment for accurate diagnosis.** As Dentist Interviewee 8 explains, "in house technology, high priced radiographic x-ray, diagnostic equipment is used to accurately assess case complexity, regardless of insurance covered" (Section 6.3.2.1) as it assist in accurately assessing referrals.

6.7.2 Bottlenecks to higher use of dental implant technology

a) **The financial system**. Patient choice appears to be based on what insurance covers. The small partial coverage generates time-consuming administrative work (Section 6.3.2.1; supported by all cases).

b) **More reliable anaesthetics techniques.** This would apply to all techniques, but the more reliable the technique, the less uncertainty to throughput, and to the safety of both dentist and patient (Section 6.4.1).

6.7.3 External knowledge contacts and motivations for use

a) **To meet continuing dental education (CDE) certification qualifications**.

Directly through dental graduate schools.[66] The CDE courses are revenue-generating business separate from their dentistry-degree programmes. Some are corporate sponsored, some are in teaching operatories equipment with Nobel Biocare consumables and equipment,[67] and others are directly sponsored by producer firms i.e. Patterson Dental, an American supplier of consumable products and equipment.

[66] University of Alberta (UofA), University of British Columbia (UBC), and at the University Michigan School of Dentistry CDE (UMSD CDE)

[67] There are no formal agreements of exclusivity but only informal arrangements of supporting their brand (Chapter 5, Dr Yen).

Sponsored by dental societies, Canadian Dental Association (CDA) Annual Convention, the Alberta Dental Association and Colleges Annual Conference (ADAC), and the Pacific Dental Conference at multiple, annual conference events in Canada. The conferences are marketed, in part, by the potential CDE hours that may be acquired (Interviewee 11, confirmed by (//.pdconf.com/cms2010/attendees/). The CDE events, are supported by corporate firms that have some commercial relationship to the dental-service-practice industry, and some speakers are directly paid by those firms.[68]

b) **Implant training**, for brand name implants, at private dental-care service firms. These firms, support training as part of their dental services and can be certified CDE providers, or not. Implant training does not quality for CDE. The trainer is the dentist owner-operator, who is an exclusive dealer of a particular implant brand, termed “local champions” or “experts” because they market and train other dentists, within a region, for the producer firm.

c) **Contact to basic science.** CDE events sponsored by dental societies may include, sessions on new science discoveries, in relation to products.

Case one summary

To achieve high levels of throughput, the General Dentist, relies primarily on the ability to execute high-quality routines and the existing referral social structure of dentistry. This specialty diffuses dental implant technology the same as for any other dental procedure, by only taking patients that do not exhibit complicated physiology oral structures, which can decrease reliability of the dental implant and jeopardize throughput. This requires high-level diagnostic skills, and the dental-specializations of other dental clinic firms.

Chapter five demonstrated how similarities were found among the cases with final observations in Ch. 9.

[68] Jasper Dental Congress 2009 programme brochure - Interviewee 4, 8, 11.

CHAPTER SEVEN
CASE - PROSTHODONTICS

7.1 Introduction

The Prosthodontic, dental-care service includes diagnosis (general check-ups), periodontics and dental hygiene (preventive maintenance), restorative dentistry (dental fillings), fixed and removable prosthodontics (crown and bridge and denture work), endodontics (root canals), oral surgery (teeth extraction), dental-implant restorative work, limited orthodontics (braces), temporo-mandibular joint (TMJ) assessment and therapy, and pedodontics (child dental health care).

The dental firm of the Prosthodontist

He is the sole owner of a small group practice started in 1956 that functions as a dental-service firm in the province of Alberta, Canada. His education, in addition the prerequisite requirement, is a four-year general-dentistry degree (DDS) with advanced graduate training in Orthodontics (1969) and Prosthodontics. This firm is representative of the dental-service-practice profile of Canada, as only 7 per cent of the total population of dentists do not work in owner-run (solo or small group-practice) firms.

The demographics of the Prosthodontist and his firm are as follows.

a) He is a male specialist over the age of sixty. In comparison to the total population of dentists employed in Canada, he is part of the 14 per cent who work in specialties, 79 per cent who are male and 14 per cent who are over the age of sixty.
b) He is Canadian born and has taken his education outside of Canada. This makes him part of the 10 per cent of the total population of dentists operating in Canada who are trained outside of Canada.
c) He has no associates. He is the sole owner of the dental-service firm and employs other dentists. Those employees include four part-time general dentists, each working two days per week. All have advanced dental-implant

training.[69] Some of the part-time general dentists also work in a research capacity. The dentist-owner works in only one location, therefore is part of the 81 per cent of dentists that work in one location.

d) The patient load of the dentist-owner is typically 10 to 12 patients per half day, notwithstanding he is over the age of seventy. His patient load places him as a top performer since 55.5 per cent of clinical dentists see 10 to 19 patients per full day (McCarthy & MacDonald, 2000). In addition to his part-time work, the Prosthodontist provides advanced clinical training to the part-time dentists who work at his firm.

The firm employs five part-time dentists, two full-time upfront staff, one full-time hygienist, one full-time equivalent dental assistant, one part-time dental assistant, a full-time business manager, and a Dental Laboratory Technician.[70] This dental practice is unique in the study, because the firm employs a business manager and owns an on-site laboratory service that also provides dental laboratory service to external dental firms.

The dental service provided by this firm is comprehensive, as previously described. The dentist-owner surgically placed implants until 1984. Since then he has specialized in the around the crown placement and restorative work of implant dentistry. The business model of the Prosthodontist reflects the economies of scale this firm can achieve through specialization in fabrication and placement (restorative work) of implant technology because it has its own in-house laboratory service.

The dentist-owner of this firm is a supporter of advanced education and was instrumental in encouraging compulsory CDE training for dentists upon entering the work force.[71] He graduated with prosthodontic training from the United States at a time when Canadian universities did not offer graduate programs, and he still considers himself a student after 51 years of practicing dentistry. He claims that in dental school you learn only 25 to 30 per cent of what you need to learn to practice. He views himself as lucky, because when he was a student it was customary upon graduation to

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[69] Two of the dentist have implant training of all three major implant brands: Straumann, Nobel Bio-Care and Astra Zeneca. One dentist has only Straumann training and the other dentist is trained for two of the three major brands.

[70] The p/t dentists and laboratory technician are paid commission at 40 per cent of gross revenue of received professional and laboratory fee billings, respectively.

[71] As the President of the Edmonton District Dental Society (1970), he proposed that dentists in Alberta be required to pass 30 hours of continuing education training courses per year, or 60 hours every two years.

be told by your professors that “you only know enough to make a living but must upgrade to become a dentist.” He is highly critical of the current state of university dental training, stating that the problem starts with the professors, who never upgrade. He claims, “These professors do not tell students that they can only learn a portion of what is needed to satisfy patients needs and to refer patients to people that can do the job properly.” He contends, “If a case is not standard, new graduating dentists do not know what to do.”

He is supportive of the dental schools in Southern California and Minneapolis, which provide regular continuing education for their professors and to other dentists, with top persons in a particular field doing the teaching. When interviewing to hire dentists for his firm, the first question the Prosthodontist asks is about the scope of their advanced training. He will not hire anyone who does only the “required” continuing education.

7.2 How the Prosthodontist links to other Dentist-specialties

A Prosthodontist can qualify to place implants. In this case, does not, choosing to specialize in crown placement and restorative work and the Prosthondoctic function, is to evaluate a patient’s oral health problems, to establish whether the patient is suitable for a dental implant, and to fabricate and place the crown (Steps 2 and 6 in Diagram 16).

The Dental Implant Technique and Sub-techniques

Subsystem One - Work up the patient

Prosthodontist { Clinical Management — Step 1
Prosthodontist { Diagnosis & Treatment Planning — Step 2
Product Choice — Step 3

Subsystem Two - Procedural

Surgical - drop the implant — Step 4
Prosthodontist { Healing for Loading w or w/o abutment — Step 5
Prosthodontist { Fabrication & Placement of the crown — Step 6

Diagram 16. Dental implant technique and the Prosthodontic sub techniques

The Prosthodontist executes the techniques of Stages 1 and 2 during the first appointment, to assess whether the patient qualifies for a dental implant. Once an oral surgeon surgically places the implant, the patient returns to the Prosthodontist. The patient during this second appointment will experience the dentist applying diagnostic techniques of Stage 2 and Stage 5. In the subsequent two appointments, the Prosthodontist also has a unique way of applying the procedural techniques of fabricating and placement of the crown (Stage 6).

This leads to a process that is the time-line of what happens to the patient.

In relation to the function provided by the Prosthodontist, the patient will experience a division of labour among dentists, as follows. The General Dentist represented in case three does not insert implants in patients who are deemed to require complicated treatment and generally refers those patients to a Prosthodontist. The Prosthodontist represented in this case study does not insert the implants and would refer the implant patient to a Surgeon to place the implant. Once the Surgeon inserts the implant, the patient returns to the Prosthodontist for the remaining work. This concludes the description of the functions provided by the other dentists that link the steps and stages the patient goes through.

The next section will link the dental specialty of Prosthodontics to specific processes and the artifacts utilized to carry out the functions of the techniques.

7.3 The techniques

In the previous section it was established that the function of the dental implant is to replace a diseased tooth, and that the Prosthodontist’s input to the dental implant is to evaluate the patient’s oral health problems to establish whether the patient is suitable for the implant. The Prosthodontic then fabricates and places the crown. Once the patient’s crown is fabricated and placed, the process is complete.

For the Prosthodontist to execute his function, the patient goes through the following four stages:

1. Clinical management
2. Diagnosis and treatment planning
3. Healing for loading

4. Fabrication and placement of the crown

These stages, along with the techniques used in each stage, are illustrated in Diagram 17, commencing at the patient-work site.

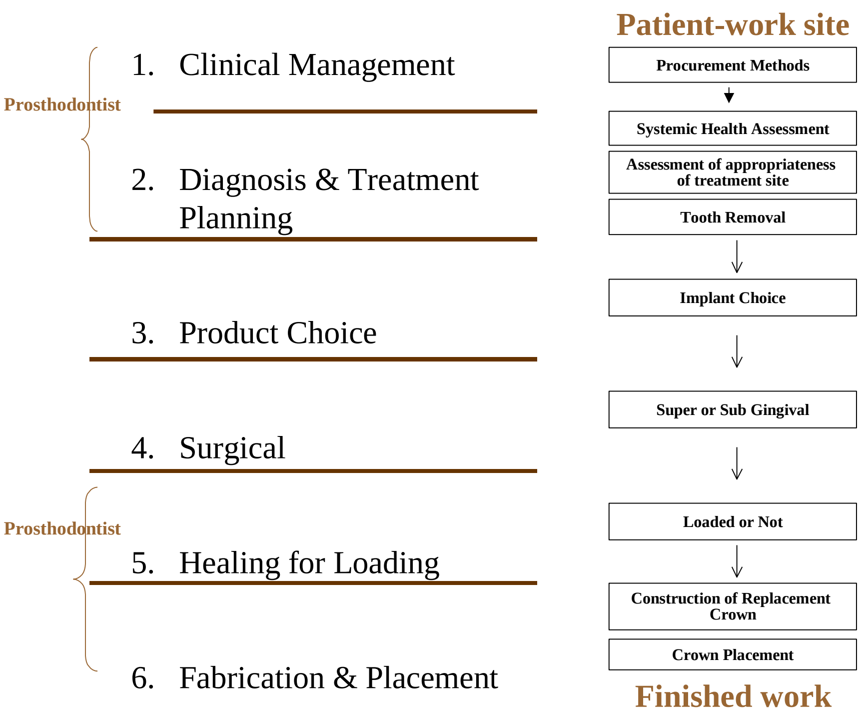

Diagram 17. The patient-work site of the Prosthodontist

The patient goes through four appointments for the Prosthodontist to apply the techniques and has a unique way of going through the stages, as listed.

The Prosthodontist executes the techniques of Stages 1 and 2 during the first appointment, to assess whether the patient qualifies for a dental implant. Once the implant is surgically placed by an oral surgeon, the patient returns to the Prosthodontist. The patient during this second appointment will experience the dentist applying diagnostic techniques of Stage 2 and Stage 5. In the subsequent two appointments, the Prosthodontist also has a unique way of applying the procedural techniques of fabricating and placement of the crown (Stage 6) over a span of two appointments.

The patient will experience the following order of techniques in a 12 month time-line that covers four appointments.

Appointment one – Stage One and Two:

Procurement method
Systemic health assessment
Assessment of appropriateness of site

Appointment two – Stage Five and Two

Healing for loading

Appointment three – Stage Six

Construction of replacement crown

Appointment four – Stage Six

Crown placement

The following sections detail each appointment and the stages the patient goes through, and if reference, Diagram 6 and 7 are in Chapter three.

7.3.1 Clinical-management stage – patient's first appointment

Diagram 5-Ch. 3 indicates that the patient has two ways to provide payment: directly and through an insurance claim. The patient paid for his own implant procedure. This dentist views the insurance firms and the consultants as the greatest impediment to advancing the dental implant as a replacement for much more complicated procedures.

The next stage the patient goes through is the diagnosis and treatment-planning stage. The following are steps and techniques the patient experiences.

7.3.1.1 Diagnosis and treatment-planning stage

In addition to establishing the payment method, the patient also goes through two steps of the diagnosis and treatment-planning stage.

During this appointment, the Prosthodontic assesses the patient's bone and gum conditions to determine whether the dental implant is an option or not. If the patient has severe periodontal (oral health) diseases the Prosthodontist may refer the patient to a

Periodontic specialty for treatment of gum disease, to increase success of implant procedure, or any other dental option may be considered.

7.3.1.2 Techniques used in the systemic health assessment

Diagram 5-Ch.3 shows the patient will experience two processes to assess their systemic health. As in the previous case, the patient fills out a health questionnaire and is then examined for oral and systemic health diseases that may lead to less chance of implant success.

Before the patient experiences a dental examination,[72] the protocol for the modified sterile surgical approach is followed to reduce infections. The dentist and dental assistants wear *masks* and *gloves*.[73] The patient will now experience the dentist performing an examination to establish the degree of teeth grinding (bruxisms) and whether gums are healthy or not, using tools and instruments from the examination tray. These tools include the *mirror, explorers, probes, air and water syringe, suction tips, occlusion papers, cotton and dressing pliers*. If smoking and/or diabetes are disclosed on the questionnaire, the dentist will discuss these with the patient. It was not indicated whether a lack of control of the diabetes would result in the Prosthodontist recommending that the implant not be utilized. If the patient were a smoker, the dentist would suggest they quit to increase the success rate. On the other hand, the Surgeon, case (Ch. 8) did not view smoking as having a negative effect on dental-implant success. The surgeon adds osteoporosis to the list of systemic diseases to watch for as a discriminating factor to implant success, whereas the Prosthodontist did not.

It is important to note, the prime concern during the systemic health assessment stage is to establish whether the patient should be allowed to proceed with the implant procedure. In addition to the techniques of the systemic health assessment, the patient will experience the Prosthodontist executing further oral examinations to ascertain the approximate bone-length of the tooth replacement site,[74] before the patient is referred to a Surgeon or some other specialist appropriate to the patient's needs.

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[72] All dental procedures are considered dental surgery. In a literal sense the term "surgery" implies that the gum (bone) structure is manipulated in some way every time a dentist looks into the mouth.

[73] Modified to imply that the dental staff or dentist will not be gowned or wear hats. Nor is the patient fully draped, with only the oral cavity exposed, as in the pervious case when the Oral Surgeon performed his surgery (Loma Linda University School of Dentistry, The American College of Prosthodontist et al., 2003).

[74] The word approximate is used here because the true bone length cannot be ascertained until the diseased tooth is removed because bone damage can occur with improper tooth removal.

7.3.1.3 Techniques used in the assessment of appropriateness of site

Diagram 5-Ch.3 shows that there are six techniques used to assess the appropriateness of the site. They are location of the diseased tooth (cosmetic zone or not), bone width/thickness, height, length, and space between the teeth. Since the Prosthodontist, at this stage, is interested only in assessing whether the implant is an appropriate dental procedure for the patient, the patient will experience the Prosthodontist assessing the foundation of the teeth using an *x-ray machine, non-digital film* and the preparation of study models. To do this, the patient will experience the preparation of the *alginates impression plates,* utilizing *metal trays* along with other tools of the *impression tray* to do a gum-line measurement of the existing natural teeth. The study models produced from the impressions help the dentist assess the patient's bite (closure pattern of upper and lower teeth), how well the patient's teeth function or work together, and whether there is space between the teeth for surgical access to place a single implant. Accurate impressions are essential for designing and placing the crown in a way that is aesthetically pleasing and at the same time positioned to encourage bone growth around the placed titanium implant. The outcome of the first appointment aids the Prosthodontist to assess the complexity of the implant installation and suitably select a Surgeon based on the patient's needs.

The patient in this case study was deemed appropriate for a dental implant, and referral was made to a Surgeon to place the implant (Step 4, Diagram 16-Section 7.2). At this stage, the patient waited four months for the initial appointment with the Surgeon. Once the diseased tooth was removed and the implant was placed, the patient returned to the referring dentist of this case, to complete the implant procedure.

The following section commences with the patient's return to the Prosthodontist for the second appointment.

7.4 Diagnosis and treatment stages – patient's second appointment

7.4.1 Techniques used to diagnose the healing for loading stage

The Prosthodontist examines the patient for appropriate healing at this stage. To reiterate, the Surgeon's functional responsibility, is to surgically insert the implant (socket part). In this case, the implant was placed with the healing cap exposed to provide the Prosthodontist access to the oral cavity to complete the installation process.

The patient will now experience the dentist following the modified surgical protocol to examine the patient's gum tissues at the implant site and the surrounding teeth. This process examines the stage of healing, to ascertain whether the length of the healing stage was adequate to proceed with the next stages of technique. For this diagnostic examination, the dentist utilizes the same techniques and tools used in appointment one (Section 7.3.2.1) and will not be repeated here. The patient experienced the dentist declaring the implant site healed and the scheduling of a third appointment for the fabrication and placement of the crown (Step 6, Diagram 15).

7.5 Fabrication and placement stage – patient's third appointment

During this stage, the Prosthodontist performs the procedural techniques to prepare the implant site for the installation of the abutment and to place the crown on top of the abutment. The outcome of the third appointment is to accurately prepare the implant site to create impressions and/or study models with precise measurements to ensure that the crown (and custom abutment if required) are designed and fabricated to maximize the functional forces of mastication (chewing). This distributes the load forces during chewing in a way that does not compromise the implant socket portion placed by the oral surgeon.

7.5.1Techniques used to fabricate the crown

Diagram 5-Ch.3 shows three ways to fabricate the crown: immediate, non-lab and laboratory-based. Research reveals that the Prosthodontist uses two of these: immediate and laboratory-based. The immediate option is an in-house, CAD/CAM, chairside-designed and manufactured crown.[75] The technology is dependent upon 3-D digital x-ray machines to take an accurate picture of the original tooth above the gum line.[76] The crown is produced after ten minutes of processing in a milling machine. It can then be immediately placed (cemented) onto the implant abutment, saving the patient one return visit.[77]

The chairside crown takes less dentist skill to design and place. For design, the CAD/CAM fabricates the crown based on a 3-D x-ray and not on the accuracy of the dentist's impressions of the patient's teeth. The work of a laboratory technician may include fabricating stone models to test the fit of the patient's teeth before making the

[75] "Chairside" denotes that the dentist can provide the treatment in one visit.
[76] Isolating the tooth for the required 3-D picture is difficult (Interviewee 8).
[77] According to Interviewee 8, his purchase of this machine added to the mix of dental services his firm could offer rather than eliminating the need of an external laboratory, as it is advertised to do.

crown. For placing, because of the flexural nature of the material properties,[78] it takes less skill to place the crown in a way that minimizes adverse load forces that may dislodge the implant in time. This method of crown fabrication was not used by any of the dentists represented in the case studies of this research.[79] Although this method is not used by the Prosthodontist, it is an option when making the crown, as featured in Diagram 5-Ch.3. It also is a growing field of scientific and technological research. The trajectory is to move toward higher levels of embodied knowledge to simplify the crown-making procedure, for general dentists. Earlier models, such as the CEREC Sirona (1983),[80] targeted general dentists; they have the first contact with the patient, and the flexible material choice was acceptable to them. Since the specialists are not pleased with a crown material that falls short of the safety and quality of porcelain crowns,[81] the most recent models appear to be producing a limited style of crown but with harder materials, e.g. Zirconia, the zirconium-oxide ceramic used by Everest KaVo.

The chairside crown-making CAD/CAM equipment trajectory was started by large dental equipment firms. It is currently utilized by laboratory equipment producing firms,[82] and marketed by two global dental-implant firms,[83] who view the general dentist as most likely expand the use of dental implant technology. The Prosthodontist's firm has an in-house laboratory for fabricating crowns, bridges, etc. This added knowledge to the firm, provides the capability to fabricate custom abutments of porcelain, if required. Otherwise the Prosthodontist purchases the abutment to match the implant brand that has been placed by the oral surgeon. The Prosthodontist makes the decision to purchase the abutment or produce a custom design based on the position of the dental implant. If the implant is placed in the anterior region of the mouth, or within the smile zone, his firm generally fabricates custom abutments. He purchases the abutments used in the posterior region. The purchased abutments are less expensive for the patient than the custom-made abutments.

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[78] Such as the polyvinyl material used by the CEREC Sirona CAD/CAM.
[79] This technology is used by one of the interviewees interviewed. The technology is in its early stages with less than 1% ownership in North American (2008). According to Interviewee 8, who recently purchased the CEREC Sirona CAD/CAM technology and lectures on its use through dental clubs, currently there are 60 General Dentist utilizing the CAD/CAM technology in Alberta. There are about 100 users across Canada and about 2000 users in the USA.
[80] The Sirona CEREC technology is about 25 years old, but, according to Interviewee 8, its purchase was only viable recently.
[81] Interviewee 21 and 22.
[82] For example, CEREC (Chairside Economical Restoration of Esthetic Ceramics) CAD/CAM technology by Sirona Dental Systems, a global manufacturer of dental equipment in Germany and Everest CAD/CAM by KaVo EWL, a German global manufacturer of dental laboratory equipment in Leutkirch, Germany.
[83] NobelProcera CAD/CAM is made by Nobel Biocare. Straumann CAD/CAM is made by Straumann.

This dental-service firm fabricates and maintains crowns for all major implant brands. Therefore the Prosthodontist has invested in the Straumann, Nobel Biocare and Astra Zeneca *restorative instrument kits*. The cost of the kits ranges from $850 to $1600 CDN each, and upgrades can be required if the styles change. Some brand-name *surgical instrument kits* can be used for restorative purposes, but most dental firms need to own *restorative instrument kits* that are specific for each implant brand a firm deals with. Such kits include multiple styles and shapes of abutments to accommodate difficult implant-placement angulations and can contain about 2000 components.[84] The brand-specific kits supply the tools and instruments for the procedures needed to take impressions of the patient's implant site and surrounding teeth as the preparatory work to send to a laboratory for the design and fabrication of the crown. The Prosthodontist's firm uses this process, shown in Chart 1 of this section, to build the crown and fabricate the custom abutment, if required. For the dentist to take impressions, the patient will first experience the dentist preparing the *impression plate,* using the *Straumann equipment* that he uses interchangeably for all implant brands. The following Chart 1 provides a guide for the dentists to the suggested Straumann method for taking the impression (sourced from Straumann sales representative).

The Prosthodontist follows the generic method to some degree, although he substitutes some tools for others and utilizes other products in a different way during the impression process. To do this, the patient will experience the Prosthodontist hand-removing the healing cap placed by the oral surgeon. The Prosthodontist will then place the *impression post with a guide screw* into the threaded interior socket of the placed implant and tighten the guide screw with the *SCS screwdriver*. He then prepares the *impression tray,* by creating access holes for the impression post and filling the impression tray with three different viscosities of *PolySil SH1* (super hydrophilic vinyl polysiloxane) impression material. The patient will experience the Prosthodontist applying the *impression material* around the impression post to ensure that a complete impression is taken. The patient will experience the Prosthodontist placing the impression tray over the teeth and allowing the material time to cure. Once the impression material is cured, the patient will experience the Prosthodontist removing the impression tray using an *explorer* and the removal of the *impression post* from the *screw guide* with *cotton pliers.* Then the impression post and guide screw are reaffixed onto the impression plate and sent to the in-house laboratory to create the

[84] Smaller firms, such as UK's Neoss, are entering the market with an implant of about 100 components (Merrill Lynch Report, October 12, 2006).

crown. To complete this process, the patient will experience the Prosthodontist hand-threading the healing cap back into the implant's empty socket.

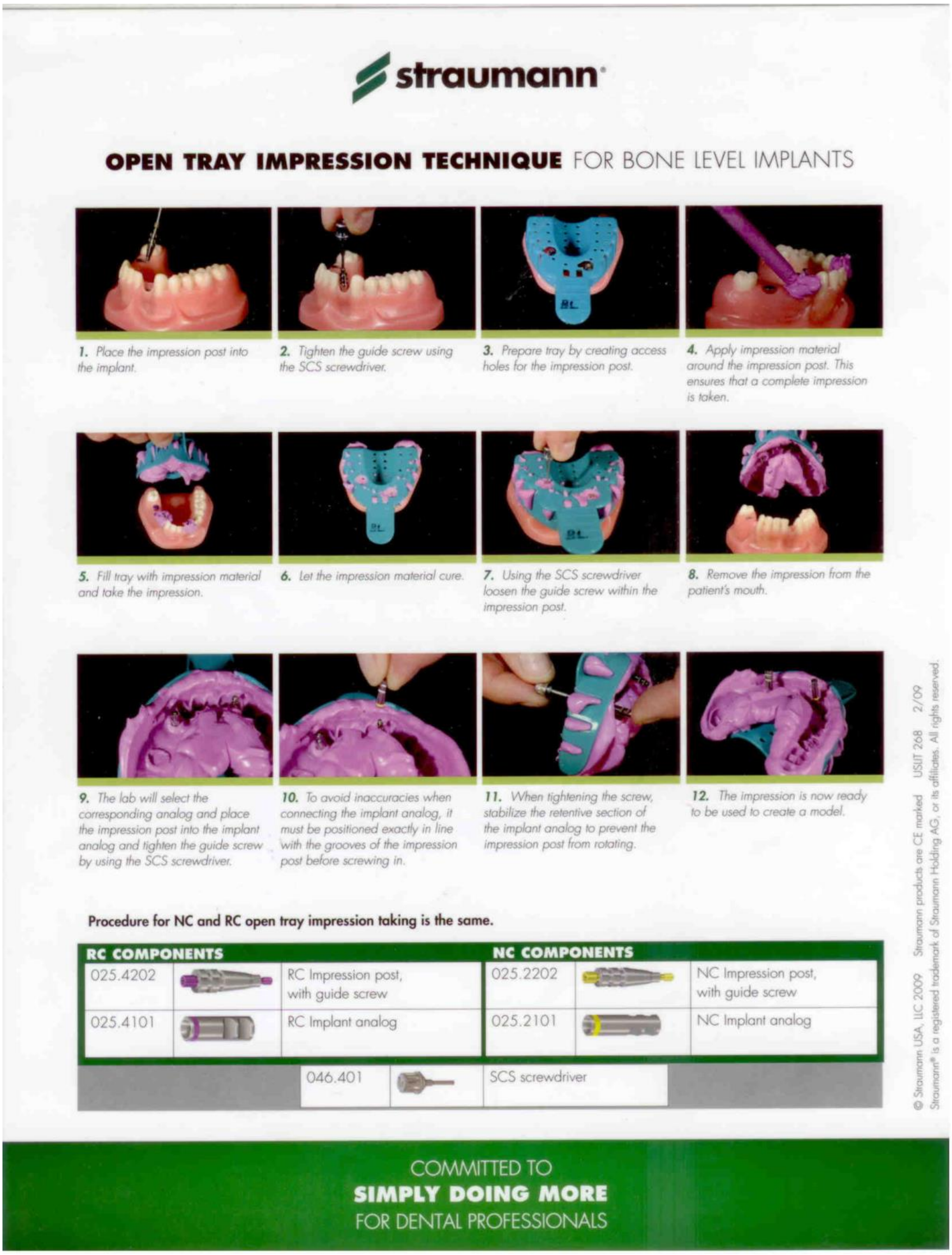

Chart 1. Straumann impression technique

The Prosthodontist determines the patient's natural tooth colour, using a palette of porcelain-crown colours supplied in the *Vita System Porcelain.* This information, along with the impression plate, is passed to a laboratory technician. The Prosthodontist's dental-service firm is unique in that it owns its laboratory. Therefore, the fabrication steps and the artefacts utilized to make the crown are part of the implementation process at this dental firm. However, to ensure that the data collected are reliable, only the techniques executed by the Prosthodontist are presented in this thesis.

This concludes the patient's third appointment. The next section works through the placing of the crown.

7.6 Fabrication and placement Stage – patient's fourth appointment

7.6.1 Techniques for placing the crown

Diagram 6-Ch.3 illustrates that there are two ways to carry out the crown placement. It can be screwed or cemented to the abutment. There are one-step and two-step versions of this technique.

The one-step cemented process provides the greatest difficulty for maintenance. This is because the abutment is a one-piece unit and the crown is cemented directly on top of the exposed part of the abutment. For maintenance to occur, the crown has to be cut off the abutment. This approach to fabrication and placing the crown requires less investment in tools and skill; therefore, it is less expensive for the patient in the short term.

The one step cemented process is not the technique utilized by the Prosthodontist. He utilizes a process where access for maintenance is easier and, in the long term, more economical for the patient. He places the crown using a two-step process, utilizing a technique that involves the installation of a two-part abutment. First, the lower part of the abutment is screwed into the implant-socket. Then the upper portion of the abutment (sometimes referred to as the abutment-screw) is screwed into the lower abutment-part. Finally, the crown is cemented onto the exposed upper part of the abutment and adjusted as required. The patient will experience the Prosthodontist performing the following techniques to place the crown.

The patient enters the office and is seated in the dental chair for the fourth appointment. The dental staff prepare themselves and the patient for the modified-sterile surgical approach.[85] The patient will go through a process, executed by the Prosthodontist, utilizing the following techniques to (a) place and test the two parts of the abutment, (b) cement the crown, (c) and adjust the crown.

During the placing and testing of the abutment, the patient will first experience the Prosthodontist removing the *healing cap post.* Then he will secure the bottom and top made-up portion of the abutment, by hand-screwing and torqueing the *abutment* and *abutment screw* into the implant cavity utilizing the tools from the *Straumann surgical/tool kit*. The surgical kit content is colour coded, which identifies to the Prosthodontist the tools and instruments to be used, based on bone protocol to ensure that the abutment is correctly tightened. The knowledge used by the Prosthodontist to choose the appropriate tools is information that is transferred from the oral surgeon to the Prosthodontist's office. This information is based on the oral surgeon's bone-protocol assessment of the patient and the implant type chosen by the oral surgeon. To conclude the testing technique, the patient will then experience *x-rays* taken with *non-digital film,*[86] which the Prosthodontist will read to ensure that the abutment is tightened accurately.

To cement the crown, the patient will experience the Prosthodontist applying two cement material resins to the crown and placing it over the top of the exposed part of the upper portion of the abutment. The *cement material* and a *self-adhesive universal resin cement* are mixed, utilizing the *three instruments* that accompanied the resin cement kit. For the dentist to adjust the crown, the patient will then experience the Prosthodontist measuring the bite by means of a *handle* with *articulating paper*. Depending on the results, the patient will then experience the Prosthodontist adjusting the bite of the new crown by using *drills* and standard drill *burs*. During this process, the *air and water syringe* will clear the patient's oral cavity of debris and water.

This completes the process, to remove and replace a diseased tooth with an implant, for artifacts see Appendix C.

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[85] The artifacts utilized in this approach have been listed elsewhere and will not be repeated here.
[86] This firm uses equipment that generates lower dosages of radiation and conventional film rather than digital technology, because the Prosthodontist sees no upside to using digital. The upside to their current non-digital is that it is cheaper and requires only standard film processing and management.

7.7 The observed case applications of throughput

Transforming high fixed costs into *low unit costs*, during the dental implant implementation process/technique (as in the cases), is the result of the dentists' post-graduate education and the accumulated, learning by doing as of the result of scaling the technique to increase reliability and efficiencies within constraints of the technology and the market.

The learning associated with scale economies, has these characteristics.
Partial increasing returns to scale – arise from:

a) Decreased cost of one factor or the other - (dentist labour) or (material-capital cost), generally by increasing quality by decreasing uncertainty associated with the factors.
b) Changes that increase capacity utilization, that is the volume by increasing throughput speed, i.e. reduced failure rates.
c) Decreasing cost in process that gives the impression of decreased cost of final product and can be thought of as penetration into new markets and areas of application.

7.7.1 Achieving quality, for reliable routines

Part of quality control is to reduce the functional uncertainty of the dental implant technology.

Case two/Prosthodontics - retains high throughput in a number of ways:

a) **The integration of a specialized knowledge input (an in-house laboratory) that can custom-design and manufacture abutments and crowns.** Implant placement angulation creates challenges for prosthodontists who focus on restorations. Natural teeth and their root systems do not always have ideal-space relationships with neighbouring teeth. Therefore, implants may be placed at an angle. If not restored properly, they can compromise the life expectancy of the implant. To compensate, producer-firms have developed restorative kits with about 2000 different components to lessen this complexity for dentists. The Prosthodontist, with an in-house laboratory, can custom-design and manufacture abutments and crowns to overcome the angulation challenge while adding aesthetic value for the patient. While the kits are developed with higher levels of embedded knowledge to reduce the complexity of the patient’s condition, this is not important, because of the in-house laboratory (Section 7.5.1).

b) **Referrals to specialists.** The knowledge specialization of the Prosthodontist would allow the surgical part of implant work, but instead he chooses to focus on fabrication and placement to capitalize on the custom in-house laboratory. He uses the division of labour referral system, to ensure longevity of implants and to increase the quality of all dental work (Section 7.5.1) and also to decrease learning time.

c) **Impression technology and in-house lab.** This specialist by specializing in the crown fabrication and placement, increases quality through impression technology. This process is highly dependent upon the accuracy of the impressions and subsequent model building of the patient’s natural teeth, to ensure the proper loading of the implant, as it affects the longevity of installed implant (Section 7.5.1).

d) **Investment in three most popular name brand fabrication kits.** The large initial cost of the capital equipment, increases volume of patients (Section 7.5.1).

e) **Reduces uncertainty of external work**, with the in-house laboratory that engineers implant parts, for more complex oral structures and also adds the extra benefit of higher-level aesthetics.

f) **Higher quality material**, through customization of crown for implant (Section 7.6.1). By economizing on the in-house laboratory, increases quality at a lower cost, than if outsourced.

7.7.2 Bottlenecks to higher use of dental implant technology

a) Threat to position, CAD/CAM chairside design and crown manufacturing (Section 7.6.1).

b) Insurance does not fully cover. The majority of patients will not choose the uninsured choice regardless the benefit of longevity. Partial coverage leads to time consuming administrative work (Section 7.3.1).

c) Prosthodontics, like Periodontics, are limited by regulations and in their ability, to use complex regeneration techniques. Interviewee 21, supported by Interviewee 7, observe patients wait too long to make use of implant technology and there is not enough bone left. This suggests earlier use of implant technology, as bone loss, most often, increases with age. To do so, would require a paradigm shift in the education and training of dentists, as currently, the natural tooth root is saved until there are absolutely no alternatives, excluding cosmetic surgery. A suggested, alternative, is for scientists, to address the disease that contributes to bone loss, and not to build products for industry to sell (Interviewee 21).

7.7.3 External knowledge contacts and motivations for use

a) To meet continuing dental education (CDE) certification qualifications of ADAC. Private graduating school and private dental schools - The University of Minnesota School of Dentistry CDE (UMN CDE), the University of California Dentistry CDE programme (UCLA CDE).

a) Implant training. Private graduate schools for industry-sponsored training from brand-name, implant producer firms, Nobel-Biocare, Straumann and Astra Zeneca. The Las Vegas Institute for Advanced Dental Studies (LVI Global Institute).

b) Conference lectures provided by experts in field. Supportive of the dental schools, mostly private, in Southern California and Minneapolis, which provide regular continuing education for their professors and to other dentists, with top people in a particular field doing the teaching.

c) Presidential role in dental society. Influencing the provincial and federal dental associations to make CDE compulsory for dentists, in work force.

d) Presidential role in two dental societies. An advocate of manufacturers to have access to dentists. Edmonton District Dental Society, sponsored by manufacturers and suppliers of dental consumables and equipment.

e) Presidential role in dental society to promote a new orthodontic treatment - The Alberta Academy of Prosthodontics.

f) Study club participation. The study club was utilized to transfer his TMJ technological knowledge to other dentists and a way of attracting referrals. The Pacific Coast Society for Prosthodontics, which is affiliated with the American Dental Society, and the Alberta-based TMJ Study Club.

g) Contact to basic science. Publications of graduating school, Loma Linda School of Dentistry (LLUDS), an American Health Sciences Institute.

h) Lectured at graduating school.

Case two summary – Prosthodontic specialization – restorative (custom or otherwise) work of implantology with the assistance of an in-house customization laboratory. This firm increases throughput by reducing uncertainty through simplifying the complexity of dental implants through in-house customization. Customization reduces the need for purchasing extra dental implant components (reduces reliance on external supply-side information), such as specialized equipment and complementary assets, hence reduces learning, and adds the benefit of extra aesthetics for the customer.

Chapter five demonstrated how similarities were found among the cases with final observations in Ch. 9.

CHAPTER EIGHT

CASE - ORAL and MAXILLOFACIAL SURGEON

8.1 Introduction

The Oral and Maxillofacial - dental-care service. He is the owner-operator of a small group practice that functions as a dental surgical firm in the province of Alberta, Canada. The office in this dental care firm resembles a hospital operating room. The firm is equipped with sterilization equipment and staff to sterilizing its own tools and instruments in house. The dentist in this firm, does all his own laboratory work and is equipped and staffed to do so.

His education, in addition to the prerequisite requirement of a minimum two- to three-year undergraduate education,[87] is a four-year general dentistry degree - Doctor of Dental Surgery (DDS) - one year of medical internship, and four years of surgery residency. This owner-operator firm is representative of the dental-service practice profile of dental-health-care delivery in Canada (only 7 per cent of the total population of dentists do not work in owner-run solo or small-group-practice firms).

The demographics of the dentist are as follows.

a) He is a male specialist over the age of forty. In comparison to the total population of dentists employed in Canada, he is part of the 14 per cent who work in specialties, 79 per cent who are male, and 49 per cent who are over the age of forty but under sixty.
b) He is Canadian born but has taken his dental education outside of Canada. This makes him part of the 10 per cent of the total population of dentists operating in Canada that are trained outside of Canada.
c) He has one associate. His associate is also an Oral and Maxillofacial Surgeon. Both dentists act individually as legal incorporations and are joint-owners of the surgical centre. Part of the business practice is working in hospitals to deal with emergencies. Therefore, the dentist of firm one is part of the 18 per cent of total dentists in Canada who practice in more than one location.
d) His patient load is around 40 per day.

[87] Some universities like the University of Alberta have a two year prerequisite requirement and some have a three year prerequisite education that covers general biochemistry, mammalian (human or animal) physiology and life sciences (biology related) courses plus one humanities or social science course (//.utoronto.ca/dentistry/admissions/undergraduateacademic.html).

The firm's full-time employees are 12 registered nurses and 4 upfront staff. The dental office resembles a hospital operating room. The dental chair in this practice is only used as a place to talk to a patient until they are moved over to the operating bed. This firm is unusually self-reliant. Its independence is based on incurring high capital-equipment costs. It follows sterilization protocol by sterilizing its own tools and instruments with its own sterilization equipment and personnel. This is an unusual practice, as even most hospitals outsource the sterilization of their instruments. Secondly, the firm does all its own laboratory work by taking advantage of the capabilities of high-tech x-ray equipment.

The business model of the dentist of case study one reflects a self-contained dental-service firm that does not rely on outside services for diagnostic, laboratory, and sterilization services indicating that economies of scale permit handling the high capital and labour costs to achieve the high throughput required of this dental-surgical service firm.

As this dental firm performs surgeries outside of a hospital, it does so under an accreditation as a Non-Hospital Surgical Facility (NHSF). This accreditation requires that its general anaesthesia and surgical procedures be approved and accredited by the College of Physicians & Surgeons of Alberta.[88] The dental profession, like the medical profession, has the right to self-governance;[89] therefore an advisory committee to the College of Physicians and Surgeons of Alberta (CPSA) does an on-site inspection of all NHSFs on a four-year cycle. These inspections monitor compliance with qualifications of physicians and nursing personnel, surgical and recovery-room practices, infection prevention and control practices, medical records and documentation, and safety practices.[90]

8.2 How the Surgeon links to other dentist-specialties

The Surgeon utilizes the dental implant for two processes. If the implant is to act as a tooth-replacement technique, as it is in this study, the dentist who refers the patient to the Surgeon will do the remaining work. Surgeon's primary responsibility is to place the

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[88] //.cpsa.ab.ca/Services/Quality_of_Care_Main/Accreditation_Facilities/Non-hospital_Surgical_Facilities/NHSF_Overview.aspx.

[89] The right of dentists to self-govern commenced with the formation of the Ontario Dental Association (1867) and in Alberta with the formation of the Alberta Dental Association (1906), Appendix E).

[90] //.cpsa.ab.ca/Libraries/Pro_QofC_shared/Annual_Report_2008_Accreditation_Programs.sflb.ashx.

implant into the upper or lower jaw bone, as illustrated with “Surgical step 4 – drop the implant” in Diagram 18.

The Dental Implant Technique and Sub-techniques

Subsystem One - Work up the patient

Oral Surgeon

Clinical Management **Step 1**

Diagnosis & Treatment Planning **Step 2**

Product Choice **Step 3**

Subsystem Two - Procedural

Surgical - drop the implant **Step 4**

Healing for Loading w or w/o abutment **Step 5**

Fabrication & Placement of the crown **Step 6**

Diagram 18. The Oral Surgeon’s implant installation sub-techniques

As illustrated above, the Surgeon executes steps 1 to 3 are executed before the procedural work of placing the implant can begin.

This leads to a process, which is the time-line of what happens to the patient.

In relation to the function provided by the Surgeon, the patient will experience a division of labour among dentists, as follows. The General Dentist represented in case (Ch. 6) does not surgically place implants in patients whose cases are deemed to be complicated. Such patients are referred to a Prosthodontist (Ch. 7), who also does not place implants and built the business around the restorative work of implant technology. The Prosthodontist refers to a surgeon to place the implant. Once the surgeon places the implant, the patient returns to the Prosthodontist for the remaining work.

The next section will link the Surgeon to specific processes and the artifact/technology utilized to carry out the techniques.

8.3 The techniques

The patient goes through the following four stages.

1. Clinical management
2. Diagnosis and treatment planning
3. Product choice
4. Surgical

These stages, along with the techniques used to solve each stage, are illustrated in Diagram 19 “patient-work site”.

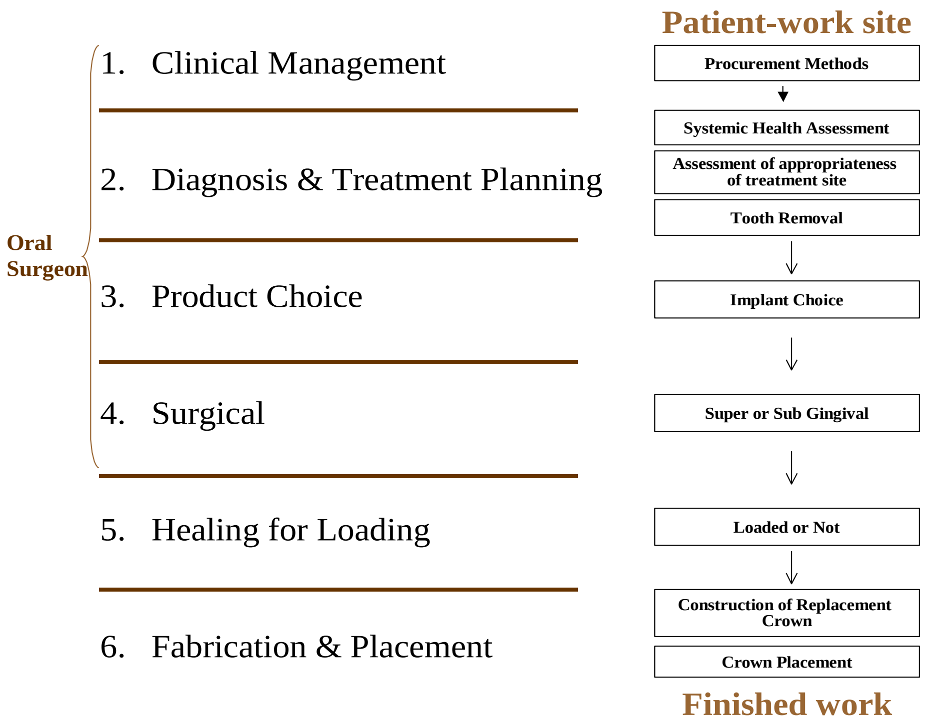

Diagram 19. The patient-work site of the Oral Surgeon

The patient goes through four appointments for the Surgeon to apply the techniques identified in the patient-work site. The order of techniques is not as linear as represented.

The surgeon has a unique way of executing the techniques of the first three stages over a span of two appointments that "works up the patient" for the third appointment and the surgical procedure of stage four. The patient will experience the following order of techniques in a time-line that covers three appointments.

Appointment one – Stage One and Two:

Procurement method
Systemic health assessment
Tooth removal
Healing for two to three months

Appointment two – Stage Two and Three

Assessment of appropriateness of treatment site
Implant choice

Appointment three – Stage Four

Site preparation
Surgical approach – super- or sub-gingival

The following sections work through each appointment. The stages and techniques executed during each appointment will be explained following the data-collection tool featured in the methodology, Diagram 5 and 6 in Ch. 3.

Following the data-collection tool of Diagram 5-Ch.3, the technique first executed is the clinical management stage.

8.3.1 Clinical-management stage – patient's first appointment

Clinical-management primarily consists of information gathering to effectively contact people, plan treatment, and track patients through the dental practice. It can also cover referral information and some financial information specific to patient flow,[91] that are important to the dentist's diagnosis submitted to insurance, for the patient to recover the cost of treatment.

Further decomposition of the procurement method, as illustrated in Diagram 5-Ch.3, indicates that there are two ways to collect payment for service provided. Even though

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[91] For a detailed description of clinical management system approaches dental practices may use, see (Yacyshyn, 2002: 130-37).

some portion, like the diagnostic services can be claimed through insurance, some dental-care firms collect directly from the patient.

If the payment is by the individual patient, research reveals that the economic health of the patient plays an important role in deciding to seek this treatment. Citing the Surgeon, “there is no shortage of people wanting to pay for this procedure”.[92] Other dentists have found that oral health is not a high priority among patients. “Most patients given the option of choosing a dental implant that currently costs about $4000 to $5000 Cdn. will choose a procedures covered by insurance and not the dental implant technology.[93] Clinical dental interviewees 1, 2, 7, 8, 22, support the view, that the implant technology will not be fully incorporated into dental practice, without insurance coverage.

If payment is through the insurance option, the type of health-plan coverage influences coverage.[94] As illustrated in Diagram 5-Ch.3, the firm they work for and/or the local union that represents the employee influences the type of health-care coverage and the employee contribution. Dentists believe that employers use dental-health options as an incentive to attract higher-level employees.[95] This research observed, employers generally follow what other firms are offering.

There are a number of national and provincial dental associations that have liaison roles, perhaps influencing insurance firms. However, it is the insurance firm’s hired assessor/consultant who advises the dental-care firms on acceptable reimbursed procedures. This person is perceived by clinical dentists to have the most influential role at the provincial level. The assessor is generally regional, and can be a clinical dentist or a professor of dentistry and may be a specialist or a general practitioner. According to the dentist-interviewees,[96] other than cost factors, it is unclear what motivates the assessors. The assessor’s identity is highly guarded by the insurance firms.

The next stage the patient goes through is diagnosis and treatment planning, following the steps and the techniques set out below.

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[92] The Oral Surgeon’s part of the total cost of implementing the implant is about $2000+ Cdn (2010).
[93] Interviewee 8.
[94] Currently there are 106 Life and Health Insurers in Canada that compete with each other (Interviewee 19 - Canadian Life and Health Insurance Association Inc. (CLHIA).
[95] Interviewee 18.
[96] Interviewees 1, 2, 22.

8.3.1.1 Diagnosis and treatment-planning stage

Diagram 5-Ch.3 lists three steps to the diagnosis and treatment-planning stage: the Surgeon completes two of those steps in the patient's first appointment. The steps are: a) the systemic health assessment, followed by the tooth removal techniques, and a three- or four-month waiting period to allow for healing time, and b) higher-level diagnosis and further treatment planning.

Techniques used in the systemic health assessment

The patient will experience the application of two processes to assess their systemic health. A health questionnaire and an ASA rating, both assist the surgeon in assessing whether the patient is healthy enough for surgery.

During this first appointment, the patient fills out a *health questionnaire* about their dental and medical condition. This questionnaire is developed by the dentist and guided by the regulations imposed on dentists by the provincial dental-regulating association, ADAC. From the questionnaire, the dentist assesses the areas of health that may contribute to a lowered chance of surviving surgery, such as heart disease and blood pressure levels.

Health for surgery also includes identifying the oral-health and medical diseases that may contribute to a reduction in implant success. In addition to the questionnaire, the patient is examined for oral and systemic diseases that may lower the chance of implant success. There are many anatomic, biological, mechanical, aesthetic and behavioural factors that may limit implant success. As illustrated in the data-collecting tool of Diagram 5-Ch.3: (a) bruxisms (teeth grinding), (b) healthy gums, (c) smoking (10% reduction in implant success), and (d) diabetes (5% reduction in implant success). If the patient is diagnosed with severe systemic diseases at this preliminary assessment stage (ASA[97] rating of 4 out of 4), the patient is deemed not healthy enough for surgery (Loma Linda University School of Dentistry, The American College of Prosthodontist et al., 2003). The Surgeon did not view smoking as having a negative effect on dental-implant success.

It is important to note, the purpose at this stage is to establish the patient's chance of surviving surgery and the risk levels associated with implant osseointegration. If the patient has diabetes and osteoporosis, and is controlling the diseases, the surgery may proceed. If a patient is not controlling osteoporosis, even though it is not a systemic

[97] American Standard Association.

disease listed in ASA rating, the Surgeon will not place the dental implant. If this occurs, the patient will be sent back to the referring dentist.

It should be noted that the Surgeon does not execute all the assessment techniques described in Diagram 5 and 6-Ch.3. Specialized skill avoids some of the steps that other dentists would need to execute.

8.3.1.2 Techniques used in tooth removal

Diagram 5-Ch.3, the patient generally experiences assessment of appropriateness of the treatment site in the diagnosis and treatment-planning stage before tooth removal.[98] This process differs when the patient is referred to the dental surgeon because the referring dentist has already completed a preliminary assessment of the patient and deemed the patient's oral-health condition difficult enough to warrant the specialized knowledge and skills of an oral surgeon.

The patient will now go through the tooth-extraction technique. An important condition relating to the success or failure of the implant, is the amount of bone (jaw or sinus) available to sink the implant. Therefore, it is important to not lose extra bone during the tooth extraction. This makes the technique of tooth removal very important. Improper tooth removal can lead to unnecessary bone damage. Reducing bone damage to less than 1mm, depends on the dentist's knowledge and skill in applying the tools to remove the tooth. As articulated by dentists, individual skill levels vary even with the same education and training.

The patient will now experience the two anaesthetic processes. The patient will be anaesthetized by injection with *Utlracaine D-S.* After a short wait to ensure that the anaesthetic has taken effect, the Surgeon will remove the diseased tooth utilizing a variety of tools. Some of the specific tools and instruments are the *sweetheart retractor*, *extracting forceps*, *root tip pick elevators.* Other tools that are used to assist in the process are *suction tips*, *dental mirror*, *curette* and *Minnesota retractors*. These tools and instruments are from his customized built dental-tray kit,[99] and their use can overlap with the surgical stage. The selection of tools differs somewhat from what other dentists would use for the extraction and surgical stages, because of the specialized surgical-training.

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[98] Bone type conditions reference the depth and width of upper or lower jaw bone required for implant stability.
[99] This distinction is stated because a dental-tray kit is a trade name and is mostly associated with certain tools and instruments used by all dentists.

Once the tooth is extracted, the patient goes through a three- to four-month healing period before returning to the Surgeon for the second appointment.

8.4 Diagnosis, treatment, product stage – patient's second appointment

Once the healing phase concludes, the patient returns. During this appointment, the patient experiences a higher level of diagnosis and treatment planning. To access appropriateness of site in terms of bone-type conditions. The outcome of this appointment results in the Surgeon drawing up a complete plan for placing the implant. The main function of this stage is to make bone-grafting decisions. This can only occur after the removal of the diseased natural tooth and after the two- or three-month healing time expires.

The accuracy of assessment at this stage is critical, because the implant technology must provide a stable foundation for the crown. To do this, the implant technology must be installed in a manner that will not affect the ability of the implant to maintain its installed position. The factors that contribute to the mechanical strength of the implant are the systemic health ASA rating of the patient, the distribution of load forces to maximize the osseo- or bone integration with the tooth implant,[100] and implant design. For an implant to retain its installed position, the Surgeon must install it in a way that contributes to retaining the amount of jaw or sinus bone and reducing bone atrophy.

8.4.1 Techniques of the assessment of appropriateness of treatment site

To assist in the assessment of the appropriateness of bone of the implant site, the patient will be X-rayed with *plain film* and/or will be scanned using *panoramic radiography* that results from the digital x-ray using the *CT Panorex*.[101] According to the Surgeon, the main diagnostic tool is the radiographic evaluation, which provides a template of all the existing teeth and their related underlying bone dimensions. This radiographic template verifies that there is adequate bone below the proposed implant location. The radiograph also verifies locations that may be used for bone graft, if required.

Additionally, the patient will be subjected to the making of plaster study models using *impression plates* to provide the above-gum-line measurements of the existing natural

[100] Proper distribution of forces between the jaw or sinus bone and implant encourages the osseointegration affect.
[101] Advanced CT (computerized tomograms) scans are an imaging method employing digital geometry processing to generate a three-dimensional image of the treatment site from a large series of two-dimensional X-ray images taken around a single axis of rotation.

teeth. These diagnostic tools provide a measure of the appropriateness of bone after the natural tooth removal, because the need for adequate bone height, width/thickness, muscle attachment, space between the teeth, and inter-arch space. The inter-arch space is the area between the teeth required for surgical access and relates to the amount of bone grafting that may be required to increase the stability of the dental implant.

With this diagnostic information in hand, the Surgeon prepares a complete surgical plan. The plan identifies the number, type, and location of the implant, how much grafting is required, where the grafting material will come from, and where and how to insert the implant to maximize its mechanical strength. It can include the installation of a surgical stent. Although the preparation of a surgical stent reduces the prosthetic dilemma for the referring dentist doing the restoration work (Step 6 of Diagram 18-Section 8.2), the Surgeon does not prepare or use a stent.[102] Instead, he relies on the advanced illumination techniques and specialized skill to ensure proper placement.

The next step in the drawing up of the plan includes the choice of the implant.

8.4.2 Techniques of the product-choice stage

The product-choice decision lies with the dentist and not with the patient. As illustrated in Figure 1-Ch.1 the dental implant has two mechanical pieces: an implant and an abutment. Once the abutment is in place, a crown or some type of prosthetic devices can be built on the visible portion of the abutment. In most cases, the choice of dental implant dictates the choice of abutment and the techniques used to build the crown. Therefore, the Surgeon's choice could ultimately affect the work of other dentists.

The product-choice stage has two processes to solve, each involving numerous steps and techniques. One process is the selection of the installation type and the other is the implant brand choice.

Diagram 5-Ch. 3 notes that the installation choice can be of three types: not loaded, restorative and immediate. Each type solves a particular implant issue, described as follows. The 'not-loaded' option has two processes: the non-loaded, no-weight-bearing process and the non-loaded, two-stage process. The non-loaded, no-weight-bearing

[102] A surgical stent is a clear impression model made of the patient's teeth. Guided by the radiographic template, drill holes can be marked, representing the exact location the implant is to be installed. The surgeon can then use this stent-template during the surgical procedure to drill holes through the soft tissue. The restoring dentist can use this information to ensure that the abutment and crown are also installed at an angulation best for ensuring longevity of the installed DIT.

technique[103] is not relevant to this study because the study uses the dental implant as a single-tooth replacement technique that involves building (loading) a weight-bearing crown on top of the implant-abutment complex.

The Surgeon chooses the ‘non-loaded, two-stage process’ that provides a foundation for building things on top of the implant-abutment complex. During this process the patient will experience the implant portion, placed in the jaw or sinus bone (Stage 4, Diagram 18-Section 8.2), followed by a three- to four-month healing stage (Stage 5) before returning to the referring dentist for the (Stage 6) to fabricate and install the crown.

The implant, the Surgeon places cannot undergo maintenance. If the implant loosens from its installed position, the dental procedure is considered a clinical failure.

The ‘immediate’ technique is chosen when the edentulous site has bone conditions favourable enough to allow placement of the implant immediately after tooth extraction. Since no healing time after tooth removal is required, eight weeks are gained. This reduces the number of the patient’s return visits and takes less chair-time for the dentist: it is thereby more economical. The dentist uses this technique only when the patient’s tooth site is clinically appropriate. Those patients who are referred to a surgeon are generally considered clinically more difficult in terms of their oral disease conditions, and that makes the immediate technique not an option for the Surgeon performing the installation procedure in this research. To conclude, the implant installation choice is the ‘non-loaded, two-stage process’.

The next step in the product-choice stage. Diagram 5-Ch3 lists four steps that the dental surgeon will take to solve the produce-choice stage: quality, patient allergic reactions, product support and price.

The composite material of the dental implant is the main factor in the quality or reliability of the implant, and in the potential for allergic reactions the patient may experience. The exterior of the implant that is inserted into the jaw or sinus bone is designed so that surface coatings that can affect the biological structuring of the living

[103] The ‘non-loaded, no-weight-bearing’ option is chosen by the dental surgeon if implant choice is to provide a means to reduce bone atrophy of the jaw and/or sinus bone in a patient who chooses to remain endentulous (toothless) or chooses to wear a prosthetic device such as dentures.

bone and the surface of the mechanical dental implant, act in a positive way for bone level maintenance to occur.[104]

The Surgeon's selection of implant brand does not conform to the user name brands. The Surgeon utilizes *Zimmer HA* titanium *coated dental implant*. The *hydroxyapatite (HA)* increases osseo capabilities and thereby shortens the time the patient has to wait for dental-implant restoration.

The Surgeon views the material change to titanium, has leveled the brand differences in terms of quality and allergic reactions in patients.[105]

The Brånemark System of dental implants is available through Nobel Biocare. Nobel Biocare has adopted a market strategy to increase their market share by recruiting general dentists to place implants through a two- to three-day training course that includes starter kits with implants. This has resulted in the fear that general dentists with limited experience will not attain the elevated standard of care expected from surgeons.[106] To counter this fear, the UK's General Dental Council and the US's Institute of Dental Implant Awareness has developed higher-level guidelines to make dentists aware of the legal liability of placing implants with limited experience.[107] Nobel BioCare (2006) reports that it was not certain whether recruiting general dentists to do implant dentistry will compensate for the loss of revenue from some of its high-volume Surgeon customers.[108]

The next two steps that influence the implant product decision involve product support and price. The Surgeon did not indicate whether he chose Zimmer for the product support or price, but Zimmer costs less than the leading brands. Product support is found to be fairly equal among the leading brands, and choosing on price alone is difficult. Diagnostic results of bone appropriateness differ with each patient. Each brand has variations of implant designs to accommodate these biological differences. Each brand is accompanied with "implementation system kits" that include implant dentistry training and tools, as those in the Zimmer surgical kit illustrated in Chart 2. [109]

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[104] This is a dynamic process in which the bone structure next to the implant is continually maintaining or regenerating its capability to adhere to the implant.
[105] Supported by Interviewee 3.
[106] Nobel Biocare partners with UBC, the University of British Columbia and therefore interviewee 3, is consider to have reliable knowledge of Nobel Biocare's concerns.
[107] http://www.gdc-uk.org.
[108] Interviewee 22 supported by Merrill Lynch 12 October 2006 report – //.osseotech.com/pdf/merrill-oct-2006.pdf.
[109] //.zimmerdental.com

Chart 2. Zimmer instrument kit (www.zimmerdenal.com)

The surgical instrument kit is an example of the upgrade required when switching implant brands. Brand switching is expensive, both in equipment cost and in retraining cost and time, so a dentist is not inclined to change brands based on price alone.[110] For example, the cost of a Straumann course in 2009 was about $12,000 plus taxes. This included a surgical implant instrument kit worth about $4000.[111]

After the implant choice, the surgical process of placing begins.

8.5 Surgical stage – patient's third appointment

During this stage, the patient will go through a series of techniques as outlined in the detailed treatment plan designed by the Surgeon based on the diagnostic results of the patient's first two appointments.

The data-collection mapping tool of Diagram 6-Ch.3, illustrates that the patient will go through three procedural stages, with the Surgeon executing the surgical stage. Diagram 6-Ch.3 illustrates the order of events the patient goes through to identify the artefacts used by the Surgeon in the surgical stage.

Diagram 6-Ch.3 shows the patient will go through a sub-gingival, sterile surgical approach. The surgical approach versus the modified surgical approach adds steps to reduce infections and doubles the cost to the dentist. According to the Loma Linda University School of Dentistry, The American College of Prosthodontist et al. (2003),

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[110] Interviewee 22. Zimmer, being aware of this, has increased market share by designing some of their implants and abutments to be used interchangeably with the Nobel Biocare and Straumann implant brands and installed using the competitors' surgical kits.
[111] Interviewee 12.

the preferred environment for implant placement is a sterile, hospital-type operating room, such as the firm of the Surgeon of this case study. The Surgeon and his assistants are *gowned* (*masks, hats, and gloves*) and they follow a protocol that avoids cross-contamination. The patient is fully *draped* with only the oral cavity exposed.

As the dentist-owner of this case study is a Surgeon, the modified sterile approach is not an option for his firm because of his accreditation to operate as a non-hospital surgical facility. The modified sterile (or clean) approach is practiced in dental school clinics and most other dental clinics (Loma Linda University School of Dentistry, The American College of Prosthodontist et al., 2003). The modified approach is described in case (Ch. 6) in which a General Dentist places the implant.[112]

The Surgeon executing a sub-gingival surgical approach places the implant with the healing collar of the implant exposed to the oral cavity. This is considered a one-stage surgery as it saves the patient time and pain, as only one incision is required. The two-stage surgical approach commenced with the Brånemark implants in the 1960s and requires the entire dental implant to be placed into the bone submerged below the gum-line. It has to remain covered for several months during healing to avoid any mechanical or microbiological challenges that may affect osseointegration of the titanium implants.[113] The second stage involves an additional surgical procedure to expose the implant. The soft tissue is then sutured around the healing collar. Whether the surgical procedure is a one- or two-stage approach is vendor- and implant-design specific.

In preparation for surgery, the patient will experience general sedation and local anaesthesia. The artefacts utilized include the Drager *anaesthetic machine* and the Nobel Biocare *inhaler*. The patient will breathe in *Sevoflurane* through the inhaler. For local anaesthetic the patient will be injected with *Ultracaine D-S*.

During anaesthesia, if grafting is part of the treatment plan, the dental surgeon will prepare the edentulous recipient site[114] using the *scalpel handle and blades* to perform an incision to expose the defect. The common condition requiring grafting is insufficient height or width of residual bone in the recipient site of the upper or lower jaw (mandible

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[112] The success rate in terms of osseointegration for implants placed under sterile vs clean conditions is very slight (Scarf & Tarnow, 1993; Loma Linda University School of Dentistry, The American College of Prosthodontist et al., 2003).

[113] Van Steenberghe, D and Naert I (2000, 1998). The first two-stage dental implant system and its clinical application. Periodontal Journal; June; 17:89-95; Loma Linda University School of Dentistry, The American College of Prosthodontist et al. (2003)

[114] The toothless area in which the implant will be inserted.

or maxilla regions). Since bone loss limits the ability to successfully place dental implants, without grafting the implants may have to be placed in anatomically unfavourable angulated positions that can lead to aesthetic dissatisfaction, mechanical overload and possible implant failure.

The patient can receive the extra bone from the following four grafting-material sources: autogenous, allogenic, xenogenic and alloplastic materials. Autogenous material is harvested from the patient's own body. Allogenic grafts are harvested from cadavers. Xenogenic grafts are harvested from animals, and alloplastic grafts are synthetic materials. The Surgeon did not mention that he used the latter two sources. In terms of osseointegration capabilities, the autogenous bone is considered to have the highest success rate.[115] This procedure is more time consuming and increases risk to the patient.

Additionally, the closer an autogenous bone-harvesting site is to the implant site, the less surgical and anesthesia time is required, which translates into decreased costs, reduced morbidity and no visible external scarring for the patient (Misch & Dietsh, 2009). Preferred donor sites include areas within the patient's lower and upper jaw that can be accessed from the oral cavity. Second-choice donor sites are the rib areas. The patients of this case study experience both the harvesting of autogenous material from their own body and the use of allogenic grafts from cadavers. The process is as follows.

Once the Surgeon exposes the patient's defective site, the surgeon will prepare the donor area. The patient will experience an osteotomy cut, that is, the dividing of the donor bone area and lifting out the pieces to be used in the defective area. To do so, the dental surgeon will utilize a *sinus-lifting instrument* and *fissure burs* to cut the bone and scrape the tissue using *chisels and other instruments from the dental tray.* During the autogenous bone-harvesting procedure, the patient's bone debris will be collected utilizing a *vacuum and filter,* and stored in containers – *mosquitoes*. The harvested graft is then positioned in the recipient area, covered with *Colla Plug* (an allograft tissue repair membrane material) and secured with *titanium screws*. The donor area is closed with *sutures,* utilizing equipment such as *Chromic-Gut Vicry suturing material,*[116] *needle drivers, dean scissors.* Other tools used during the surgical procedures are:

[115] Loma Linda University School of Dentistry, The American College of Prosthodontist et al. (2003).
[116] This is an absorbable threading material composed of purified connective tissue (mostly collagen) derived from the serosal layer of beef (bovine) or the submucosal fibrous layer of sheep (ovine) intestines (//.egeneralmedical.com/cepj416h.html).

needle drivers, dean scissors, periosteal elevators, curettes, suction tips, Potts elevators, bone rongeurs and the *Minnesota and Sweetheart retractors.*

In addition to the autogenous grafting process, the patient will experience the Surgeon adding bone volume to the recipient site utilizing allografting material. The Surgeon utilizes the *Puros Allograft cadaver bone,* and although the product is advertised as replacing the need for autogenous bone harvesting,[117] the Surgeon utilizes both techniques to increase the primary stability of the subsequently inserted implant. The grafting procedures used depend on the patient's severity of bone atrophy and bone damage during tooth extraction. The allograft material can be purchased in block form, to be administered as specified in the previously described autogenous application, and in a syringe form, which can be injected to fill the defect cavity with grafting material before the implant is inserted.

Once the surgical part of grafting is completed, the next step includes the preparation of the site to place the implant part, into the bone. The patient, still under anaesthetic, will experience a series of steps that result in preparing the osteotomy site (making the hole in the bone in which to place the implant).

For dentists less skilled than the Surgeon, the initial drilling steps would be guided by the surgical stent, which could have been prepared by a laboratory from the results of the diagnosis and treatment-planning stage. When placed over the patient's existing teeth, the surgical stent acts as a drilling template, guiding a dental surgeon to ensure that the implant is placed with no nerve encroachment, particularly to the mandibular (lower jaw). Use of a surgical stent reduces the risk of irreparable damage to the nerve that carries sensation from the lower lip and chin to the brain.[118]

Based on the Surgeon's skill and utilizing high level radiographic x-rays, the patient will experience the surgeon preparing the site utilizing *burs* and *bone files* to align ridges and progressively utilizing larger *drill bits* powered by a *drill* to enlarge the diameter of the upper part of the cavity (hole) enough to receive the cone-shaped implant socket. The Surgeon will use sequencing drill bits and guide pins from the Z*immer Drill Surgical Kit* to verify implant alignment and countersinking depth. The surgical kit

[117] This solves the problem of the limited amount of bone that can be taken from a donor site thereby saving operating room time and costs, reducing pain and possible morbidity (//.zimmerdental.com/rg_puOverView.asp).
[118] Nerve damage can result in a temporary or permanent numbness of the lip, chin or tongue and maybe accompanied by unconscious drooling. Additional, the use of the stent reduces the risk of damaging the neighbouring tooth that may result in the loss of the tooth during the site preparation to receive the implant.

identifies drills[119] to be used for each implant diameter, and the kit is arranged so the instruments and tools are used in a sequential manner in a logical, colour-coded order from left to right. The colour code arranges the tools and instruments by soft or dense bone protocols. During this entire process, care is taken to reduce bone damage by minimizing heat production. The Surgeon utilizes a Nobel Biocare dental *self-irrigating drill* to cool the drilling surface. As previously mentioned, Zimmer tools can be powered by competitors' process equipment.

For the remaining steps, the Surgeon will dispense the *Zimmer HA coated implant* in a manner that does not disrupt the HA coating. He will hand-thread the implant into the prepared site. The implant at this stage has a top assembly in which the Surgeon attaches a *hand piece* to 'drop' (place) the implant farther down into the bone. He then removes the hand piece and attaches a *hand-racket* to further drop the implant. These instruments are all gauged for specific patient bone conditions to ensure that the final implant is dropped to an exact measurement. The final steps include the hand removal of the insertion assembly attached to the upper part of the implant-socket and the placing or threading of the *healing cap screws* into the empty socket. Once the healing cap is placed, the patient will experience the Surgeon suturing the site opening with the healing screws exposed, utilizing the same tools that were used in suturing the donor site in this section.

The patient will now experience a two- to three-month healing period before returning to the referring dentist, placing the patient at the healing-for-loading stage (stage 5, Diagram 18-Section 3.2).

This concludes the case. For artifacts, see Appendix C.

8.6 The observed case applications of throughput

Transforming high fixed costs into *low unit costs*, during the dental implant implementation process/technique (as in the cases), is the result of the dentists' post-graduate education and the accumulated, learning by doing as of the result of scaling the technique to increase reliability and efficiencies within constraints of the technology and the market.

[119] The dental literature refers to drills but really they are drill bits and need to be powered by some type of process machine.

The learning associated with scale economies, has these characteristics.

Partial increasing returns to scale – arise from:

a) Decreased cost of one factor or the other - (dentist labour) or (material-capital cost), generally by increasing quality by decreasing uncertainty associated with the factors.

b) Changes that increase capacity utilization, which is the volume during a set period of time, by increasing throughput speed, i.e. reduced failure rates.

c) Decreasing cost in process gives the impression of decreased cost of final product and can be thought of as penetration into new markets and areas of application.

8.6.1 Achieving quality, for reliable routines

Part of quality control is to reduce the functional uncertainty of the dental implant technology.

Case one/Oral and Maxillofacial Surgeon, retains high throughput in a number of ways:

a) **By treatment of osteoporosis.** For the Surgeon, the disease of osteoporosis affects the reliability, thus treatment reduces return visit and material costs.

b) **By the use of high-cost, high-tech capital equipment to expedite assessment of the physiological oral structure to allow for accurate surgical intervention.** Since surgeons are trained to work on the most serious clinical cases, advanced digital 3-D imaging tomography is used to assess the degree of surgical manipulation required before and during implant placement. This equipment is purchased, irrespective of whether insurance will cover their cost.

c) **In house technology.** The high priced equipment assessment tools, circumventing external laboratory costs for diagnostic services (Section 8.4.1) and sterilization services (Section 8.1).

d) **By bone regeneration techniques.** The Oral Surgeon's expertise removes most of the limitations on surgically placing the implant. However, as pointed out by the Prosthodontist, better bone-regeneration techniques would allow more kinds of dentists, to do more, more quickly.

e) **By using one implant brand and design.** Generally dentists use multiple implant designs to accommodate the different natural bone conditions of patients. However, the Oral Surgeon's higher level of training and skill allows him to work on more difficult conditions and use only one implant design. This standardization process eliminates the need for multiple-component kits and lessens the learning that is required to use them. The brand utilized may also be used with interchangeable equipment, reducing capital costs.

f) **Advanced skill, reduces operational time.** This reduces the need for extra techniques and products (Section 8.4.1), fewer steps decrease risk to the patient and lower cost to the surgeon. The reduced steps can increase risk to the referring clinical firm, during the fabrication process (Step 6, Diagram 18- Section 8.2).

g) **Advanced implant surface coatings to reduce implant failure**. The use of these coatings, decreases potential return visits and higher maintenance and therefore, reduces material capital costs (Section 8.4.2). The use of implant surface coatings increases the speed of healing, reducing the overall implant procedure time. The latter benefit also accrues to the referring clinical firm, as it increases the patient turn over rate.

h) **Relies on advanced bone/tissue regeneration to innovate techniques**. For expediency, this surgeon relies on industry to keep current on the latest scientific advancements in bone regeneration that may affect the current routines.

The Oral and Maxillofacial Surgeon relies solely on referrals for patients through the division of labour, referral system. The knowledge specialty and high capital cost equipment, circumvents almost all complex physiology oral structures that can decrease the quality of dental implants. This surgeon bypasses, the dental-care financing system (Section 8.3.1) that slows down the process and adds extra steps. He simplifies the complexity of dental implants, thus reducing uncertainty, by using high-level radiographic x-ray equipment and the application of bone regeneration techniques.

8.6.2 Bottlenecks to higher use of dental implant technology

The height and width of available bone is important to long-term dental implant stability as longer implants are more stable.[120] The surgeon's skill overcomes the shortcoming of the current implant design.

The rate of use by other dental specialties, would expand, if they were able to place in less than ideal bone conditions, without the extra steps of bone regeneration techniques that not all specialties are qualified to do. If they are qualified, they are limited to the extent to which their specialty can qualify.

The two current limitations are: a) The length of implant that is required for stability, and b) the natural biological limitation, in the way bone grows. What is required for ease of placement[121] is an implant of four millimetres that is as stable as the sixteen millimetre[122] and/or to be able to place the implant in a mushy bone condition and a way to get the bone to growth around the implant, very tight. The message to scientists, "all implants "integrate or osseointegrate" effectively to the titanium surface, so what is required is a totally new twist on the osseo topic" (Interviewee 21). The current effective, bone regeneration techniques, to increase the bone width and depth, are autogenic grafts[123] and allogenic (cadaver) grafts, with the former the most painful and risky to the patient (Interviewee 10), and thus, the need of a Surgeon's level of skill and knowledge.

8.6.3 External knowledge contacts and motivations for use

a) To meet continuing dental education (CDE) certification qualifications. Attendance of conferences at graduating school, sponsored by dental society of specialty i.e. University of San Francisco (UCSF) School of Dentistry, for their annual meeting and conference, and the annual meeting and conference of the American Association of Oral and Maxillofacial Surgeons (AAOMS). Both of these events offer CDE by continuing education certified providers through CDE CERP courses that are certified by the Alberta dental regulating and

[120] The current dental plant length is from eight to sixteen millimetres in length.
[121] Ease of placement implies an implant placement within any bone length/width condition.
[122] Interviewee 2 and 22.
[123] Grafting from bone parts of your own body.

licensing body, ADAC.[124] All *CERP-certified* courses qualify for the CDE credits required to practice in Alberta and across Canada, and it is rare for a Canadian provincial dental-regulating body to not accept them (Interviewee 24, supported by Interviewee 2 – Director of Continuing Dental Education, UofA).

b) Conference lectures provided by experts in field, for introduction to new science-based technological tools relating to dental specialty. Tools purchase involves products, officially certified by dental specialty society - AAOMS-certified manufacturer of products that partners with dental schools.

c) Contact to basic science. Implant producer firm direct-market to surgeon, and the surgeon expects them to impart, what is new in, the tissue-repair and regeneration field, which could impact processes in practice.

d) Conference location, motivated by top people in the field of oral surgery, and warm climate for family to holiday.

Case three summary

The Oral Surgeon of this case does not rely on outside services for diagnostic, laboratory and sterilization services. High levels of throughput are used to cover the high capital and labour costs by increasing quality of technique, to reduce the uncertainty of implant technology, through the use of bone regeneration techniques.

Chapter five demonstrated how similarities were found among the cases with final observations in Ch. 9.

[124] The courses are approved for CDE credit on an hour-for-hour basis by the ADA's CERP programme.

CHAPTER NINE
OBSERVATIONS and CONCLUSIONS

9.1 Introduction

This thesis improves our understanding of innovation by observing the difficulties of post-adoption innovation of dental implant technology, in institutionalized markets. The thesis explores dental care, a sub-sector often characterized by non-market forms of co-ordination. The thesis highlights the role that institutions play in planning, coordinating and controlling the throughput requirement of the dental care delivery service. As a result, the researcher observes a particular style of technological advances that mediate the influence of market demand.

The research applies the value of the Chandler's (1977, 1990) emphasis on through-put to the dental-care sector, which is linked to Johnson's (2010) institutional learning model to understand some of the constraints on the diffusion of dental implant techniques.

The dental implant technology has been commercially available for almost three decades and still not fully diffused, so the outcome of this research will assist in showing how new technology diffuses and how post adoption risks should be taken into consideration.

The dental industry has a unique structure and characteristics. In Canada, it emerged from a non-market construct of the late 1800s in which society allocated certain functions (educational accreditation, admission criteria, quality of practice, ethics, fees) associated with highly educated professionals, to self-governing dental practitioners and their collectives, who in turn made various arrangements with educators, suppliers and institutions (Diagram 11-Ch. 4).

The **main research question** is, "**How do institutions affect demand for dental technologies?**" as a more general interest in the influence of institutions on innovation.

The sub-questions help to understand how new technology diffuses through the dental care system of innovation.

1. **How does the need for high throughput influence innovation in a dental technique?**
2. **How do institutions and institutionalized activities influence the innovation in the particular technique being explored**?

9.2 Institutional and Throughput Considerations

Dentists operate largely as independent or small group practitioners in a non-market business model and rely on external institutions, third party organizations and cooperative activities for information, financial management, access to specialized skills, technology and strategic direction (Diagram 14-Section 5.1). **Yet they remain entrepreneurs providing the production function, and are the key interface with the customer. Throughput is the primary source of economic advantage for a dental practitioner. As highly educated professionals, they are one of the high unit cost elements in service delivery and also have the power to make decisions about adopting new technology.**

Dentists instinctively apply *throughpu**t,*** profitability based on speed, to the processes they use to repair diseased teeth. The two mechanisms for increasing throughput are economies of scale and economies of scope. In a dental-care firm, when dentists want to work at higher speed, they seek to simplify their routines, consume less material and energy and manage a higher volume of patients within a set period of work-time per day.

Dentist-owners of clinical dental firms are the gatekeepers of the practical technological knowledge. The CDA and ADAC (dental regulatory associations), and the dental health-care financial managers (insurers) expect clinical dentists to adopt new technology. Clinical dentists are free to modify demand for new technology as long as they operate within Canadian dental regulatory provisions.

Dental-care service firms do adopt new technology to innovate their techniques, in ways that illustrate learning to achieve economies of scale or scope, **supporting the findings of Gelijns and Rosenberg (1994), that physician-users increase demand.** In most cases, dental-care service firms, adopt technology and products developed for particular techniques. Thus producer and supplier firms have adopted a technology-push innovation model. Producer firms recognize dental implant technology diffuses among dental specialties, **suggesting that Gelijns & Rosenberg's idea, of adjusting**

the specialist/generalist mix to reduce costs to the American health care system may, open up avenues to technical change, that may in the long run, result in cost increases.

Technique and knowledge tend to become associated with sectors Malerba (2005), and with occupations and professions (Nelson 1967, 2005; Nelson and Winter, 1977; Dosi, 1982; Rosenberg, 1982). Professional knowledge is thought of as highly standardized, scientific and systemic (Schön, 1991). **Dentists with less depth of skill appear to provide more technological opportunities for producer firms. This aligns with Gelijns & Rosenberg (1994) observation that "medical generalists" use less high technology than specialists.**

In Canada, businesses and government, as employers, mainly support prepaid dental plans, at little or no charge to their employees. Life- and health-insurance firms manage the plans and limit usage through waiting time and preauthorized procedures. The insurance firms reimburse the dentist a set number of units (15 minutes = 1 unit) per year per procedure. The technology cost, material, labour, and other operating costs are all included in the procedure code. Interviewees describe – regular disagreements between the clinical dental firms, and the insurer, about what is best for the patient.

The constraints of the "market-based fee schedule" could lead to price setting among dentists. More so, **it leads firms to adopt a business model in which innovation relates to high throughput.** A dental clinical practice, that uses high capital cost equipment and labour, and is highly leveraged, depends on innovation. "Throughput" or "speed per procedure" becomes important. Throughput and profitability are important factors for both the insurers and the dental-service firms. Although the main driver is reduced cost, it overlooks the fact that lower cost associated with longevity can potentially be more profitable, if long term economies of scale arising from more reliable technology are considered.

Throughout this research, dentists referred to the time-consuming nature of dental-implant work, and how it takes continuous practice to get high-quality results. Because of the hand-intensive work and the cumulative nature of learning, dentists have to make decisions between the heavy work-load of sustaining particular techniques and throughput (Ch 4). ***This suggests that, if the service mix of a specialist is too***

diverse, quality could suffer. Division of labour is an approach for providing high-quality dental service, decreasing learning by doing.

The operating distortions identified in dental care are:

a) The requirement for cumulative learning,
b) Uncertainty of insurance acceptance,
c) Insurance focus on keeping costs down,
d) The timeline for return on investments in new medical operational technologies, and
e) Limitations associated with insurance approved procedures leading to increased return visits.

9.3 The case observations

The study set out to explore the process of innovation in dentistry by understanding perceived constraints on the diffusion of dental implant technology. A pilot study was used to understand the functional and utilization claims associated with dental implant technology and clarify if dental implant innovation would be an interesting research area. This pilot work highlighted the problematic diffusion of the technology.

Chapter 3 explores the research methodologies and the use and weaknesses of using semi-structured interviews in a case study approach. It highlights how preliminary research was based on exploratory, semi-structured, interviews supplemented by a review of academic and professional literature, while the second phase involved engaging with 39 individuals in the dental-care sector.

A multi-case study of dentist practitioners was undertaken to follow the progress of knowledge at the technology (dental implant) level. The functional relationships between the process and the dentists, provided opportunities to observe, how the dental-care firms apply throughput, to transform technology into existing techniques, utilized in dental clinical care.

To increase the reliability of routines and to reduce the uncertainties associated with implant failure and other technologies, while sustaining the rated capacity (time in chair), the case observations, identified possible quality improvements including:

a) Specialized diagnostic equipment, instruments,

b) Compatible processing equipment,
c) Technologies relating to implant success,
d) Reducing maintenance and return visits,
e) Decreasing learning-by-doing time, and/or
f) Expanding the scope of practice.

***Dental-care service firms are all conditioned by the same learning conditions*.** They are:

a) Their specialization societies, including education acquired in graduate school,
b) The required scale of throughput, and
c) Market distortions, caused by the dental-care financing system.

Therefore it is reasonable to conclude, that in the cases of this research, all their learning is related to the economic logic of the firm. It is an institutionalized profession, as illustrated (Table 7, Ch. 5) by the following major institutional components:

- Canadian Dental Association (CDA), regulating association
- Province Governance Associations (ADAC), regulating association
- Dental Society, facilitates the accreditation boards
- Study Clubs/University/Private School of Dentistry, and
- Insurance firms, act as a bank and adjudicate claims.

9.4 Case similarities and differences

Each case is unique to the dentist in the techniques that are executed. Each case is functionally linked to one complex process or technique. The techniques are based on the professionally controlled medical knowledge that is specific to the particular knowledge type of dentist and which sets the boundary on how dentists solve problems and limits the design trajectory of technical advance (Nelson & Winter, 1977; Rosenberg, 1982). **This alters the flow of innovation in unexpected ways**.

The Oral and Maxillofacial dental care service is a self-contained surgical firm that does not rely on outside services for diagnostic, laboratory and sterilization services (Ch. 8). This suggests **that high levels of throughput are used** to cover the high capital and labour costs, which in turn is achieved by simplifying the complexity of the dental implant through the application of bone regeneration techniques.

The Prosthodontic dental care service specializes in the restorative (custom or otherwise) work of implantology (Ch. 7). **Here the higher capital and labour costs are recovered by high throughput** achieved by simplifying the complexity of dental implant technology through in-house customization techniques that also have the benefit of providing higher-level aesthetics.

The General Dentist dental care service relies on executing high-quality routine procedures (Ch. 6). **Throughput is maintained by exploiting routines** that allow the selection of procedures that do not exhibit complicated physiological oral features that may decrease the reliability of the dental implant, increase maintenance and jeopardize throughput. This firm simplifies its procedures by referring complex clinical cases. The General Dentist has an acute awareness of self-skill limitations and relies on high-level diagnostic skills and machinery and the expertise of external laboratory technicians for assistance in diagnosis, if required.

The cases (Ch. 6, 7 and 8) observed a number of mechanisms associated with increasing returns from scale and throughput that are used by the three dental firms involved with dental implant technology. They are summarized in Table 9 (Ch. 5). ***The mechanisms focused on learning by doing are all associated with the production process itself and do not reflect marketing and distribution or other business processes to a significant degree.*** This would seem to relate to the non-market nature of the sub-sector in which costs beyond throughput improvements are mediated by non-market actors such as dental associations and insurance. ***Regularities in learning by doing are associated with division of labour through referral leading to specialization, reducing complexity through technology and increasing speed and or reliability through technology (all cases do this).***

A ***key difference*** is that the more highly skilled professional is more likely to rely on personal skill for throughput improvement and technology to reduce uncertainty of performance while ***the less specialized professional relies more heavily on technology to reduce complexity and skill and standardizes around a single reliable brand, an opposite response to that observed in Chapter 4*** (Gelijns & Rosenberg, 1994).

Learning by using is associated mainly with continuing education, a mandated and regulated requirement for continuing practice, and therefore a regularity.

Incidental benefits from CDE include learning about new technology and how it can be used.

Insurance imposes another external learning by using requirement on the dentists – how to work with the insurance industry – which is their primary financial connection with the market. Uncertainties in this aspect result in the three cases observed with each taking some steps to improve predictability by pre-screening patients or choosing lower cost materials that will be accepted by the insurer. ***There appears to be minimal customer influence on the technology except through a user-pay option*****.** ***All three cases enable that approach.***

Learning by searching is possible, and all three cases maintain some level of connection with the scientific community, but it is unclear that any of the firms employ a structured search process, perhaps a reflection of the non-market nature of dental care.

Collectively, these case studies suggest that throughput-time or speed per procedure provides a useful basis for understanding technological change, with all else kept equal. As mentioned before, throughput speed or speed per procedure are emphasized at university and reinforced by the financial reimbursement structure *per dentist-type* (University of Alberta Faculty of Medicine and Dentistry, 2007-08).

9.5 The institutionalization of dental care

Entities, associated with dental-care, **that influence communication and interaction patterns in dental-care service firms**, were identified from the cases and interviews Table 7 (Ch. 5). **The bolded entries are considered to influence dental-care service firms. Non-bolded entities interact predominantly with producer-firms.**

Each dentist in Canada must belong to two dental associations in order to practice. One must be a provincial jurisdiction, such as the Alberta Dental Association and College (ADAC), and the other is the national jurisdiction – Canadian Dental Association (CDA). The dentist knowledge specializations are protected by dental societies - associated with educational accreditation and with the ability to officially certify products, and dental regulating authorities - the associations, and disseminated by dental graduate, teaching schools. Canada, like the United States, has instituted mandatory continuing dental education (CDE) and professional or similar bodies sponsor certified CDE courses and conferences approved by ADAC. Study clubs are organized by interest or geographical location. They may be specific to a dentist-specialty, research topic, or equipment (i.e. concerns with computers in dentistry).

Producer firms sell directly to clinical dental firms who expect the producer firms, to impart what is new in tissue-repair and regeneration, related to the dental implant that could impact current practice techniques. Producer firms gain accreditation for their technology/product from schools of dentistry and dental societies. Some universities have exclusive agreements with only one type of implant brand, such as Nobel Biocare. Others, such as the dentistry department at the University of Alberta, work with a number of implant providers – Nobel Biocare, Straumann and Astra – and do not have deals of exclusivity.

Dental implant training does not qualify for CDE credit. Implant producer firms like Nobel Biocare, Straumann and Zimmer, use regionally located, private teaching, clinical care firms to train and promote their products to other clinical dental firms. The curriculum for these courses is built around the industry implant brands. Dental implant firms build (or offer donations to build) university clinical teaching operatories supplied with their technologies. Students, who become familiar with the brand-name implants during their education, can subsequently be hired by the dental-implant producer firms to deliver courses to train other clinical dentist-gatekeepers. To attract the practitioners, the implant producers build their own continuing-education sites and hire practicing dentists to provide leading-edge instruction.

The financial system modifies the direction of learning of clinical dental firms by conditioning what new knowledge the dental-care service firm can absorb. There is a continual potential for disagreement between the dentist's belief about what is best for the patient and what the insurer, based on their consultant, interprets as best for the patient.

Innovation in dental care is predominantly privately funded and profitability depends on implementing business practices that result in economies of scale, permitting the high throughput required of highly leveraged profession. A dentist's clinical practice generally involves the use of high capital cost equipment, accumulated years of expensive education and labour that builds on the economies of scale arising from reliable routines, interchangeable tools and instruments, and compatible processing equipment.

To understand the institutional and institutionalized effects on capacity utilization that drives dentists' to achieving throughput, a complex single process executed by dentists, needed to be observed to see the effects. In a non-market environment, where revenue is largely controlled by insurers by attributing specific time to a procedure, high throughput or speed, becomes the surrogate marker, to dentists and to the adoption of specialized machinery and associated instruments. ***It is apparent from the adaptation of the Chandler approach to the dental sector that these distortions result from separation of business functions such as finance from the production function associated with service delivery.***

9.6 Research observations and conclusions

Theory for evaluating the application and diffusion of a new technology in the dental-care industry should provide a framework for overall analysis; identify knowledge sources and configurations and how they evolve; and link to the business and institutional reality of dentistry.

Institutional theory informs, institutions do not, promote technical progress, they provide the stability necessary for it. Individuals in this environment act in a collective, be it a firm, profession, or a network of firms. The operating principles of the institutional theory are to recognize regularities that influence firms to innovate; establish, break-up and reestablish out-of-firm relationships; and to institute learning by forgetting.

The thesis observed that using the level of analysis at the national level, to understand regularities at the microeconomic level, has weaknesses. This research has illustrated, that trajectories to technical change in dentistry, have sub-sector, process level effects that vary with professional specialization within the same sector, to which learning is mediated by the need for high throughput, supporting a modified Chandler (1977, 1990) throughput framework, supported by (Nightingale, 2000; Lazonick, 2005).

The researcher has adapted the Chandler model to the dental-care sector and linked it to Johnson's learning and institutional models to understand the constraints to diffusion of the dental implant based on analysis of a technique.

The institutions and the institutionalization of the financial management of dentistry co-evolved, and still exist. The graduate schools, as recognized by industry (Ch. 4), teach the gatekeepers. The Associations reinforce the institutionalized non-market model.

In this environment, the organizational (division of labour) and throughput factors to achieve competitive advantage, through opportunities of new technologies, important in the Chandler framework, are functionally linked to institutional needs and to the institutionalized market and not to, the prevailing market and income elasticities, thus preventing a full understanding of the transformation effects of the new technology to practice. The institutionalized activities impose a particular style and limitation to technological advances, excluding responses to market demand.

9.7 Conclusions

In chapter four, the researcher hypothesized that particular institutional set ups, such as the financial managers that mediate the dental-care market, can obstruct the flow of information between users and supplier firms and hence constrain dental-care innovation.

This thesis has shown highly institutionalized nature of the dental-service care industry. It describes how financial and other institutions mediate the articulation of demand and the decision of dental-care firms as they seek to drive profitability from implants. ***The level of institutional mediation observed suggests our hypothesis related to economic efficiency in the dental service care sub-sector has been demonstrated.***

The main research question was "How do institutions affect demand for dental technologies?" In answering this question, the researcher focused on answering two sub-questions addressed below.

a) How does the need for high throughput influence innovation in a dental technique?

This research observes where revenue is largely controlled by attributing specific time for a procedure, high throughput or speed, becomes an important surrogate marker of profitability. ***The case studies confirm*** that the gatekeeper guiding the transformational technique is the dentist.

***The focus on throughput, helped to understand how new technology diffuses through the dental care system of innovation, and how institutions mediate pre and post-adoption constraints to innovation*.** From this work, *to utilize implant technology*, a dentist's clinical practice would be expected to use of high capital cost equipment and labour, that builds on the economies of scale arising from reliable routines, interchangeable tools and instruments, and compatible processing equipment or any other approach that may increase speed and throughput.

New technological procedures (options) have to be accepted by the dental society, dentists then have to implement and experiment out of their own pocket (hopefully by patient pay) and then try to make it a reimbursable procedure code (task) from insurance with sufficient allowable units of costs for technology, materials, labour, laboratory and other items. ***This creates a high degree of uncertainty and financial risk.***

Linkages should be more efficient*.* It is easier for dentists to go to industry for knowledge directly related to a process, than to advance their theoretical knowledge about medical conditions. ***Dentists identify their need for new science to assist with the transformation effect of their technique, not encouraged by the financing system****.* Throughput guides technological learning toward advances such as the need for smaller implant technology, superior performance or less expensive materials (Ch. 4). That's probably why scientific linkages from dental firms to science are relatively weak.

Supplier linkages with science are stronger because they maintain connections to identify future product potential, *supporting von Hippel (1976, 1988).* Medical innovation literature shows a very tight connection between firms sponsoring clinical studies, the clinicians (physician user) and academic scientists. The supply chain is interdependent, user and supplier are effectively one, removing all market independence of consumer and supplier and competitions, considered important to sustain incentive for innovation (Schumpeter, 1939; Nelson & Winter, 1977).

***Learning by using is associated mainly with continuing education*, *a mandated and regulated requirement for continuing practice, and therefore a regularity*.** Incidental benefits from CDE include learning about new technology and how it can be used.

Dentists do adopt and then innovate (transform) their technique. They are non-market firms with little incentive to prevent others from adopting their successful innovations. The three cases show specialities transform techniques in accordance with their specialities.

There is little opportunity to learn from the market or to keep innovations from others. Nelson & Winter (1977) observe this could affect the incentive for a competitor company to develop better technology. ***The firms do direct some of their learning to the present capabilities of suppliers*****,** considered important by von Tunzelmann (2009: 442) and Helfat, et al. (2007) and others (section 2.4.3) ***but are less shaped by the market*****,** as direct contract with the payers or financiers of the dental plan is obscured, ***supporting the hypothesis that financial managers obstruct flow of knowledge to the suppliers of new technology.***

There may still be benefits, because the lack of market competition leads the person who implements improvements to a technique, to share them. Study clubs identified in the study provide evidence that learning about improvements in techniques associated with implants is being widely shared.

Institutionalized structure of dental care and its focus on throughput limits the knowledge absorption by dentist, but in a different way than in medicine. Gelijns & Rosenberg (1994) work on technology adoption in medical care, found that technology was often adopted for reasons of prestige, a distortion to the market that enables science push. This occurs because the gatekeeper of innovation in medicine, the clinician, works in a publicly funded environment, disconnected from the cost of technology application. In dentistry, technology adoption is related more to throughput. Although dentistry still operates as a non-market, private firms prevail and adoption is constrained by return on investment considerations.

Dentists relate more to commodity logic, closer to a production model, but still somewhat disconnected from the real market – the insurance interface removes their connection to the economic fluctuations of a customer, leading to a form of market distortion. But they are still connected to the customer by virtue of the success or failure of the technique. If an implant loosens, it has failed. ***"Failure visibility" makes the dental implant very unique*** **–** thus it cannot be generalized to many medical and dental procedures where the reasons for failure are generally less apparent and obvious to the patient.

***The dental implant installation technique imposes a very heavy learning by doing workload on a practitioner to become good at a required speed*.** That is why the general dentist refers anything that is complex or where there is a risk of failure and the Prosthodontist refers the actual implant installation to the surgeon. Diagnostics tools become very important to recognize complexity and failure uncertainty at an early stage.

Post adoption risk considerations can change the direction of learning*.* Risks of utilization/translation and diffusion just begin with adoption. Technology and technique need to be continually refined. Dentists do that and provide feedback through their study clubs. However, the focus is on transforming technology through technique rather than iterating with science to advance technology. ***Dentists have a very stable adoption pattern, certain parameters must be met before dentists will look at new technology****.* They do so based on throughput but a demonstrated medical advance is also seen to be important. ***This is different than the clinician approach in medicine*** that can lead to a technology (i.e. a drug) being implemented before all of its side effects are fully understood.

b) How do institutions and institutionalized activities influence innovation in the particular dental technique being explored?

This research found institutions stable enough to trace knowledge and learning flows. **The** ***institutions direct the learning through specializations*** that have paradigmatic knowledge that guide the trajectories of learning (Nelson & Winter, 1977; Dosi, 1982; Rosenberg, 1982).

The research found a key difference with prior work of (Gelijns & Rosenberg, 1994: Ch. 4*)* in that the more highly skilled professional relies on personal skill for throughput improvement and technology to reduce uncertainty of performance while the generalist professional relies on technology to reduce complexity and skill and standardizes around a single reliable brand (Ch. 5, Table 9).

Insurance may be a proxy for what’s important for oral health Gelijns & Rosenberg (1994) even though, by practise guidelines, dentists have to present all options, including those requiring out of pocket payment. **G*elijns & Rosenberg (1994) found reimbursement rates are connected to physician induced demand – if reimbursed for a procedure, more will be used. In dentistry, reimbursement for a procedure is constrained by insurance acceptability*** and a Canadian study Grignon (2010) shows patients typically doesn't seek access to a procedure without insurance. This research showed in all three cases that dentists offer patients a user pay option in the event of insurance limitations.

There are more distortions than acceptable procedures and the billing formula*. *This study found the rules are not clear about what constitutes an "acceptable claim", and are also not applied consistently to similar claims. Arguments between what is best for a patient and what is allowed are a concern. ***The dentist doesn't typically connect to the ultimate financier of the procedure*** - the employee benefit plan that buys the insurance. ***Marketing and distribution are thus distorted.***

From the research, there is no obvious model in dental-care for financing innovation and transformation of technique in the form of public or other funding. The financing model of insurance reimbursement for services does not provide financial incentive for technological change.

9.8 Contributions to theory and method, limitations, generalizations, and future research

Contributions

This research is original in that it makes an empirical contribution to innovation studies, by introducing dentistry as an important sub-sector of medicine, to which patterns of innovation differ from medicine.

This research contributed to medical innovation knowledge, in that it, observed that General Doctors do not use less advanced technologies than Specialists (c.f. Geljins & Rosenberg, 1994), suggesting policy aimed at shifting the mixes maybe counterproductive to medicine efficiency.

This research supports the methodological approach of focusing on one medical procedure, rather than on all of medicine, to understanding the mechanisms of action that underlie technical change, supported by Gelijns & Rosenberg (1994).

Within that condition, this research supports the methodological approach that focuses on post-adoption constraints to understand mechanisms that enable innovation Rosenberg (1976, 1982), David (1986) and others Section 2.4.2.3 Iterative learning between technology and the market.

The constraint to innovation in Dentistry is the financial system as it changes the direction of innovation. It is linked to institutional needs and to the institutionalized market that excludes responses to market demand, distorting the business functions of marketing and distribution. This prevents a full understanding of the transformation effects of new technology to dental care practice. Insofar, the mechanisms of action important to innovation in dental care, identified in this research are: higher throughput, as in "increasing speed of treatment at a given level of reimbursement" and the importance of the latter to capacity utilization of dentist's time – decrease dentist's time at the chair per treatment). These interrelationships are important to increase quality in dental care services and to the adoption of new technology. In this context, continuous dental education is the key enabler of innovation in practice. That is my contribution to knowledge in innovation.

This research extended the Chandler (1990) "Economy of Scale" theory by adding field of dentistry.

Chandler developed theory for a semi-skilled production oriented manufacturing application. This research adapted the model to the highly skilled activities of professionals as part of the dental-care production function. A key insight taken from Chandler, is not the importance of scale, as in spreading fixed costs over large amounts of output by adding more dentist's chairs, but instead the importance of increasing speed of treatment at a given level of reimbursement and that is, the "capacity utilization" of the dentist's time, its influence on cost structures and how they can be improved by better coordination.

This research has advise for institutional/innovation system theory, which currently talks about supply of knowledge as means for trajectory change but does not take into account, at a disaggregated level, how institutions condition the knowledge firms can apply.

This research extended Granberg's (1997) innovation system data mapping technique, designed for industry, to map the work-process of highly skilled medical professionals. The key success of this mapping technique, and its success to this research, is that it was modified to collect data in real time - considered a contribution to this method.

Limitations

a) To make this research generalizable, more directly comparable data should be collected from others samples that could include, other regions in Canada and countries.
b) To make this research more generalizable, other complex dental procedures should be analyzed to see if the pressures on capacity utilization are as sharp.
c) Dentists are high paid professionals, and it maybe that there are other motivations that affect learning, that have not been brought out.

Generalizations

Generalizing is something that should be done with care until more comparative data are collected. Chapter one talks about how the implant technology is unique, as the learning by doing aspect, is particularly sharp. However, it is possible to generalize around the theoretical arguments of the thesis.

a) All cases support the modified Chandler (1977, 1990) application to understand how highly skilled professions, manage the throughput effect in their service firms.

b) All cases confirm learning is institutionalized. All cases confirm the application of Johnson's (2010) model assists in identifying institutionalized activities.

c) All cases support the "learning by doing" paradigm supported by innovation system theory (Arrow, 1962; Rosenberg, 1976, 1982; David, 1986). Medical innovation theory (Gelijns & Rosenberg, 1994; Nelson & Buterbaugh et al. 2011; Morlacchi & Nelson, 2011). Institutional theory (Johnson, 2010; Nelson and Winter, 1977).

d) All cases confirm the institutionalized effect of insurance, and how the insurance based financial model inhibits and/or molds innovation, as found in medical innovation Gelijns & Rosenberg (1994).

e) All cases support, adoption is the beginning of the innovation process, which is the theoretical underpinning of the innovation theory (Ch. 2), supported by Marx (1858), Rosenberg (1976, 1982), Pavitt (1984), Gelijns &Roserberg (1994) and in the medical literature supported by Nelson et al. (2011) and Morlacchi et al. (2011).

Opportunities for further research

a) More innovation theory work is needed in relation to post adoption risks and constraints, associated with transformation of technique. Innovation risks are not only found in the science (upstream) end of the linear model widely used for medical innovation, risks of transformation of technique begin with adoption.

b) Post adoption risk is an important consideration because it can change the direction of learning. From an innovation and economic policy consideration, it maybe that, transforming technology through technique is more important or equally as important to advance an economy, as iterating with science to advance technology. Such work could attempt to clarify the "do's and don'ts" of the innovation, if recognized by innovation and economic policy.

c) This research observed a very strong connection (casual) between continuing professional education and changes in practice, suggesting potential policy concerns that justifies further testing for two reasons: a) it is mostly large firms that provide that function in the dental industry, and smaller firms outsource this function. The fact that Canada's firm structure composition, is mostly small firms, this may be an important topic for innovation and industrial policy, and b) it could relate to efficiency issues in medical health care that could be taken up by health care policy. In relation to possible efficacy concerns, **throughput this research, dentists' that practice dental-care have shown dedicated concern for the oral health of their patients, or this research would have not been possible.**

d) Dentistry is one of many regulated professions. It would be valuable to apply the approach used to look at other professions to see if some or all of this research can be generalized to other professionals.

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Japan, Mexico and Canada. Japanese Market for Dental Implants and Final Abutments (2009), Mexico Market (2009), Canada (2009) sourced (iData Research, www.reportlinker.com).

APPENDICES

Appendix A. Research Report – Assess Functional and Utilization claims

Understand the efficacy criteria dental implant technology must meet to assist in securing effective utilization.

Implant technology - functionality:

A. Provides a stable foundation for building things on top.
B. Provides a foundation to retain the jaw bone – counter bone resorbtion.[125]
   Although this functionality also requires jaw bone retention, this option does not require the stability to building things on top.
      Primarily used for the elderly to counter bone antrophy.

Functionality (A) enables: Ultimately, the replacement of the entire dentition…to enable the process of tooth maintenance to physically mimic natural teeth (the making up of a set of teeth including their kind, number, and arrangement).
Why replacement of entire dentition:

1. To simplify the tooth repair process by replacing complicated procedures such as dentures, root canals, crowns, etc.
    a. Each procedure and multiple-step procedures increases risk to patient, for example:
        i. Infections
        ii. Poor fit causing pain
        iii. Longer appointments, multiple appointments
        iv. Installation error
    b. Each multiple-step procedure increases cost to paying customer (patient, corporation, insurance) through increased cost for the dentist in the form of material, infrastructure and labour costs.
    c. Masticatory[126] performance better with implant than dentures. A satisfactory rating of 8.4 to 6.7 with conventional complete dentures (Loma Linda University School of Dentistry, 2003: ref 5, Geertman, ME, 1999).
2. Resorption – reduction in bone with dentures. Bone antrophy still occurs with dentures.

Criteria for a stable foundation:

- stability (no mobility), or (no mobility for a determined term) based on mechanical strength of installation.

Factors that contribute to a stable foundation: The degree of osseo or bone integration with the tooth implant.
Factors that contribute to the efficacy of osseointegration.
1. Structural configuration of the implant.

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[125] Or resorption – reduce bone antrophy.
[126] Mastication – to reduce to a pulp by crushing or kneading.

2. Manner in which it is installed affects or determines the ability of implant to maintain its installed position.
    a. Choice of implant system
        i. Use titanium, as allergic reaction is rare.
    b. Installation
        i. Use of slow-speed drill to minimize heat production and subsequent damage to bone.
        ii. Vital structures such as nerves or sinuses must not encroach on the position of implants.
    c. Accuracy of assessing if medically healthy.
        i. If able to undergo minor surgery
        ii. Uncontrolled diabetes – 5% difference between with and without[127]
        iii. Smoker – affects L/T success - increases failure by 10%
        iv. Healthy gums
        v. Clenching and grinding at night (bruxism). Not all mentioned this one.
    d. Accuracy of assessing "appropriateness of bone". Upon natural tooth removal, bone height and width/thickness important.
        i. Bone condition is assessed with X-rays and study models of teeth and jaw bone. Generally computerized tomograms and software simulation are used in complicated situations.
            1. How much bone height and width/thickness required in 'mm' to achieve an average success rate with today's titanium implant?
            2. What % of bone in height and thickness increases probability of no mobility or min. success
                a. What is the variation with type of implant?[128]
                b. Is a 'no mobility' achievable with present day technologies? Appears NO.
    e. Proper implant placement
        i. Distribute load forces - excessive loading on a small section of the alveolar bone due to the inadequate distribution of load forces.[129]
        ii. Formation of biological width around implant more important for longevity of implants than osseointegration.[130]
    f. Proper construction of replacement teeth to maximise the functional forces of mastication.
    g. Post-operative care by patient
        i. Good oral hygiene - brushing, etc.

In summary, success of new implant technology should functionally improve the implants:

1. stability
2. reliability
3. strength
4. longevity

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[127] www.dentalgentlecare.com/implants.htm. Updated February 27, 2007.
[128] Passos, Linke, Larjava, French, Clin Oral Implants Res. 2014. doi:10.1111/clr.12504
[129] Screw implants for example exert six times the force of normal teeth on the alveolar bone generated by average vertical masticular loads. Over time due to increased pressure applied to the alveolar bone and surrounding areas may result in implant coming loose from the alveolar bone .
[130] Dental Oral Med 2006, V8(01), Poster 310

Success of new implant technology based on:

1. Availability
    a. based on ease of installation increases number of practitioners doing them.
        i. less finicky, less room for installation error
        ii. less training
            1. therefore more available and number of practitioners doing them increases.
2. Lower cost – likelihood of insurance acceptance higher.
3. Comparably successful to competing technologies.
4. Faster implementation
    a. reduces material & labour costs such as less anaesthetic or anesthesia.
5. Healthier person
    a. Physiological health
        i. Less room for assessment and installation error.
        ii. Resorption activities with dentures – jaw bone antrophy more problematic as we live longer
        iii. Endentulous (toothless) patients have speech and eating problems that will eventually manifest to both physiological and psychological health problems.
        iv. Denture instability and functional difficulties (poor mastication performance).
            1. Denture wearers ingested 1.2 x less fibre than with fully dentate, and less fruits and vegetables[131].
            2. High probability that aged denture wearers made significantly more chewing strokes than aged dentate subjects to reach swallowing threshold and particle size for the former group was significantly poorer[132].
    b. Psychological (Mental) health
        i. Less maintenance,
        ii. fewer visits
        iii. cosmetic value).
6. Reduces costs – lowers material, labour, infrastructure costs, etc.
7. Simplicity
    a. no healing phase required (immediate drop in),
    b. less pre-evaluation
    c. less room for installation error
8. More predicable success through implementation (healing) phase.
9. More predicable success through maintenance phase (life of the prosthesis)..less prone to attacks from bacteria and other problems.
10. Longer term prognosis – if procedure more reliable forecasting on probably course or action made easier, for example
        i. If procedure faster, reduces material/labour costs
        ii. If procedure more reliable, less return maintenance or warranty work required.
            1. highly dependent on whether the patient pays, dentist pays, or insurance pays.

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[131] Study group of 3794 with 36% indentulous and/or wore complete dentures. see Ref 28 Raymer, Novejack in section, Benefits of Implant Dentistry, [Loma Linda University School of Dentistry, 2003 #810].

[132] see Br J Nutr. 2007 Aug1:1-8, Mishellany-Dutor, Renaud, Peyron & Woda.

11. Generally, if procedure more robust
    a. not finicky, and
    b. able to take some abuse
        i. i.e. not susceptible to conditions such as:
            1. teeth clinchers who put high loads on implants.
            2. tissues resulting from slow healers because of dry mouth.

Scale performance measurements the new technology must functionally meet or exceed the average performance of the competing technology in terms of success. i.e. Higher/longer longevity than a crown with a root canal.[133] Even if costs are higher, over life span of insurance it will cost less.
Are there measures to indicate longevity of tooth implant?
Yes and they are the:

1. degree of growth of bone (osseo-integration of bone) required into present day titanium implants to achieve a "no mobility" status?
2. degree of probability of growth of 'soft tissue interface' with titanium implants thereby indicating when a failure in implant would occur.

Success of crowns:

1. Dependent on:
    a. Oral hygiene
    b. Skill
        i. Of dentist
        ii. Lab technician
    c. The material used
    d. Appropriate treatment planning and case selection.
2. Longevity
    a. Average lifespan 10 years. Insurance allows replacement usually after 5 years. Traditional PFM with occlusal porcelain 7% higher chance of failure per year than a full gold crown.
    b. Crown, false tooth paced on top, has to replaced every 10 to 15 years.[134]
    c. Average lifespan 7 to 10 years sourced from insurance actuarial report.[135]

Success of implants:

<u>Source 1</u>. Jan. 1993, 78 month study period. Updated 2007.
http://findarticles.com/p/articles/mi_m0815/is_n188_v20/ai_16395123
1993 Mayo Clinic study, 353 people, ages 8 to 82, 1778 implants, success 98% lower jaw, 89% upper jaw, using Branemark technique. Two step, screw or cylinder inserted by a Oral Surgeon or Periodontist. 3 to 6 months waiting period, bridge or artificial teeth inserted to post top by Prosthodontist or General Dentist with special training.
<u>Source 2.</u> Dr. G.A. Zarb and A. Schmitt, University of Toronto, 5 year study period, 105 dental implants of the posterior upper or lower jaw, where greatest pressure is exerted, average 94% success (International Journal of Prosthodontics, March/April 1993)

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[133] Interview, August 17, 2007, Dr. James Yacyshyn, BSc, DDS, MASc. Director Continuing Dental Education; Director New Technologies; Health Informatics Consultant, Department of Dentistry, University of Alberta.
[134] http://www.aboutcosmeticdentistry.com/procedures/dental_implants/pros_and_cons.html. Updated Sept. 17, 2007.
[135] williamkarpdds.com/dental-FAQ.htm#fag10. No updated date.

findings supported by
http://findarticles.com/p/articles/mi_m0815/is_n188_v20/ai_16395123, updated 2007.
Source 3. Generally agreed by experts implants last 10 years. www. web.singnet.com.sg/~gowso ms//Dentalimplant.html. Updated 2010.
Source 4. Single tooth implant study. 1- 5 –10 year study period. 294 patients received therapy from 1988-1992. 218 patients were recalled with 1057 implants examined. Significant relationship between implant loss and periodontal bone loss of the remaining teeth at implant placement. Maxillary, as apposed to mandibulary implants showed more implant loss if implants were placed in jaw. 5 year survival rate 97 and 94% respectively for the 2 and 1 stage implants. 10 year survival at 97% for 2 stage implant and 78% for one stage implant (Lindahl and Renvert, Clin Periodontol 2006; 33:283-289; Baelum and Ellegarrd, Periodontol 2004:75:1404-1412; www.dentalgentlecare.com/implants.htm updated February 27, 2007).
Source 5. Ten year study of 4591 Strauman Implants, placed in 2060 patients between 1999 and 2012. Multivariate survival analysis – patients evaluated after 2-3 months, 1, 3, 5 and 7 and in some cases 10 years. Cumulative survival rates at 3, 5, 7 years were 99.3%, 99%, and 98.4% respectively. Patient level rates varied based on implant location, length and design, timing of implantation, bone grafting procedures and gender. Tissue and bone level implants had higher survival rates than tapered effect implants. Short implants did well in mandibular posterior sites, less well in maxillary posterior sites (French, Larjava, Ofec, 2014).

Appendix B. The formation of provincial dental associations (1867-1906)

To describe the formation of provincial dental associations and acts between 1867 and 1906, the researcher drew on (Dyck and Sperber, 2007; CDA's, A Century of Service (II-1-II) – contributing authors (Maclean, 1987; Gullett, 1971; Shosenberg, 1992; Sykora, 1991).

With one exception, each province initially established a Dental Association that took on the task of creating a bill to seek formal legislation. It did that by creating a formal act respecting dentistry and then seeking legislation to pass the bill to become a law.

Provincial Associations & Acts	**Organizing Dentist and generally the first president of the established associations**	**Explanations**
Ontario Dental Association (1867), Royal College of Dental Surgeons of Ontario (1868)	Dr. Banabus Day of Kingston, ON, received training by articling for six months.	While continuing to practice dentistry he studied at Queen's University and received a medical degree in 1862.
Dental Association of the Province of Quebec (1869)	Dr. George Beers indentured in 1856 and served Canada as an author, editor, sportsman, soldier and statesman. It is not clear how he became a specialist.	He first proposed legislation in 1840. He is considered to be one of the most influential individuals in the profession as he took on the task of separating the unqualified from the qualified to define dental professionalism.
Manitoba Dental Association (1883)	Dr. Benson apprenticed in Ontario	He established the first dental practice in Manitoba.
College of Dental Surgeons of British Columbia (1886)	Dr. Thomas Joseph Jones received his dental education in ON.	The first act was created in 1886 which provided for an appointment of a Board by the Lieutenant-governor in Council and it was this act that created the new Act of the College of Dental Surgeons of British Columbia, 1908
New Brunswick Dental Society (1890)	Dr. C. A. Murray of Moncton.	The registration fee was no more than \$3.00 and no less than \$1.00 and practicing without registration was subject to a fine of \$20.00 per day.

Provincial Associations & Acts	**Organizing Dentist and generally the first president of the established associations**	**Explanations**
Nova Scotia Dental Association (1891)	Dr. Alfred Chipman Cogswell, of Halifax, indentured to a dentist in Portland, Maine and then attended the Philadelphia Dental College for one winter in 1869.	Candidates for licensure required 36 months of indentureship of a qualified preceptor or had studied for 36 months in a dental college.
Prince Edward Island Dental Association (1891) – this act did not name an association or society as a governing body	Dr. John S. Bagnall was the first person born on the island of PEI to practice dentistry with a dental degree.	In 1901, he formed an association with amendments in 1904, 1906 clarifying who could practice dentistry on the island and established an examination board.
Newfoundland Dental Association (1893)	Unknown who led the 1st dental legislation of 1893. It provided for a Dental Board of four physicians or laymen and three dentists. It lay inactive, until 1890, when Dr. Whitman Smith Goodwin became the 1st registered dentist to receive a license to practice.	Before the registration of Dr. Goodwin, dental work in Newfoundland was mainly done by itinerant or traveling dentists.
The North West Territories Council (1889). At that time, the Territories included the districts of Regina (Saskatchewan) and Alberta.	The North West Territories Council led the adoption of the Territorial Dental Ordinance for control of dentistry without consulting dentists.	Dr. Walter D. Cowan, an 1888 graduate of Baltimore College of Dentistry came to Regina and was instrumental in passing the Dentistry Ordinance legislation to seek amendments that resulted in the North West Dental Association (1897). The amendments gave the association power to issue registration certificates and govern the practice of dentistry. Authors that have contributed to the University of Alberta Archives have recorded this event in 1883 and not 1897.
North West Territories Dental	Two members of the Royal	Building on the initiatives of Shaw

Provincial Associations & Acts	**Organizing Dentist and generally the first president of the established associations**	**Explanations**
Association (1883) This act is considered a precursor to the Alberta Dental Association (1906). The founders paid tribute to their past involvement with the Canadian Mounted Police by incorporated its image of a bison head in the Alberta Dental Association logo, which remained the central feature until 2006.	Canadian Mounted Police (RCMP) who took on the role of providing dental services without formal training, are considered the founding members of the North West Territories Dental Association (1883). DRs' F. D. Shaw and William 'Tug' Wilson opened a civilian practice after retiring from the RCMP force (Maclean, 1987), (Dyck and Sperber, 2007).	and Wilson, dental practitioners in the Canadian west formed the North West Dental Association and led for the adoption of the Dentistry Ordinance legislation to make the Dental Association self governing. This was passed in 1897 and the association now had the authority to design its own standards and grant certification on its own terms, rather than relying on recruiting certified practitioners from Ontario or the United States (Dyck and Sperber, 2007):92-93).
The College of Dental Surgeons of Saskatchewan (1906)	Dr. Walter Cowan served as the first President and was also the first dentist to be elected to the House of Commons in Canada.	
Alberta Dental Association (1906). In 2001, ADA became the Alberta Dental Association & Colleges (ADAC)	Unclear who was the initiator. Dr. R. B Sullivan of Calgary was elected first President . Dr. A. E. Auger of Stettler as Vice President and Dr. O. F. Strong of Edmonton, Secretary-treasurer.	Sixteen dentists led this movement, as it was known in advance that the District of Alberta was to become an autonomous province of Canada.

Appendix C. Artifacts and industrial actors, case (Ch.8) Oral and Maxillofacial Surgeon

Artifact	Entity
Questionnaire	ADAC
Sterilizer	Amsco, USA
Anaesthetic, Utlracaine D-S (brand-HoeschstAG)	Sanoti-Aventis, Germany
Sweetheart retractor	Miltex, USA and Germany
Extracting forceps	Miltex
Root tip pick elevators	Miltex
Suction tips	Miltex
Curettes	Hu Friedy, USA
Minnesota retractor	Miltex
X-ray	KaVo, Germany
CT Scan	Gendex Co., USA
Zimmer HA coated DIT	Zimmer Dental Inc., USA
Gown, masks, hats, and gloves	Sinclair Dental, CDN distributor
Patient drapery	Sinclair Dental
Anaesthetic machine	Drager Co., Germany
Inhaler (process equipment)	Nobel Biocare, Switzerland, Mfg. US and Sweden
Sevoflurane	Buys direct from local pharmacy
Ultracaine D-S	Sanoti-Aventis (Germany) distributes exclusively through Hansamed Ltd. located in Canada.
Scalpel handle	Miltex
Scalpel blades	Bard-Parker, USA
Sinus lifting instrument	H and H Co., USA
Fissure burs	Brasseler, USA
Chisels and other instruments from the dental tray	H and H Co.
Vacuum and filter	H and H Co.
Mosquitoes	Miltex
Colla Plug	Integra Life Sciences Corp. (USA) distributed by Zimmer and Canada Microsurgical Inc.
Titanium screws	NDC, USA
Suturing equipment	Miltex
Chromic-Gut Vicry suturing material	Ethicon Co., UK
Needle drivers	Miltex

Artifact	**Entity**
Dean scissors	H and H Co.
Periosteal elevators	Miltex
Suction tips	Miltex
Potts elevators	Miltex
Bone rongeur	Miltex
Minnesota retractors	Miltex
Sweetheart retractors	Miltex
Puros Allograft cadaver bone	RTI Biologics, USA distributed by Zimmer
Burs	Brasseler, USA
Drill bits	Zimmer
Implant Drill Kit (Surgical Kit) (process equip)	Zimmer drill-bits work with Nobel Bio-Care Drill
Self-irrigating drill and syringes and suction	Nobel Biocare
Handpiece	Zimmer Dental Inc.
Hand-racket	Zimmer Dental Inc.
Healing cap screws	Zimmer Dental Inc.

Appendix D. Artifacts and industrial actors, case (Ch. 7) Prosthondontist

Artifacts	**Entity**
Questionnaire	ADAC
Masks	MEDICOM, USA
Gloves	HEDY, Calgary, Canada
Mirror	Miltex, USA and Germany
Explorers	Miltex
Probes	Miltex
Air Water syringe	Miltex
Power drills, syringes and suction to capture amalgam and mercury	?
Suction tips	Hu-Friedy, USA
Occlusion paper	GC America, USA (both Mfg and supplier)
Cotton and dressing pliers	Miltex
X-ray machine	Belmont, USA
Non digital film	Kodak, USA
Impression tray	Waterpik Technologies Co., USA and UK
Impression plates	Waterpik Technologies Co., USA and UK
Alginates	Package by Henry Shein, UK
Straumann Implant System – Restorative Kit	Bazil, Switzerland (Straumann Canada – ON, Canada)
Nobel Bio-Care Implant System – Restorative Kit	Gothenberg, Sweden (Nobel Biocare Canada Inc. – ON, Canada)
Astra Zeneca Implant System – Restorative Kit	UK, (Astra Zeneca Canada Inc., ON, Canada)
Impression post and screw guide	Straumann, Nobel Biocare, Astra
Implant impression kit	Straumann, Switzerland Mfg in USA, Switzerland, Sweden
Implant impression kit	Nobel Biocare, Switzerland Mfg in Sweden, USA
Implant impression kit	Astra Zeneca, UK
Impression material – PolySil SH1	SciCan GmbH, Germany – (packaging office SciCan, Toronto, ON
Vita Porcelain System	Zubler Geraetebau GmbH, Germany
SCS screwdriver	Straumann, Nobel Biocare, Astra
Dye stone	Dentsply, USA – Supplier is Dental-U Inc. Richmond, BC, Canada
Scalpels	Barb-Parker, USA

Artifacts	**Entity**
*Waxes	Renfert, USA (MFG and supplier)
*Waxing unit	AmannGirrbach AG, Germany
*Hot wax dipping pot	Renfert, USA
*Investment material	Dentsply, USA
*Burn-out oven	Jelenko, USA
*Gold	Kerr Co., USA
*Torch	Buy anywhere
*Porcelain Kit	Zubler, Germany
*Porcelain material	William Justi Ivoclar, Schann, Liechtenstein
*Porcelain baking oven	Zubler, Germany
*Measurement tool for crown making	Ivoclar Vivadent AG, Schann, Liechtenstein
Healing cap – Implant brand specific	Brand chosen by Oral Surgeon
Abutment – custom or brand specific	Straumann, Nobel Bio-Care, Astra
X-ray Machine	Ritler Sybron Corp., USA
Film	Kodak, USA
Cement material – Justic Silament	Williams Justi Ivoclar, Liechtenstein
Resin cement and instrument kit	3M ESPE, Germany (supplier warehouse in USA)
Bite adjusting instrument – handle	BDM Co., Germany
Articulating paper	HANEL Co., Germany
Hand drill	Midwest Dental, USA
Burs	Clive Craig Co., USA

Appendix E. Artifacts and industrial actors, case (Ch. 6) General Dentist

Artifacts	**Entity**
Insurance firms	106 Life and Health Insurers – 80% are CDN. Others mainly from UK, USA
Policy Institute	ADAC, Edmonton
Health questionnaire	ADAC
Masks	Ansell HeathCare, USA, Mfgs in 18 countries, not in Canada.
Gloves	Ansell
Mirror – Tarno brand	Hu-Friedy, USA
Explorers	Hu-Friedy, USA
Radiograph x-rays	Belmont, USA
Non-digital film	Kodak, USA
Film radiography processor	Air Techniques Co., USA
Impression plates	Premier, USA
Metal impression trays	Caulk Manufacturing, USA, Mfgs for Dentsply, USA (Dentsply supplier in Vaughn, ON)
Alginate – Kromopan Paste Glue	Lascod Co., USA
Laboratory	David Reynolds (953295 Alberta Ltd), Edmonton, AB
Study models	David Reynolds
Anaesthetic – Septanest	Novocol / Septodont Inc., USA, Mfg in USA, France, India and Canada – Novocol Pharmaceutical of Canada Inc., Cambridge, ON)
Anaesthetic – Scandonest Plain	Septodont Inc.
Extracting forceps	Hu-Freidy
Root tip pic elevators	Hu-Freidy
Pliers	Hu-Freidy
Dental tool tray	Hu-Freidy
Implant surgical kit – Anchor- Simpler	Simpler, Canada (Vancouver, BC)
Implant surgical kit – Nobel Biocare	Switzerland (domiciled), Sweden HO and Mfg in Sweden and USA
Implant surgical kit – Straumann	Switzerland Mfg in Switzerland, Sweden, USA
Surgical stent	Made in Laboratory – David Reynolds
Antimicrobial mouth rinse – Amoxicillin	Medicom, USA
Self irrigating drills	WandH, Austria
Healthco central air compressor to power	Air Systems International, USA, Mfg in USA

Artifacts	Entity
drills, syringes and suction, etc.	
Saline solution NaCI	Baxter Corp, UK
Healing collar	Straumann
Implant post	Straumann
Sutures	Ethicon Co., UK, supplier Sinclair Dental, CDN
Cyanoacrylate tissue glue – PeriAcryl	Glustitch Inc., CDN, Mfg in Delta, BC distributed by Citagenix, Quebec
Healing screw	Straumann
Implant scaler	Deppeler, Switzerland supplier by Citagenix
Implant impression tray	Straumann
Implant impression post	Straumann
Implant guide screw	Straumann
Impression material – 3M ESP	3M ESPE, Germany, supplier 3M ESPE USA
Impression material – PolySi	SciCan GmbH, Germany, packaged and distributed by SciCan, Toronto, ON.
Impression material – Regisi	Dentsply, USA supplier Dental-U Inc. Richmond, BC
Putty material – Super Hydrophili	BHT Hygiene, Germany, Division of Sci Can
Vita System Porcelain Kit	Zubler, Germany
Filtek Supreme composite resin	3M ESPE, Germany
Clearfil bond	Kuraray Medical Inc., Japan
Articulating paper handler	Miltex, USA and Germany
Articulating paper – Mynol	Becker-Parkin, USA
Handpieces	WandH
Handpieces	KaVo, Germany
Drills	WandH
Drills	KaVo
Air and distilled closed water syringe	DCI Equipment, USA, Mfg Division of Danaher, USA