A Review of Clinical Outcomes Associated With Dental Implant Treatment Performed by Residents in Advanced Training Programs at the University of Minnesota School of Dentistry

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Dedication

To family and friends and the joy we share

To colleagues hard at work

To the scholar's journey

To the peace and forgiveness our smiles can bring

Abstract

Purpose: The central focus of this retrospective chart review is the comparison of survival rates for dental implants placed by residents in Oral and Maxillofacial Surgery and Graduate Periodontics in coordination with restorative treatment provided by residents in Graduate Prosthodontics at the University of Minnesota School of Dentistry.

Materials and Methods: Records for 246 patients treated at the University of Minnesota School of Dentistry, Minneapolis, Minnesota between 1994 and 2008 met the inclusion criteria for this study. Potential records were initially identified using an existing database maintained by the school's Implant Program that contains dates, record numbers, implant types, and departmental affiliations of the restorative and surgical clinicians who planned the implant surgeries. A total of 968 patients with 2,591 implants in this database had a resident in Graduate Prosthodontics listed as the restorative clinician and a resident associated with either Oral and Maxillofacial Surgery or Graduate Periodontics listed as the surgical clinician. The 246 records in this review were selected based on the patient having a recorded visit to any department in the School of Dentistry within the last 12 months. Approval for this review was obtained through the Institutional Review Board. The principle investigator performed a manual review of the patient records and collected data relating to implant survival, grafting, restoration survival, and technical complications. Statistical analysis was performed by consultants from the Biostatistical Design and Analysis Center.

Results: A final total of 228 patients and 707 implants were available for analysis. The exclusion of 17 charts was based on final implant placement being performed by faculty or restorative work provided by faculty or dental students. A total of 39 failures were observed in 29 patients. The 5-year survival rate for all implants observed in this study was 95.3%, which includes failures due to implant fracture (0.99%). Oral and Maxillofacial Surgery residents treated 106 patients with 329 implants and a 5-year survival rate of 95.4%. Graduate Periodontics residents treated 134 patients with 378 implants and a 5-year survival rate of 96.9%. Survival rates for both departments were calculated without failures due to implant fracture. Accepting a threshold value for significance of $p<0.05$, Cox Proportional Hazards Regression demonstrated no significant difference in survival rates between the two departments as the p-values obtained were 0.59 when all failures were included and 0.4 when failures due to fracture were excluded.

Prosthetic utilization of the implants included single crowns (49.65%), fixed partial dental prostheses (23.76%), mandibular fixed complete dental prostheses (9.90%), maxillary removable complete dental prostheses with implant supported fixed bars (6.65%), mandibular removable complete dental prostheses with implant supported fixed bars (3.54%), two-implant retained mandibular removable complete dentures (1.42%), and other restoration designs (2.69%). Seventeen sites (2.40%) were not restored with implant support as planned.

The 5 year survival rates for single crowns (SC 83%) and fixed partial dental prostheses (FPD 89%) were obtained using life table analysis. The 5 year complication rates included luting cement fracture (SC 14%, FPD 47%), screw loosening (SC 12%, FPD 5%), screw fracture (SC 3%, FPD 2%), and porcelain fracture (SC 5%, FPD 1%). Complication and failure counts were provided for the remaining prosthetic types.

Conclusions: Within the limitations of this review, and in light of results found in similar studies, the 5 year survival rate of 95.3% for all dental implants placed by residents in Oral and Maxillofacial Surgery and Graduate Periodontics at the University of Minnesota School of Dentistry further demonstrates that satisfactory and predictable survival outcomes can be achieved by clinicians at this level of training. Statistical analysis revealed no significant differences in survival based only on the departmental affiliation of residents placing the implants. Residents in Graduate Prosthodontics provided the restorations for these implants; however, the 5 year survival and complication rates for the restorations were further removed from corresponding values established in the dental literature. This may have proceeded from the inclusion criteria for this review that selected charts having dental school visits within the last 12 months. The unexpected variances in the restoration survival and complication rates warrant further investigation and demonstrate the long term treatment information that must be communicated to patients as part of their planning and consent process. Implant survival rates alone do not adequately summarize clinical outcomes.

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Introduction

Residents in the Graduate Prosthodontics program at the University of Minnesota began treatment planning and restoring dental implants in the early 1990s. The surgical aspects of care were coordinated through partnerships with fellow residents training in either Oral and Maxillofacial Surgery or Graduate Periodontics. The patient referral process among restorative and surgical residents has mainly been haphazard recruitment based as much on working relationships as finding the first available person willing to take on a new case. Over time the number of implants placed and restored at the Dental School has increased. And while dental implant tooth replacement provides restorations with superior support and function, this treatment is costly both in terms of treatment time and finance. Implant born restorations offer, in many instances, a result that closely mimics the natural teeth they replace. Nevertheless, the metal components, biological interface, and mechanical dynamic of the restoration-implant complex present an array of potential problems. Providing information about anticipated outcomes based on the vulnerabilities unique to a patient's implant treatment is necessary for enabling him to elect a course of treatment properly aligned with his circumstances and long term expectations. Some studies are available in the dental literature that offer information about the survival rates for implants placed by clinicians in training, but no formal investigation has been made of the survival rates for implants placed at this institution. This study will establish the overall survival rate for implants placed and restored by residents in advanced training programs at the University of

Minnesota and will compare survival rates between the two departments delivering surgical services.

Literature Review

The history of modern dental implants began in 1952 when Per-Ingvar Branemark[1] serendipitously discovered that the microscope heads imbedded in the thighs of rabbits to observe their circulation were exceptionally difficult to remove. He found this was because the rabbits' bone had developed a tight adaptation to the titanium surface of these microscope heads. The establishment of the biocompatibility of titanium through direct observation of osseointegration[2,3] prompted scientists and clinicians to develop implant forms that could be used for replacement of missing teeth.[4] Several designs were used initially, each attempting to favorably distribute stress throughout the bone to implant interface.

A study of one successful design began in 1965 when Adell, Lekholm, Rockler, and Branemark[5] installed 2,768 screw-shaped implants over a fifteen year period using a surgical and prosthetic technique they asserted to be minimally invasive and predictable. The original guidelines for determining implant success were established in 1978 at the Harvard consensus conference where it was agreed that an implant survival rate of 75% after five years of functional service was acceptable[6]. However, it was not until a conference held in Toronto in 1982[7] that dental implants began to be regarded a reliable treatment option. It was at this conference that Branemark[8] presented the

results of his controlled clinical study where success rates were observed in the 90% range.

Shortly thereafter more stringent criteria for implant success were outlined by Tomas Albrektsson[9] and Dale Smith.[10] These criteria comprised clinical immobility, the absence of peri-implant radiolucency as observed on a radiograph, less than 0.2 mm annual vertical bone loss after the first year of service, no persistent pain or infection, and implant placement that allowed for natural and pleasing restoration of missing tooth structure. Smith also indicated that an 85% five year survival rate and 80% ten year survival rate should further qualify success for an implant system. Implant design and surface modifications were continually experimented with as manufacturers competed to produce implants with higher long term survival rates and in 1990, five year survival rates greater than 95% were reported with the use of hydroxylapatite-coated implants.[11]

During this same period Carl Misch[12] expanded upon the work of James[13] and developed an index for describing the quality of peri-implant health. Later, in 2007 at a consensus conference in Pisa, Italy[14], the James-Misch Health Scale was modified to describe four groups of clinically observed conditions. In the Pisa Implant Health Scale, implants classified in Group I are termed Success and are characterized by an absence of pain and mobility and less than 2 mm of bone loss measured from radiographs at the time of initial surgery. Groups II and III are subdivisions of implant survival. Group II, Satisfactory Survival, is characterized by the absence of pain and mobility, but

radiographic measurements of bone loss may be in the range of 2 to 4 mm. Group III, Compromised Survival, are also characterized by the absence of pain and mobility, but radiographic bone loss may exceed 4 mm. Implants in this group may have a history of exudate; however, greater than 50% of the implant body must still be within alveolar bone. Group IV, Failure, can be either absolute, as when an implant has been removed or exfoliated, or clinically diagnosed while still in the mouth. Clinical failures may show any of a constellation of conditions that warrant removal. These include pain on function, mobility, uncontrolled bone loss or exudate, and bone loss greater than 50% the length of the implant body. Unrestored implants left in place below the gingiva, known as sleepers, are also considered in this group.

Today, many dental implant manufacturers claim survival rates above 95%. These reports usually refer to absolute survival, meaning the continued presence or loss of an implant after placement. One study utilizing Astra Tech implants (Astra Tech, Mölndal, Sweden)[15] reported a 99.4% survival rate after an average of 37 months in function while another report[16] showed ten year survival rates of 99% for single tooth restorations using Bicon implants (Bicon Dental Implants, Boston, MA). Continual refinements in implant design as well as better informed surgical and prosthodontic protocols have contributed to the high survival rates enjoyed today. And with wider application of systems like the Pisa Implant Health Scale, the quality of implant survival can be further evaluated and improved upon. However, these anticipated survival rates may not be universally applicable as practitioner experience and other patient

specific factors must be accounted for when planning treatment and informing patients of risk with individual pertinence. Furthermore, the practice of appealing to published survival rates may become less appropriate as the application of electronic records and more uniform outcome monitoring will increase the availability of institution and even provider specific performance data.

As dental professionals must pass through a period of training to acquire the knowledge and skills needed to place implants with predictable success, investigations have been performed to illuminate whether discrepancies in experience manifest in clinical outcomes. Harold Preiskel[17] and Pepie Tsolka presented data in their retrospective study on the influence of experience on implant survival. This study was apparently the first to evaluate the effect of operator experience on implant survival. Their design involved two groups of practitioners using Brånemark implants (Nobelpharma AB, Göteburg, Sweden). Twenty-one patients (79 implants) were treated at a teaching institution by experienced Oral and Maxillofacial Surgeons who were learning how to place implants and another 32 patients (127 implants) treated by a group of private practice Periodontists and an Oral and Maxillofacial Surgeon, all having at least 2 years of experience placing implants. Restorative work was performed by an experienced Prosthodontist. The follow-up time was 30 months and the earliest treatment began in 1985. For implants placed by the inexperienced group, 4 implants failed before restoration (all in the mandible) and 5 failed after restoration (2 in the mandible, 3 in the maxilla). For implants placed by the

experienced group, 1 failed before restoration (maxilla) and 2 failed after (both in the maxilla). Some information was also provided describing the restorative prostheses used and common complications associated with them. Preiskel and Tsolka concluded that treatment outcomes were more favorable among patients treated by the experienced surgeons because there was a statistically significant difference in survival numbers for implants before loading between the 2 groups, but there was not a significant difference in survival numbers after prosthetic loading.

Another study in 1995 published the findings of Jeffrey Cummings[18] and Nancy Arbree where the prosthetic restorations provided by clinicians in training was the focus. Here, supervised senior dental students at Tufts University performed the restorative work for implants placed by a single, experienced surgeon. The 5 year follow-up period covered the years 1987 through 1991 and included data for 24 patients treated with 71 implants. The implant system used here (IMZ implants, Interpore International, Irvine, CA) contained a novel internal element which was purported to mimic the resiliency of the periodontal ligament. The restorations included overdentures and a mixture of fixed partial dental prostheses (FPDs), some supported solely by implants and others that combined both tooth and implant abutment support. The authors observed no implant failures, but found 2 overdenture fractures associated with IMZ clips. Counts were given for the number of technical complications occurring, which included denture retentive clip replacement (11 events) for overdentures and for FPDs: screw fracture (3 events), porcelain fracture (2 events), and breakdown of

the internal mobile elements of the IMZ implants (9 events). The authors point out that the faculty had to perform a significant portion of the treatment for more complicated FPDs. However, with simpler treatment plans, such as those utilizing implants for O-ring attachment overdentures or 2- to 4-unit FPDs supported by implants alone, the authors felt supervised predoctoral students could perform well and recommended the implementation of clinical implant dentistry in the dental school curriculum.

In a report published in 1997, Lambert[19] showed that a clinician's level of surgical experience could influence implant survival rates. Inexperienced surgeons, those who had experience placing fewer than 50 implants, had statistically significant higher failure rates. The number of failures, 5.9%, was greatest for the first nine implants placed by inexperienced surgeons, versus 2.4% for experienced surgeons. The author concluded that surgeon experience played a measurable role in survival outcomes.

Recent studies have continued to examine the survival rates of implants placed by clinicians in training. David Kohavi[20] published a post-entry chart review in 2004 of 303 implants and 93 patients treated at the Hebrew University Hadassah School of Dental Medicine in Jerusalem. Clinicians performing the surgical implant placements in this review included residents of varying experience levels from the departments of Oral and Maxillofacial Surgery, Periodontics, and Prosthodontics. The sole inclusion criteria was treatment with either Branemark (Nobel Biocare, Yorba Linda, CA) or Taper-Lock (Zimmer Dental, Carlsbad, CA) brand dental implants. The follow-up period ranged from

12 to 24 months. Twelve implants required removal during this time and were deemed failures, providing a cumulative survival rate of 96%. General information was provided about the nature of the restorations placed, such as whether the restoration was fixed or removable and whether it was to restore a completely or partially edentulous arch. The restorative providers were not identified and there was no explicit explanation of implant failure relative to the time of restoration nor to differences in survival rates achieved by the different departments involved in the implants' surgical placement. Many of the implants in this study were surgically placed by faculty-student teams, making it difficult to draw conclusions about the role of operator experience in determining implant survival; nevertheless, the authors felt that operator experience played only a minor role in implant survival.

In a similar retrospective review in 2006, Maico Melo, Hamid Shafie, and George Obeid[21] looked at the survival outcomes for 175 implants placed in 54 patients by Oral and Maxillofacial Surgery residents during their training at the Washington Hospital Center in Washington, D.C. Data was obtained through a chart review of patients treated between July 1, 2002 and June 30, 2004. Implants included in this study were followed over at least a 6 month period. Data for implant type, width, length, location, and resident level were entered into a database and statistical analyses were applied. No information about prosthetic restoration was included. Implant failure was defined as removal of the implant. The authors noted 22 failures, giving an overall survival rate of 91%. Infection was cited as the cause of failure for 20 of the implants. The remaining

two failed to integrate because of provisional denture irritation. First year residents placed 22 implants with a 96% survival rate, second year residents place 22 implants with a 91% survival rate, third year residents placed 27 implants with a 89% survival rate, and fourth year residents placed 104 implants with a 91% survival rate. There was no statistically significant difference between the level of resident experience and implant survival outcome, thus the authors' felt experience was not a significant contributor to implant survival. The authors did express concern over their inability to fully account for past experience of the residents prior to entering the oral surgery program as their program's applicants come from private practice, other general or surgical internships, in addition to matriculation directly from dental school. The authors also acknowledge that the follow-up period neglected any observation of the effect prosthetic loading and expressed interest in further investigating the relationship of case complexity to implant survival.

Also in 2006, Starr and Maksoud[22] submitted additional results which expanded upon their earlier retrospective study[23] which followed the survival rates of implants placed and restored by first year general dentistry residents. These implants were placed by residents under faculty supervision at the University of Florida College of Dentistry, Jacksonville Clinic. Data were collected from an administrative database on a total of 263 patients and 790 dental implants. A cumulative implant survival rate of 96.6% was observed with follow-up ranging from 6 months to 7 years. In this review the authors provide information on implant failure related to anatomic location of implant placement.

They also report some details regarding the different restorations used in conjunction with the implants but did not elaborate on the survival or complication rates or the restorations, nor did they explain the timing of implant failure in relation to prosthetic loading. The authors concluded that the high survival rate was a confirmation that surgical inexperience did not significantly affect survival outcomes.

In a 2008 article, Mats Kronstrom, Lisa McGrath, and Douglas Chaytor[24] reported results for 95 patients whose restorative work was planned for and restored by pre-doctoral dental students enrolled in an elective undergraduate implant program at Dalhousie University. The 166 implants included in the review were placed by both Oral and Maxillofacial Surgeons and Periodontists who were experienced in the surgical placement of implants. Data was obtained from from records of patients treated between 1994 and 2004. Branemark implants (Nobel Biocare, Yorba Linda, CA) and a 2 stage protocol were employed for all surgeries. An implant survival rate of 93% was observed; the failures comprised 4 implants lost before prosthetic loading and 6 lost after. Nine of the failures occurred in the mandible (6 in the posterior mandible, 3 in the anterior mandible) and 1 failure occurred in the anterior maxilla. Restorations included 7 fixed dental prostheses, 33 overdentures, and 64 single crowns. While the surgeons placing the implants were experienced, the authors point out that students had the primary responsibility for planning treatment, providing surgical guides, and performing the restorative work. The authors favored the idea that experience was not a significant factor in implant treatment

outcomes and felt the results of this review contributed to the rationale for a wider implementation of implant dentistry in the undergraduate dental curriculum.

Sebastiano Andreana[25] further supported the idea that inexperience did not adversely affect implant survival in his 2008 retrospective study of 133 randomly selected patient records. Treatment and follow-up dates ranged from 1997 to 2004 with an average 2.5 years of follow-up. This review considered 302 implants placed by post graduate students in Periodontology, Oral Surgery, and the AEGD program at the University at Buffalo School of Dental Medicine. Although the operators were inexperienced in implant surgery and the patients were medically complex (111 subjects were noted to have significant medical conditions) only 9 failures were reported, giving a survival rate of 97.5%. The classification of medical complexity in this study included a range of conditions such as allergies, depression, arthritis, joint replacement, and diabetes. Four of these failures were from sites augmented via bone grafting, four occurred in smokers (one of which was removed because of unrestorable stripping of the internal threads), and one in a previous smoker. The restorative plan and restorative provider were not identified. The author states that most implants considered were placed by residents with little or no prior experience but does not offer any additional quantifying information. No differentiation in the survival data was made between departments and no observations were made of the subsequent prosthetic restoration. The author felt these results provided yet

more evidence that lack of experience was not a detrimental factor to implant survival.

In 2009, Smith[26] and colleagues reported their results from a retrospective chart review covering a 6 year period. It included observations of 105 patients and 236 implants. The patients were treated by supervised residents in an Oral and Maxillofacial Surgery program at the Royal Dental Hospital in Melbourne, Australia. Failure was defined here as removal of the implant for any reason, but the study also included a separate category for intra-operative failures where primary stability could not be achieved and implant placement was aborted. A total of 15 failures were observed, but the 5 intraoperative failures were not included in the calculations for implant survival. Of the 10 failures considered for implant survival, 8 were removed within 6 weeks of insertion because of failure to integrate while the other 2 were removed beyond the 6 week mark because they were incorrectly positioned. One-year survival was 94% and five-year survival was 92.8%. Analysis of various patient health conditions, such as smoking status, diabetes, and bisphosphonate use, as well as anatomic location of implant placement revealed no significant effect on failure rates. It was found, however, that perioperative bone grafting increased the relative risk of implant failure to a level that was statistically significant. Prosthodontic residents and students in Implantology provided the restorative treatment and brief descriptions were given about the type of restorations the patients received but no technical complications were outlined. The results confirmed to the authors that trainee surgeons could achieve survival results comparable to those

reported in larger studies but they expressed interest in further differentiating biological and technical failures and investigating the effect that grafting at the time of implant placement has on survival.

In 2010 Ricardo Vidal[27] and his group presented their findings on the success of implants placed at the time of tooth extraction performed by residents in the department of Graduate Periodontics at the University of Louisville. Fifty-one patients were treated with a total of 62 implants. A 100% survival rate was reported after the 12-month observation visit. Vidal follows this up with a provision that at the time of placement implants were "excluded from the study if the operator could not achieve primary stability, as judged by a faculty mentor." No data was offered about the number of aborted attempts. An effort to stratify the "success" of each survival based on the Pisa Implant Health Scale categorized 42 of the implants as success and 20 as survival. Non-standardized periapical radiographs were used to measure the crestal bone level in relation to the implant collar and found a mean loss of 1.3 mm. Restoration types planned for the implants included crowns and overdentures. Dental students performed the restorative work for the implants and at the 12-month visit a patient satisfaction survey rating the appearance of the restoration was also obtained. A strong majority of patients (82%) rated their restoration's appearance as "excellent," while 16% rated the restoration as "very good," and 2% rated it as "good." The author's concluded that novice operators could obtain predictable implant survival and acceptable aesthetic results with the immediate placement technique.

Also in 2010 Mikael Bonde[28] and colleagues reported results for a final number of 45 consecutively treated patients whose implant surgeries and restorations were carried out by dental students under the supervision of experienced dentists and Oral and Maxillofacial Surgeons at the School of Dentistry, Aarhus University, Denmark. A two-stage protocol was used in the placement of the observed 49 Brånemark Mk. II implants (Nobel Biocare, Göteborg, Sweden). If grafting procedures were required they were performed by experienced surgeons. This retrospective study covered treatment provided from 1996-1999. Patients were recalled for exam and follow-up ranged from 7.5-12 years (mean 10 years). Three failures were recorded, all in the anterior maxilla and all before prosthetic loading, giving an implant survival of 94%. All restorations were single unit crowns. Three crowns required remake after at least 7 years of functional service. Other technical complications included 2 porcelain fractures not requiring crown replacement and 3 instances of abutment screw loosening. It should be noted that not all of the patient follow-up or maintenance occurred at the dental school. The author concluded that the 94% implant survival rate provided further justification for extending training in implant dentistry to pre-doctoral dental students as long as protocols for case screening and procedural supervision are in place. Table 1 summarizes these studies.

Table 1: Summary of Survival Studies with Clinicians in Training

Author	Study Type	Period	Providers	Patients	Implants	Fails	Survival
Kohavi 2004	Review of Records	12-24 month follow-up	Surgery: OMFS, PERIO, and PROSTH residents Restore: not identified	93	303	12	96.0%
Starr 2006	Review of Records	1998-2005	Surgery & Restore: General Practice Dentistry residents	263	790	27	96.6%
Melo 2006	Review of Records	2002-2004	Surgery: OMFS residents Restore: not identified	56	175	15	91.0%
Kronstrom 2008	Review of Records	1994-2004	Surgery: Faculty Restore: Dental students	95	166	10	93.0%
Andreana 2008	Review of Records	1997-2004	Surgery: OMFS, PERIO, AEGD residents Restore: not identified	133	302	9	97.5%
Smith 2009	Review of Records	2002-2007	Surgery: OMFS residents Restore: PROSTH, Implantology students	105	236	10	92.8%
Vidal 2010	Prospective Clinical	1 year	Surgery: PERIO residents Restore: Dental students	51	62	0	100.0%
Bonde 2010	Review of Records with clinical follow-up	10 year follow-up	Surgery & Restore: Supervised Dental students	45	49	3	94.0%

The number of studies seem now to favor the concept that supervised clinicians being trained in the surgical placement of implants can achieve predictable survival rates. This literature review also indicates implant dentistry is expanding to a wider range of clinicians who are being taught surgical techniques at earlier and earlier stages in their professional training. Starting

with experienced surgeons learning new implant related surgical techniques (Preiskel 1995), to graduate-level clinicians placing implants (Kohavi 2004), to the recent results Periodontal residents achieved with immediate placement techniques (Vidal 2010) and supervised dental students placing and restoring their own implants (Bonde 2010). Yet, one must interpret these results with caution as the follow-up time is limited in some of the studies and case complexity is not equal among them. Reporting of restorative treatment also varies in detail and for the most part is either generalized or completely lacking. Because long term treatment success with dental implants depends on survival after restorative loading, not to mention the survival of the implant borne restorations driving the treatment, more work investigating implant and restorative outcomes remains to be done. Particularly, data is lacking that accounts for prosthetic, aesthetic, and surgical outcomes that do not result in implant removal but nevertheless represent complications which reflect on clinician experience.

Information about prosthetic survival and complication rates planned for the implants placed by novice operators in the above studies is variable. In Preiskel's 1995 review, restoration type is described for both the experienced and inexperienced group of surgeons. Restorations included single crowns, multi-unit fixed dental prostheses, and overdentures with varying lengths of cantilever support. Restorations provided for implants placed by the less experienced operators were generally overdentures while more advanced restorations, such as longer span fixed prostheses and fixed telescopic

prostheses, were used to restore a greater number of the implants placed by the experienced operators. Complications observed during the 2 year period of prosthetic function included resin fracture, framework fracture, compromised aesthetics, redesign, inappropriate vertical dimension for various fixed dental prostheses, and bar fractures and clip maintenance issues associated with overdentures.

Kohavi (2004) classifies the nature of the restorations in his study, such as the type of retention, fixed or removable, and the extent of edentulism being restored. He states no complications were recorded but concedes that the 24-36 month follow-up period was too short for observing technical complications. Starr (2006) details the nature of the associated restorations in his study but no complications are given. Melo's (2006) work focused entirely on the pre-prosthetic period and alludes to case complexity by citing the average number of implants the first through fourth year Oral and Maxillofacial Surgery residents were placing. Andreana (2008) gives no explanation of the restorative plans behind the implant treatments in his study and Smith (2009) simply outlines the three prosthetic types found in his review: single crowns, fixed dental prostheses, and overdentures. Patient satisfaction results for the single crowns and overdentures are available in Vidal's (2010) paper.

Two of the more recent reports included prosthetic complications as part of their review. Bonde's (2010) research, limited to single crowns for implants placed and restored by dental students, offered a survival rate of 94% for the crowns. Technical complications here included 2 events of porcelain fracture

(4%) and 3 occurrences of abutment screw loosening (6%) for the 55 crowns. The most thorough coverage of prosthetic complications was found in Kronstrom's chart review of implant treatment planned for and restored by dental students. It describes 64 single tooth restorations, 33 overdentures, and 7 multi-unit fixed restorations. The majority of single crowns were screw retained (39 units) and the remainder were cement retained (25 units). None of the single unit crowns had a complication requiring re-fabrication. Relining was required for 24% of over-dentures. Fifty-two percent of over-denture clips required adjustment, 14 over-dentures (40%) required clip replacement, and 4 over-dentures (12%) required remake. Other prosthetic complications included 10 loose prosthetic screws (7%), 16 loose abutment screws (11%), and 3 abutment screw fractures (2%).

Because the restorative purpose drives implant treatment, it is important to consider the survival and complication rates associated with implant borne dental prostheses. Few studies were available covering this topic in the context of implant survival for clinicians in training so a wider array of articles were reviewed that presented survival data for restorations. Current survival and complication rates for dental prosthesis have been compiled in a number of review articles.

A literature review published in 2003 by Charles Goodacre[29] and friends presented a summary of complications reported in the literature from 1981 through 2003. Their review collected data from studies that reported implant survival along with a range of surgical, mechanical, aesthetic, and soft tissue

complications. Here, implant failures were placed into the context of their prosthetic restoration. The mean incidence of implant loss was 3% for implants associated with single crowns, 3% for mandibular fixed-detachable complete dentures, 4% for mandibular overdentures, 6% for multi-unit fixed dental prostheses, 10% for maxillary fixed-detachable complete dentures, and 19% failed in association with maxillary overdentures. These numbers indicate higher implant failure rates follow prosthetic cases of increased complexity. Timing of implant loss with relation to prosthetic loading was also disclosed. Approximately 40-50% of failed implants were lost after prosthesis placement, showing the need for longer term follow-up to fully appreciate implant survival. This finding included Tord Berglundh's[30] reported 2.5% of implants failure before prosthetic loading and another 2-3% failure after. Bjarni Pjetursson[31] bore this out in his 2004 review of implant supported fixed partial dental prostheses which showed that 49% of failed implants were lost before restoration and 51% were lost after. Technical complications in Goodacre's study included loss of overdenture retention (30%), porcelain veneer fracture of fixed dental prostheses (14%), abutment screw loosening (6%), abutment screw fracture (2%), and implant fracture (1%).

Michael Norton's 2006 records review of 54 consecutively treated patients with a total of 173 implants also included a report of prosthetic complications. All patients were treated by a single clinician in private practice with an average follow-up time of 3 years, covering the a period from 1997-2003. All implants considered were placed in the posterior maxilla or

mandible and were restored with single crowns. One failure occurred before prosthetic delivery, with no additional failures over the 7.5 year observation period, giving a survival rate of 99.4%. Prosthetic complications included crown decementation, 32 episodes (17.7%); porcelain fracture, 13 crowns (7.2%); and abutment screw loosening, 4 episodes (2.2%).

In 2007, Bjarni Pjetursson[32] and colleagues published a systematic review comparing the survival and complication rates of tooth supported versus implant supported fixed dental prostheses that included results from 85 studies. The authors noted that because there were no randomized controlled trials evaluating fixed dental prosthesis supported by either teeth or implants, prospective or retrospective cohort studies were included for their meta-analysis. Their inclusion criteria stipulated a mean follow-up time of 5 years and required examination of patients at a follow-up appointment. Studies based solely on patient records, questionnaires, and interviews were excluded. Data were collected for survival, biologic complications, and technical complications. The authors defined survival as the restoration remaining on its supporting abutment irrespective of the restoration's condition and success as the restoration remaining unchanged and free of all complications for the entire observation period. For implants the biologic complications ranged from soft tissue derangements, periimplantitis, bone loss greater than 2 mm, intrusion, and esthetic complications. Technical complications covered abutment screw loosening, screw fracture, loss of screw access hole covering, fracture of the luting cement (decementation), porcelain fracture, fracture of the implant, and

framework fractures. The authors found that most studies on conventional, tooth-supported FPDs were retrospective while studies on implant-supported FPDs and SCs were prospective. One acknowledged limitation of this review was that the treatment studies they reviewed were conducted in university or other institutional environments, thus the authors felt the conclusions might not apply to outcomes in a private practice environment. Nevertheless, these results provide a good reference for comparing the survival and complication rates observed in other university based reviews. Findings from Pjetursson et al's systematic review of cumulative 5-year complication rates pertinent to this review are summarized in Table 2.

Table 2: Summary of Pjetursson et al's Study

	SC	FPD
5 Year Survival (all materials)	94.5%	95.2%
5 Year Survival (metal-ceramic)	95.4%	96.7%
Implant Fracture	0.14%	0.5%
Abutment Screw Fracture	0.35%	1.5%
Abutment Screw Loosening	12.7%	5.6%
Luting Cement Fracture	5.5%	5.7%
Veneering Porcelain Fracture	4.5%	11.9%

A 2008 analysis led by Ronald Jung[33] and colleagues systematically selected and reviewed articles for the survival and complication rate of implant-supported single crowns. There were 26 studies selected with a follow-up

period of 5 years minimum. Their results showed a survival rate of 96.8% for the implants and 94.5% for the single unit crowns they supported. They noted a significant difference in the survival rates of metal-ceramic crowns (95.4%) and all-ceramic crowns (91.2%). Complications noted included implant fractures (0.14%), screw fracture (0.35%), porcelain fracture (4.5%), and screw loosening (12.7%). These results align with the 5 year cumulative survival and complication rates published by Pjetursson (2007) because Jung's review is a build out of Pjetursson's work.

While Pjetursson's 2007 and Jung's 2008 papers provide clinically relevant information for referencing the common technical complications a patient might expect when making treatment decisions, the strength of their evidence is limited. The critical scrutiny of Jung's meta-analysis received exemplifies this. Jim Bader[34] graded the level of evidence as good quality with a grade A strength of recommendation, but he expressed concern with the lack of quality analysis of the studies Jung included as well as the assumption of constant even rates over time inherent in the Poisson regression used. A subsequent review of Jung's meta-analysis by Thomas Salinas and Steven Eckert[35] graded the level of evidence slightly lower, appraising it as limited in quality and gave the study a grade B strength of recommendation. Their chief point of contention was with the pooling of data into complication categories that failed to distinguish maintenance issues from the other problems in the continuum of complications. Add to this, as Elliot Abt[36] pointed out, the difficulty of establishing the independence of events, as one complication may

make future events more or less likely, and one can begin to appreciate the complexity of truly sorting out prosthetic complication rates from implant survival, let alone unravel the effects of operator experience.

Despite the shortfalls of these meta-analyses, they represent the limits of available information and are the current resource for informing patients and clinical decision making. Data available for implant and prosthetic survival provided by clinicians in training is even further limited by the small number of studies and their retrospective nature. With this in mind, and a respect for the limitations of retrospective reviews, a study was initiated to compile data for implants placed and restored by residents at the University of Minnesota School of Dentistry. The objectives of this study include comparing the survival rates of implants placed by residents in the departments of Oral and Maxillofacial Surgery and Graduate Periodontology with treatment planning performed by residents in Graduate Prosthodontics, to provide a restorative context for these survival rates and report some of the salient technical complications associated with the final restorations provided by the Prosthodontic residents.

Statement of the Problem

A patient's ability to consent to treatment relies on the clinician providing adequate information about the potential risks and benefits. Residents in Graduate Prosthodontics refer patients to fellow residents in either the Oral and Maxillofacial Surgery or the Graduate Periodontics departments, but the survival rates for implants placed in these departments is unknown. No reports are available in the current dental literature that directly compare the survival rates

of implants placed by trainees in these two separate surgical disciplines. Furthermore, the survival and technical complication rates for the associated restorations provided by Prosthodontic residents at this institution have not been established.

General Objectives

The general objectives of this study include the following:

1) Establish the overall survival rates for dental implants treatment planned and restored by residents in Graduate Prosthodontics whose surgical placement was performed by residents in either Oral and Maxillofacial Surgery or Graduate Periodontics.
2) Establish the survival rate of implants placed by residents in Oral and Maxillofacial Surgery (OMFS).
3) Establish the survival rate of implants placed by residents in Graduate Periodontics (PERIO).
4) Establish the survival and technical complication rates for the related implant restorations provided by residents in Graduate Prosthodontics (PROSTH).

Specific Objective

The central aim of this study will be the comparison of survival rates for dental implants placed by residents in Oral and Maxillofacial Surgery and Graduate Periodontics and to evaluate any potential difference for statistical significance.

Null Hypothesis (H_0)

There is no statistically significant difference in the survival rates of dental implants placed by residents in either the Oral and Maxillofacial Surgery or Graduate Periodontics programs.

Alternative Hypothesis (H_1)

There is a statistically significant difference in the survival rates of dental implants placed by residents in either the Oral and Maxillofacial Surgery or Graduate Periodontics programs.

Methods and Materials

A retrospective chart review was performed to collect information related to implant treatment provided by residents at the University of Minnesota School of Dentistry. Residents associated with training programs in Oral and Maxillofacial Surgery, Graduate Periodontics, and Graduate Prosthodontics were included. For these cases, residents in Graduate Prosthodontics provided planning, case coordination, and definitive restoration for implants placed by residents in either Oral and Maxillofacial Surgery or Graduate Periodontics. Eligible patient records were identified using a database kept by the Implant Program at the University of Minnesota School of Dentistry. This database contains information for all implants placed at the school from 1986 to present regarding patient's name, date of birth, chart number, number and type of implants placed, the date of stage one and stage two surgery, and the names of the prosthodontic and surgical clinicians involved in treatment. The database also contains limited information regarding implant failure dates that were

reported to personnel in the Implant Program. The data from 1986 through 2008 were combined into a single spreadsheet and sorted according to the restorative clinician name and the restorative clinician's departmental association, such as faculty practice, graduate prosthodontics, or undergraduate. All implant treatment associated with Graduate Prosthodontics was selected and further sorted in a separate spreadsheet. A total of 968 patients and 2,591 implants were associated with treatment by residents in Graduate Prosthodontics between 1994 and 2008. Patient charts with sufficient follow-up documentation were desired so further inclusion criteria were applied. Each patient record number was verified in the University of Minnesota Dental Clinics Clinical Computing Information System and the date of each patient's most recent recall appointment was recorded. Charts selected for review were identified on the Clinical Computing Information System as being currently held in the school's central records room, having a recall appointment at the school within the last 12 months, and having a Prosthodontic resident's name associated with the implant related treatment. 246 patient charts were thus identified for manual review.

An application for Medical Record Chart Review was submitted to the University of Minnesota Institutional Review Board (IRB) requesting research privileges to acquire and review patient charts from the School of Dentistry and to compile information related to endosseous dental implant treatment provided by residents. IRB approval was obtained on July 24, 2009 and manual review of the charts followed shortly thereafter. Chart requests were submitted

electronically and were fulfilled by staff in the central chart room. If a chart had been divided into multiple volumes, all volumes were obtained for review. The charts were reviewed by a single investigator (BD). Patient name, chart number, date of birth, and consent for the use of patient records for research were verified. Information collected from the patient chart included implant type, date of placement, graft type, graft material, graft date, restoration type, restoration date, verification of the departmental association of the resident placing the implant, namely Graduate Periodontics or Oral and Maxillofacial Surgery, verification of Prosthodontic resident treatment planning and restoration of the implant, various outcomes related to the restorative course of treatment, and outcomes related to implant survival.

Upon manual review, 17 of the 246 charts were excluded. Reasons for exclusion included either surgical placement of the implant by faculty, restoration of the implant by faculty or undergraduate student, restoration of the implant by a practitioner outside the school, and one chart whose original volume could not be located. Data was collected for inclusion from a final total of 228 charts. An electronic spreadsheet (Microsoft Excel 2003 for Macintosh) was used for the collection of data. Software within the spreadsheet program was used for organizing information and applying summary statistics to the data. After reviewing all charts, a second review was conducted to verify data collected and further clarify data entries. Statistical consultation was obtained from statisticians at the Biostatistical Design and Analysis Center, a part of the Clinical and Translational Science Institute at the University of Minnesota.

Statisticians assisted in the application of descriptive statistics for evaluating differences in implant survival results based on the department of residents placing the implants, the anatomic location of implant placement, as well as developing life tables for implant survival, restoration survival, and complication rates. Life table results were produced using SPSS version 16.0 (SPSS, Inc. Chicago, IL). Other statistical analysis including Kaplan-Meier and Cox Proportional Hazards Regression were performed with SAS version 9.2 (SAS Institute, Inc. Cary, NC).

Results

A final total of 228 charts were included for data analysis. These charts represent 228 patients, a total of 707 dental implants, and an average of 3 implants per patient. Average follow-up time was 64 months as measured from the date of stage one surgery to the date of the last patient visit entry in the chart (range 5 months to 15 years). A total of 39 implant failures were identified. The 39 identified failures were shared by a group of 29 patients, therefore 12.72% of the 228 patients experienced at least one implant failure. Six patients experienced 2 implant failures at separate sites and 2 patients experienced 3 implant failures at separate sites. Only initial implant placement was considered for these results and replacement of failed implants were noted but not included in this analysis. Implant failure in this review was defined as implant removal or non-functional retention of the implant, colloquially known as the implant being "put to sleep."

Twenty of the implant failure chart entries referred simply to loss of integration, 10 included a description of peri-implant infection, 2 entries cited improper placement, and 7 noted fracture of the implant platform or body as reason for removal. A total of 67 implants were identified as immediate placement by chart entries that specifically included notation of extraction of a tooth from the site and placement of the implant into the extraction socket. Only 1 implant associated with immediate placement failed.

The distribution of patient referral from Graduate Prosthodontics to the two surgical departments follows: 329 implants were used in the treatment of 106 patients by residents in Oral and Maxillofacial Surgery; 378 implants were used in the treatment of 134 patients by residents in Graduate Periodontics. Twenty-two implant failures occurred in 14 patients treated by residents in Oral and Maxillofacial Surgery. Seventeen implant failures occurred in 16 patients treated by residents in Graduate Periodontology. A comparison of these results is available in Table 3. Failure counts were done with and without fractured implants because this failure mode may not appropriately reflect the performance of residents in either department.

Table 3: Implants Placed and Patients Treated by Department

	OMFS Residents	Perio Residents	Total
Implants Placed	329 (46.5%)	378 (53.5%)	707
Patients Treated	106	134	228 (12 were treated by both departments)
Average Implants Per Patient	3.1	2.8	3
All Implant Failures	22	17	39
Failures (Excluding Fractured Implants)	19	13	32
Patients with Implant Failure (including fractured implants)	14 (13.21%)	16 (11.94%)	29 (12.72%) 1 patient had 2 failures, one with OMFS and one with PERIO
Patients with Implant Failure (excluding fractured implants)	12 (11.32%)	12 (8.96%)	24 (10.5%)
Implants Immediately Placed	17	50	67
Immediate Placement Failures	0	1	1

A summary of implant survival was also done based on anatomic location. 348 implants were placed in the maxilla: 222 in the posterior maxilla and 126 in the anterior maxilla. 359 implants were placed in the mandible: 269 in the posterior mandible and 90 in the anterior mandible. 11 failures (4.95%) occurred in the posterior maxilla. 7 failures (5.56%) occurred in the anterior maxilla. 18 failures (6.69%) occurred in the posterior mandible. 3 failures (3.33%) occurred in the anterior mandible. Table 4 provides details on the number of implants placed by each department according to anatomic location. It also contains the number of failures by anatomic location and department with counts to segregate the location of implant fractures. A comparison of departments here shows that residents in Graduate Periodontics placed fully double the number of implants in the anterior maxilla than residents in Oral and Maxillofacial Surgery. Meanwhile, the residents in Oral and Maxillofacial Surgery placed a relatively higher number of implants in the anterior mandible.

Data for implant survival were organized into life tables using SPSS software by consultants in the Biostatistical Design and Analysis Center. Three tables were created to analyze implant survival over the given observation intervals. The first life table (Table 5) provides the survival rates of all implants placed by both departments with all implant failures included. The second and third life tables (Table 6 and Table 7) provide the survival rates for implants placed by residents in Oral and Maxillofacial Surgery and in Graduate Periodontics, but failures due to implant fracture were excluded from the survival calculation in these tables. A side by side comparison of these survival rates is

presented in Table 8. A fourth life table was generated to demonstrate the timing and number of implant fractures alone (Table 9).

Table 4: Anatomic Location of Implants and Failures

	OMFS Residents	PERIO Residents	Total
Anterior Maxilla	42	84	126
Posterior Maxilla	109	113	222
Anterior Mandible	55	35	90
Posterior Mandible	123	146	269
Anterior Maxilla Failures (w/fx)	1 (2.4%)	6 (7.1%)	7 (5.56%)
Posterior Maxilla Failures (w/fx)	7 (6.4%)	4 (3.5%)	11 (4.95%)
Anterior Mandible Failures (w/fx)	3 (5.5%)	0	3 (3.33%)
Posterior Mandible Failures (w/fx)	11 (8.9%)	7 (4.8%)	18 (6.69%)
Anterior Maxilla Failures (wo/fx)	1 (2.4%)	5 (6.0%)	6 (4.8%)
Posterior Maxilla Failures (wo/fx)	5 (4.6%)	4 (3.5%)	9 (4.1%)
Anterior Mandible Failures (wo/fx)	3 (5.5%)	0	3 (3.33%)
Posterior Mandible Failures (wo/fx)	10 (8.1%)	4 (2.7%)	14 (5.2%)

Table 5: Life Table Analysis - Cumulative Survival Rate for All Implants

Obs. Period	Implants Entering Interval	Implants Withdrawn during Interval	Implants Exposed to Risk	Failed	Proportion Surviving Interval	Cumulative Survival Rate
< 6 months	707	2	706	6	99%	99.2%
6-12 months	699	10	694	5	99%	98.4%
1-2 years	684	68	650	3	99%	98.0%
2-3 years	613	69	578.5	5	99%	97.2%
3-4 years	539	154	462	5	99%	96.1%
4-5 years	380	76	342	3	99%	95.3%
5-6 years	301	77	262	0	100%	95.3%
6-7 years	224	50	199	3	98%	93.9%
7-8 years	171	42	150	3	98%	92.1%
8-9 years	126	24	114	4	96%	89.1%
9-10 years	98	26	85	1	99%	87.9%

Table 6: Life Table Analysis for Implants Placed by OMFS

Excludes implant failures due to fracture.

Obs. Period	Implants Entering Interval	Implants Withdrawn during Interval	Implants Exposed to Risk	Failed	Proportion Surviving Interval	Cumulative Survival Rate
< 6 months	329	0	329.0	5	98%	98.5%
6-12 months	324	5	321.5	2	99%	97.9%
1-2 years	317	5	314.5	0	100%	97.9%
2-3 years	312	27	298.5	1	99%	97.6%
3-4 years	284	74	247.0	3	99%	96.4%
4-5 years	207	33	190.5	2	99%	95.4%
5-6 years	172	52	146.0	0	100%	95.4%
6-7 years	120	23	108.5	3	99%	94.5%
7-8 years	96	25	83.5	3	98%	92.5%
8-9 years	69	15	61.5	4	95%	88.2%
9-10 years	51	8	47.0	1	99%	88.2%

Table 7: Life Table Analysis for Implants Placed by PERIO

Excludes implant failures due to fracture.

Obs. Period	Implants Entering Interval	Implants Withdrawn during Interval	Implants Exposed to Risk	Failed	Proportion Surviving Interval	Cumulative Survival Rate
< 6 months	378	2	377.0	1	99%	99.7%
6-12 months	375	5	372.5	3	99%	98.9%
1-2 years	367	63	335.5	3	99%	98.1%
2-3 years	301	42	280.0	2	99%	97.4%
3-4 years	257	81	216.5	1	99%	96.9%
4-5 years	175	44	153.0	0	100%	96.9%
5-6 years	131	26	118.0	0	100%	96.9%
6-7 years	105	28	91.0	1	99%	95.8%
7-8 years	76	18	67.0	0	100%	95.8%
8-9 years	58	9	53.5	1	98%	94.1%
9-10 years	48	18	39.0	1	97%	91.0%

Table 8: Comparison of Cumulative Survival Rates for OMFS and PERIO

Observation Period	Implants Failed OMFS	Cumulative Survival Rate OMFS	Implants Failed PERIO	Cumulative Survival Rate PERIO
< 6 months	5	98.5%	1	99.7%
6-12 months	2	97.9%	3	98.9%
1-2 years	0	97.9%	3	98.1%
2-3 years	1	97.6%	2	97.4%
3-4 years	3	96.4%	1	96.9%
4-5 years	2	95.4%	0	96.9%
5-6 years	0	95.4%	0	96.9%
6-7 years	1	94.5%	1	95.8%
7-8 years	2	92.5%	0	95.8%
8-9 years	3	88.2%	1	94.1%
9-10 years	0	88.2%	1	91.0%
10+ years	0	88.2%	0	91.0%

Table 9: Life Table Analysis For Implant Fractures

Interval	Implants Entering Interval	Implants Withdrawn during Interval	Implants Exposed to Risk	Failed	Proportion Failing Due to Fracture	Cumulative Survival
0-1 year	707	12	701	0	0.00%	100.0%
1-2 years	695	70	660	0	0.00%	100.0%
2-3 years	625	71	589.5	2	0.34%	99.7%
3-4 years	552	157	473.5	1	0.21%	99.4%
4-5 years	394	78	355	1	0.28%	99.2%
5-6 years	315	82	274	0	0.00%	99.2%
6-7 years	233	51	207.5	1	0.48%	98.7%
7-8 years	181	43	159.5	1	0.63%	98.1%
8-9 years	137	26	124	0	0.00%	98.1%
9-10 years	111	28	97	0	0.00%	98.1%

Statistical analyses were then performed to assess whether the survival rates observed for implants placed by Oral and Maxillofacial Surgery residents and Graduate Periodontics residents were significantly different. Fischer's Exact Test was performed first to obtain preliminary results regarding the relationship between implant failure and the departmental affiliation of the residents placing

the implants. This test does not account for time of event occurrence or clustering of data. The next analysis employed, Kaplan-Meier, demonstrated the relationship between failure and department with time accounted for. The Kaplan-Meier survival plots given in Figures 1 & 2 provide a graphic representation of survival as a function of time and illuminate the length of time each implant was observed. The dots on the lines in these graphs represent the end of each implant's observation period. Observation time was measured starting from the date of stage 1 surgery to the date of the last patient visit chart entry. Figure 1 shows the Kaplan-Meier analysis for Oral and Maxillofacial Surgery and Graduate Periodontics with implant fractures excluded. The graph in Figure 2 includes implant fractures in the analysis.

Finally, a Cox Proportional Hazards Regression[37] analysis was applied to account for the clustered nature of the data since multiple implants could be placed in the same patient. The threshold for significance was set at $p < 0.05$. A p-value of 0.59 was obtained when all implant failures were considered for both departments. A p-value of 0.4 was obtained when failures due to implant fracture were excluded. Therefore, in either interpretation of implant failure, there was no statistically significant difference between implant survival rates based on the departmental affiliation of the resident placing the implant.

Figure 1: Kaplan-Meier Survival Plot for Implants Placed by Residents in Oral and Maxillofacial Surgery or Graduate Periodontics (fractures excluded).

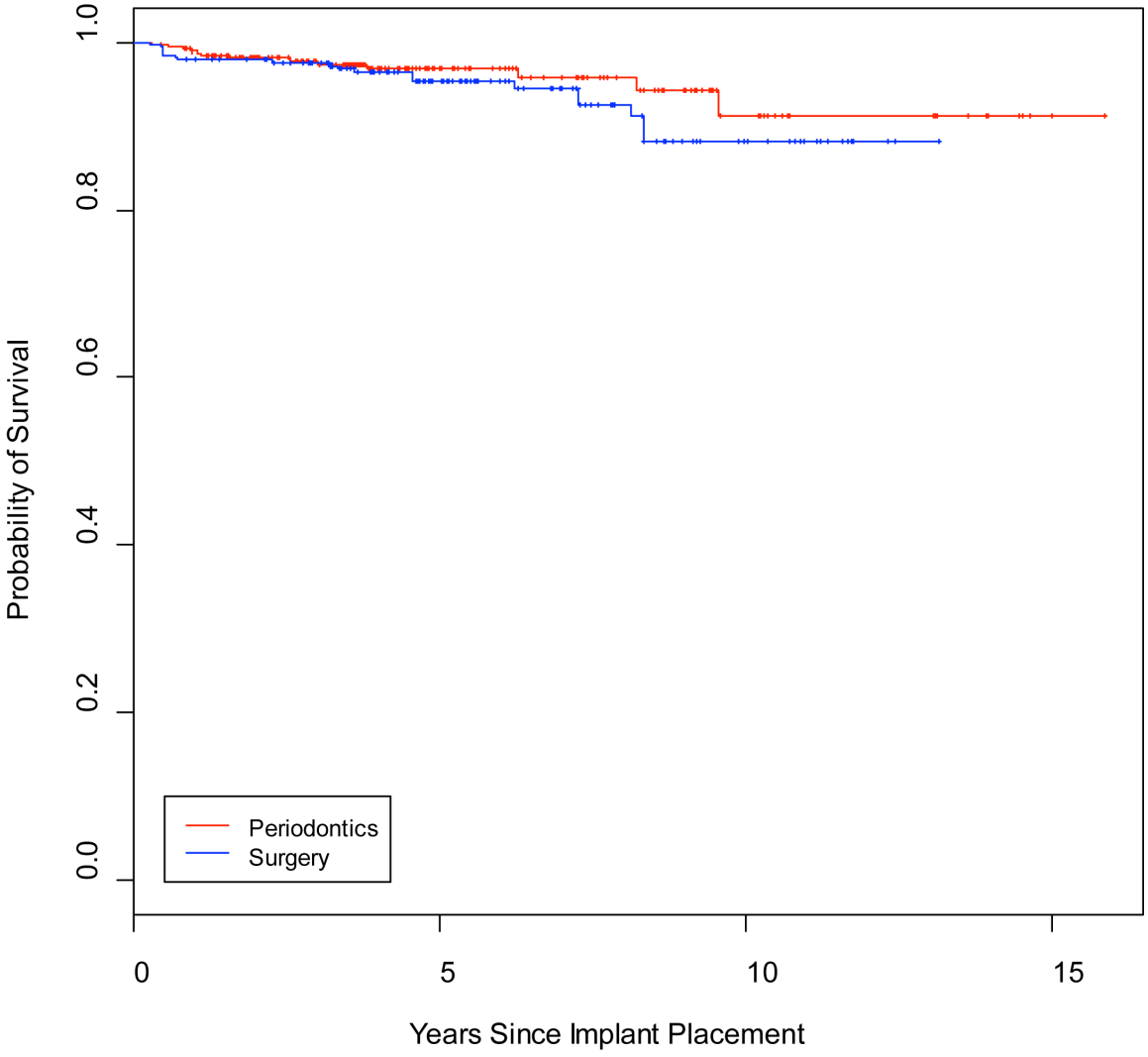
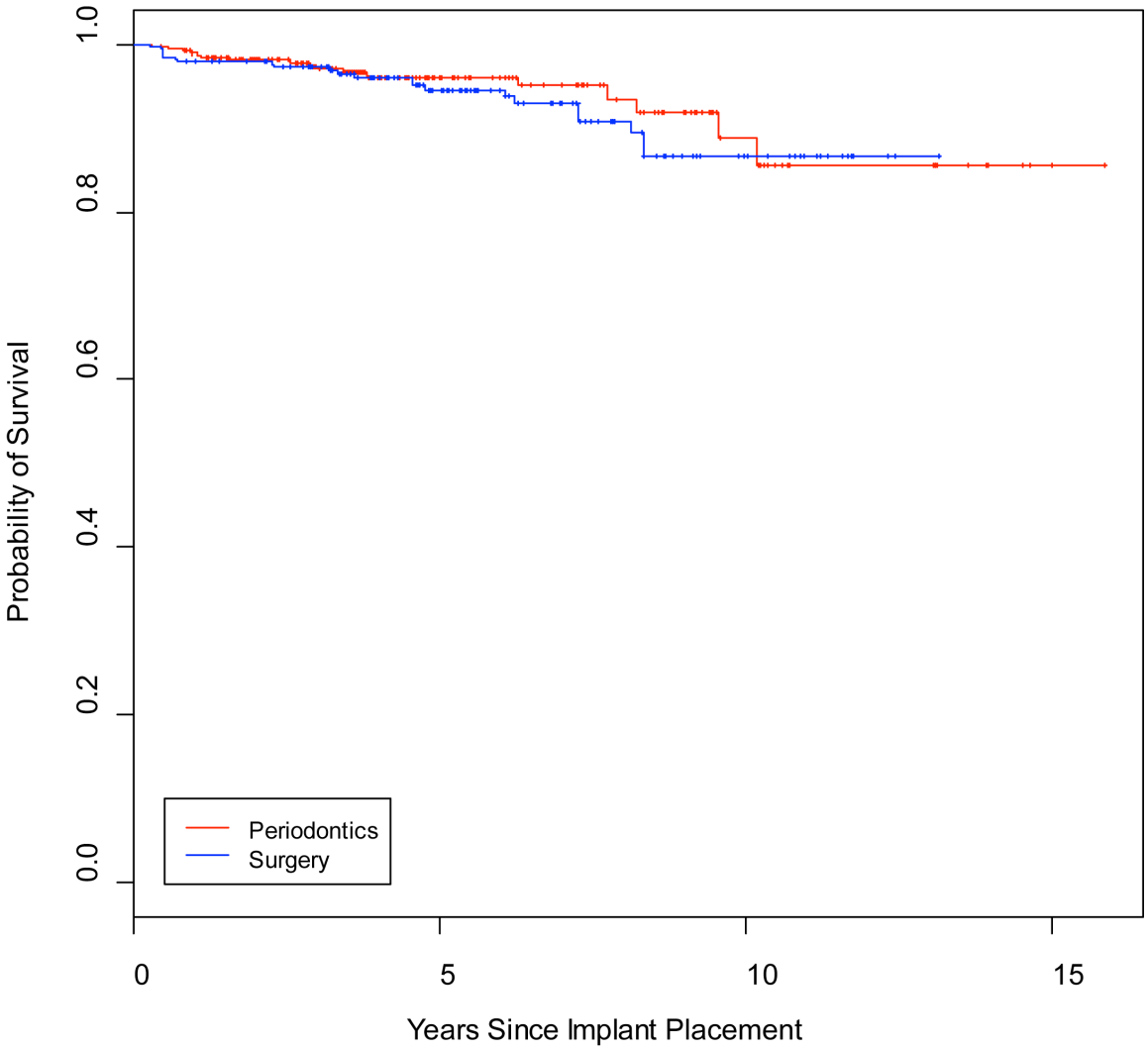


Figure 2: Kaplan-Meier Survival Plot for Implants Placed by Residents in Oral and Maxillofacial Surgery or Graduate Periodontics (fractures included).



Cox Regression was also performed in consideration of the anatomic location of the failed implants, anterior versus posterior position in both the maxilla and the mandible and a p-value of 0.3 was obtained for all failures. A p-value of 0.5 was obtained when the analysis excluded failures due to implant fracture. Both values were outside the threshold of significance, indicating there was no statistically significant difference in implant survival based on anatomic location.

Additional information relating to implant survival and grafting procedures are given in Tables 10, 11, & 12. This information helps characterize the nature of implant related treatment performed at the graduate level. A summary of implant failures based on time relative to restoration is contained in Table 10. Thirteen implants (1.8%) failed before prosthetic restoration and 26 failures (3.7%) occurred after prosthetic loading. Table 11 outlines the various grafting procedure entries recorded for each department. This includes grafts done prior to or at the time of stage 1 surgery. Graft types were classified as particulate if any variety of non-autogenous bone filler was referred to being placed as part of site preservation or augmentation. Block grafts were identified by the anatomic region they were harvested from, such as the mandibular menton or ramus regions. Maxillary sinus elevations were categorized based on the written description of the operator's approach: direct, indirect, or unspecified. Table 12 further segregates the graft data by limiting the summary to grafts done at the time of surgery. It can be observed here that the residents in Graduate

Periodontics have a relatively higher number of chart entries describing grafting procedures.

Table 10: Implant Failures Before and After Restoration

	OMFS Resident	PERIO Resident	Total
Before Restoration	7	6	13
After Restoration (including fractures)	15	11	26
After Restoration (without fractures)	12	7	19

Table 11: Total Number of Grafting Procedures

	OMFS Resident	PERIO Resident	Total
Particulate (preservation or augmentation)	20	100	120
Menton Block	10	7	17
Ramus Block	1	4	5
Direct Sinus Elevation	21	31	52
Indirect Sinus Elevation	0	12	12
Sinus Elevation, Approach not Specified	3	1	4

Table 12: Grafting Procedures Performed Perioperatively

	OMFS Resident	PERIO Resident	Total
Particulate	14	57	71
Menton Block	0	1	1
Ramus Block	0	1	1
Direct Sinus Elevation	4	18	22
Indirect Sinus Elevation	0	12	12
Sinus Elevation, Approach not Specified	1	1	2

The following tables provide a context for the prosthetic utilization of implants in this study. Presented in Table 13 are the numbers and percentages of implants employed for all identified restoration types provided by the residents in Graduate Prosthodontics. Table 14 summarizes the prosthetic abbreviations. Single crowns (SCs) were the restorative prosthesis for half of all the implants placed. Another near quarter of all implants were used for supporting various multi-unit fixed partial dental prostheses (FPDs). Mandibular fixed-detachable (LFD) type prostheses utilized almost 10% of implants while maxillary fixed-removable (UFR) and mandibular fixed-removable (LFR) overdentures accounted for another 10% of implants placed. Only a little more than 1% of the implants observed were used for 5 mandibular overdentures (OD) retained by 2 implants each. The remaining implants were used for a variety of other fixed and removable prostheses. The other fixed restorations

combined implant and natural tooth abutments for their support while the other removable prostheses included 3 removable partial dental prostheses whose retention was enhanced by ball-o-ring or locator abutments and 1 maxillary complete overdenture retained by 4 ball-o-ring abutments. Eleven patients with 17 implant sites were not restored. Two patients had a single implant each put to sleep. Five patients had their implants removed and not replaced. Two patients were delaying restoration for financial considerations and two patients were waiting for implant integration.

Table 13: Prosthetic Utilization of Implants

	Prostheses	Implants	Percent of All Implants Placed	Patients
SC	351	351	49.65%	156
FPD	73	168	23.76%	58
LFD	14	70	9.90%	14
UFR	7	47	6.65%	7
LFR	5	25	3.54%	5
OD	5	10	1.41%	5
Other Removable	4	12	1.70%	4
Other Fixed	4	7	0.99%	4
Not Restored	N/A	17	2.40%	11
Total	N/A	707	100.00%	N/A

Table 14: Key to Restorative Abbreviations

SC	Single Crown
SCC	Single Crown, Cement Retained
SCS	Single Crown, Screw Retained
SCU	Single Crown, Unidentified Retention
FPD	Fixed Partial Dental Prosthesis, implant supported
FPDC	Fixed Partial Dental Prosthesis, implant supported, cement retained
LFD	“lower fixed-detachable” = Mandibular Fixed Complete Dental Prosthesis
UFR	“upper fixed-removable” = Maxillary Fixed Bar(s) Supporting a Removable Complete Dental Prosthesis
LFR	“lower fixed-removable” = Mandibular Fixed Bar Supporting a Removable Complete Dental Prosthesis
OD	“overdenture” = Mandibular Complete Denture retained by 2 implant supported abutments (ball or locator type)

Tables 15 and 16 separate the prosthetic utilization of implants by surgical department. These two tables provide context for the placement of implants; showing both the restorative treatment plans they were a part of and further distinguishing the mode of failure relative to the time of restoration. Failures before loading have been separated from failures after loading and implant fractures are identified in their own column. Single crowns (SC) have been further divided by their means of retention: cement retained single crowns (SCC), screw retained single crowns (SCS), and retention unidentified (SCU).

Table 15: Prosthetic Restorations for Implants Placed by OMFS

	Restoration Count	Implant Count	Percent of All Implants for Restoration Type	Percent of Implants Placed by Department	Failures Before Loading	Failures After Loading	Implant Fracture
All SC	125	125	35.61%	37.99%			
SCC	99	99	34.14%	30.09%		1	2
SCS	18	18	37.50%	5.47%			1
SCU	8	8	61.54%	2.43%		1	
FPD	37	84	50.00%	25.53%	1	8	
LFD	8	40	57.14%	12.16%			
UFR	5	34	72.34%	10.33%	1		
LFR	4	20	80.00%	6.08%		2	
OD	4	8	80.00%	2.43%			
Other Rem.	3	10	83.33%	3.04%			
Other Fixed	0	0	0.00%	0.00%			
Sites not Restor'd	8		0.00%	0.00%	5		

Table 16: Prosthetic Restorations for Implants Placed by PERIO

	Restoration Count	Implant Count	Percent of All Implants for Restoration Type	Percent of Implants Placed by Department	Failures Before Loading	Failures After Loading	Implant Fracture
All SC	226	226	64.39%	59.79%			
SCC	191	191	65.86%	50.53%	2	5	2
SCS	30	30	62.50%	7.94%			1
SCU	5	5	38.46%	1.32%			
FPD	36	84	50.00%	22.22%			1
LFD	6	30	42.86%	7.94%			
UFR	2	13	27.66%	3.44%			
LFR	1	5	20.00%	1.32%			
OD	1	2	20.00%	0.53%			
Other Rem.	1	2	16.67%	0.53%		1	
Other Fixed	4	7	100.00%	1.85%		1	
Sites not Restor'd	8		0.00%	0.00%	4		

The average observation time for each type of restoration and number of failures are given in Table 17 below. Failures on this table have been classified into two categories. The first, combined failures, refers to all restorations lost. This includes restorations lost to technical failures as well as those lost in association with implant failure. The second category, technical failures, is a subset of the first. Technical failures represent restorations removed and replaced with a new restoration on the original implant for any reason. Average observation time for each restoration type was calculated based on the date of

the restoration's insertion to the date of the most recent patient visit chart entry noted at the time the record was reviewed.

Table 17: Prosthesis Observation Times and Failure Counts.

	Prostheses	Avg. Obs. Time (months)	Technical Failures (replaced on original implant)	All Restorations Lost (includes loses associated with implant failure)
All SC	351	47	32	43
SCC	290	42	28	36
SCS	48	72	4	6
SCU	13	55	0	1
FPD	73	69	7	13
LFD	14	62	0	0
UFR	7	48	4	4
LFR	5	55	0	1
OD	5	73	1	1
Other Rem.	4	62	1	1
Other Fixed	4	69	1	1
Not Restored	N/A	68		

Life table analysis was performed for the two restoration types, SC & FPD, with the greatest numbers. This was appropriate for these restoration types because the recommended minimum population for life table analysis is 30. The life tables for all SCs (Table 18) and FPDs (Table 19) were calculated using the combined failure counts and dates.

Table 18: Life Table Analysis for all Single Crowns

Obs. Period	SCs Entering Interval	SCs Withdrawn during Interval	SCs Exposed to Risk	SCs Failed	Proportion Surviving Interval	Cumulative Survival Rate
0-1 years	351	34	334	9	97%	97%
1-2 years	308	53	281	9	97%	94%
2-3 years	246	80	206	15	93%	87%
3-4 years	151	46	128	0	100%	87%
4-5 years	105	18	96	5	95%	83%
5-6 years	82	10	77	1	99%	82%
6-7 years	71	16	63	3	95%	78%
7-8 years	52	14	45	0	100%	78%
8-9 years	38	14	31	1	97%	78%
9-10 years	23	10	18	0	100%	78%

Again, failures in Table 18 are the combined failures which include SCs lost to technical complications and those lost in association with failed implants. SCs retained by cement (SCC = 290), screw (SCS = 48), or whose retention mode was not identified (SCU = 13) were all included in these calculations.

Table 19: Life Table Analysis for all Fixed Partial Dental Prostheses

Obs. Period	FPDs Entering Interval	FPDs Withdrawn during Interval	FPDs Exposed to Risk	FPDs Failed	Proportion Surviving Interval	Cumulative Survival Rate
0-1 years	73	5	70.5	2	97%	97%
1-2 years	66	2	65	2	97%	94%
2-3 years	62	6	59	3	95%	89%
3-4 years	53	5	50.5	0	100%	89%
4-5 years	48	13	41.5	0	100%	89%
5-6 years	35	6	32	1	97%	87%
6-7 years	28	8	24	0	100%	87%

Failures in table 19 are the combined failures and include FPDs lost to technical complications and those lost in association with failed implants. FPDs retained by cement (FPDC = 63), screw (FPDS = 5), or whose retention mode was not identified (FPDU = 5) were all included in these calculations. Analysis was ended at the 7 year mark because the number of FPDs was below the recommended number of 30 needed for valid calculations.

Table 20: Restoration Survival Rates based on Technical Failures

Obs. Period	SC	SCC	SCS	FPD	FPDC
0-1 years	98%	99%	93%	97%	97%
1-2 years	96%	96%	93%	93%	93%
2-3 years	91%	90%	93%	90%	90%
3-4 years	91%	90%	93%	90%	90%
4-5 years	87%	85%	93%	90%	90%

Table 21: Restoration Survival Rates based on Combined Failures

Obs. Period	SC	SCC	SCS	FPD	FPDC
0-1 years	97%	98%	93%	97%	97%
1-2 years	94%	95%	90%	94%	93%
2-3 years	87%	87%	87%	89%	88%
3-4 years	87%	87%	87%	89%	88%
4-5 years	83%	81%	87%	89%	88%

Survival rates for the most numerous restoration subtypes were also obtained by life table analysis. The survival rates for the first 5 years of function are presented in Tables 20 and 21. Table 20 provides a comparison of survival rates based on technical failures for all SCs, subtypes SCC and SCS, as well as all FPDs and the subtype FPDC. Table 21 provides a comparison similar to Table 20 with the exception that survival rates are based on combined failures. The restoration survival rates in Table 21 are lower than those presented in Table 20 because the number of combined failures are greater than technical failures alone. Cement retained single crowns showed the lowest 5 year survival rate.

Table 22: Technical Complications / Maintenance Event Overview:

	Luting Cement Fracture	Screw Loosening	Screw Fracture	Porcelain Fracture	Loss of Screw Channel Cover	Denture Tooth Fracture	Denture Attachment Replacement
SCC	30 (10.34%)	19 (6.55%)	5 (1.72%)	9 (3.10%)			
SCS		15 (31.25%)	1 (2.08%)	0	4 (8.33%)		
SCU	0	1 (7.69%)	1 (7.69%)	0	0		
FPDC	27 (42.90%)	4 (6.30%)	1 (1.60%)	3 (4.8%)	0		
LFD		1 (7.14%)	2 (14.29%)	0	3 (21.43%)	2 (14.29%)	
UFR		0	1 (14.29%)	0	0	5 (71.43%)	6 (85.71%)
LFR		0	0	0	0	0	1 (20.00%)
OD						0	5 (100%)
OR						1 (20.00%)	2 (40.00%)
OF	0	0	0	0	0		

The number of complications occurring by restoration type are collected in Table 22. This table shows the number of restorations experiencing at least one of the defined complication or maintenance events. The percentage given below the number in each cell refers to the percent of restorations affected per total number of restorations of the specific restoration type.

Table 23: Complication / Maintenance Event Rates

Obs. Period	Complication Type	All SCs	SCC	SCS	All FPDs	FPDC
0-1 year	Cement Fracture		5%			13%
2-3 year	Cement Fracture		11%			36%
4-5 years	Cement Fracture		14%			47%
0-1 year	Screw Loosening	5%	3%	19%	0%	0%
2-3 year	Screw Loosening	10%	7%	28%	3%	4%
4-5 years	Screw Loosening	12%	9%	35%	5%	6%
0-1 year	Screw Fracture	0%	0%	2%	0%	0%
2-3 year	Screw Fracture	2%	2%	2%	2%	2%
4-5 years	Screw Fracture	3%	2%	2%	2%	2%
0-1 year	Porcelain Fracture	1%	1%	0%	1%	2%
2-3 year	Porcelain Fracture	3%	3%	0%	1%	2%
4-5 years	Porcelain Fracture	5%	6%	0%	1%	2%

Life table analysis was performed to obtain complication rates for common complications of the most numerous restoration types. Table 23 provides the complication rates at 1, 3, and 5 year intervals. Complication rates for loss of screw channel access covering, a common maintenance issue for SCSs, are not listed on this table include but were found to have a 1 year rate of 5%, 3 year rate of 8%, and 5 year rate of 11%.

Additional information regarding the characteristics of the implants observed in this study are provided in Tables 24, 25, 26, and 27. Table 24 collects information about all the implant lengths, the number of each length used, as well as the number of failures associated with each length. The most commonly prescribed length was 13 mm, representing 58.3% of all implants observed. Table 25 offers a similar presentation for implant widths. The two most common implant widths observed were 3.7 mm diameter (25.5%) and 4.7 mm diameter (23.9%). The most commonly identified implant type based on manufacturer designation was Screw-Vent (Zimmer Dental Inc, Carlsbad, CA) representing 47.4% of all implants placed, while two different Lifecore implant designs (Lifecore Biomedical Inc, Chaska, MN), Restore and Sustain, represented another 36.4%. Table 27 enumerates the number of implants placed each year by department. Additional information about specific implant design characteristics and surface modifications were not obtained. The results in Tables 24-27 are provided as a matter of general interest and conclude the presentation of results.

Table 24: Implant Lengths Observed

Length (mm)	Number Placed	Percent of all placed	Number Failed	Percent Failed per Number of Length Placed
8	2	0.3%	0	0.0%
10	63	8.9%	5	7.9%
11.5	54	7.6%	2	3.7%
13	412	58.3%	27	6.6%
15	93	13.2%	1	1.1%
16	83	11.7%	4	4.8%

Table 25: Implant Widths Observed

Width (mm)	Number Placed	Percent of all placed	Number Failed	Percent Failed per Number of Width Placed
3.25	9	1.3%	1	11.1%
3.3	39	5.5%	2	5.1%
3.4	55	7.8%	8	14.5%
3.7	180	25.5%	7	3.9%
3.75	79	11.2%	3	3.8%
4	92	13.0%	6	6.5%
4.1	2	0.3%	0	0.0%
4.2	31	4.4%	2	6.5%
4.25	7	1.0%	1	14.3%
4.7	169	23.9%	4	2.4%
5	32	4.5%	4	12.5%
5.5	1	0.1%	0	0.0%
6	11	1.6%	1	9.1%

Table 26: Implant Types by Manufacturer

	Placed	% total	Failed	% Failed
Brånemark (Nobel Biocare, West Mount, IL)	9	1.3%	0	0.0%
Centerpulse (Centerpulse Dental Inc, Carlsbad, CA)	5	0.7%	0	0.0%
Certain (BIOMET 3i, Palm Beach Gardens, FL)	44	6.2%	4	9.1%
Micro-Vent (Paragon Implant Co, Encino, CA)	54	7.6%	4	7.4%
Restore (Lifecore Biomedical Inc, Chaska, MN)	153	21.6%	9	5.9%
Screw-Vent (Zimmer Dental Inc, Carlsbad, CA)	335	47.4%	12	3.6%
Sustain (Lifecore Biomedical Inc, Chaska, MN)	105	14.9%	10	9.5%
Spline (Sulzer Calcitek Inc, Carlsbad, CA)	2	0.3%	0	0.0%

Table 27: Number of Implants Placed Each Year by Department

Year	OMFS	PERIO
1994	0	6
1995	0	13
1996	7	3
1997	20	2
1998	16	7
1999	18	12
2000	15	17
2001	28	11
2002	28	17
2003	52	23
2004	48	50
2005	27	71

Year	OMFS	PERIO
2006	54	58
2007	10	74
2008	6	14
Total	329	378

Discussion

The cumulative 5 year survival rate of 95.3% for the dental implants observed in this study is well within the findings of other researchers (Jung, Pjetursson, Goodacre). A total of 228 patient records where documentation of dental implant treatment planning, placement, and restoration were provided by residents in advanced training programs at the University of Minnesota School of Dentistry were verified in this review and 707 implants were included for analysis. Assessment of the two surgical disciplines performing implant placements in coordination with Graduate Prosthodontics showed 329 implants were used in the treatment of 106 patients by residents in Oral and Maxillofacial Surgery (OMFS) with a 5 year survival rate of 95.4%. Another 378 implants were used in the treatment of 134 patients by residents in Graduate Periodontics (PERIO) with a 5 year survival rate of 96.9%. A comparison of these survival rates using Cox Proportional Hazards Regression indicated the difference between departments was not statistically significant regardless of whether failures due to implant fracture were included ($p = 0.59$) or excluded ($p = 0.40$). It should be pointed out that the 5 year departmental survival rates of 95.4% and 96.9% are both higher than the cumulative, combined 5 year survival rate of

95.3% because the department specific rates do not include failures due to implant fracture in their calculation.

Because failure due to implant fracture may be complicated by manufacturing processes, material defects, or functional overloads, this failure mode does not lend itself for consideration of surgical department performance. The 7 failures due to fracture seen in this review result in a mean incidence of 1% and are consistent with other reports of implant fractures in the dental literature. Goodacre reported a 1% mean incidence in his paper (see Goodacre Table V). The fractured implants in this study were associated with 4 SCCs, 2 SCSs, and 1 FPD. This gives an incidence of implant fracture of 0.17% for (6/351) SCs and 0.14% for (1/73) FPDs in this study and is on a similar level with with Pjetursson's 2007 meta-analysis which showed 0.14% occurrence with SCs and 0.5% with FPDs.

And while survival rates were not different between departments, some relative differences were observed between the departments. Prominent among these are the number of grafting procedures done before or at the time of stage 1 surgery (see Tables 11 & 12). Residents in Graduate Periodontics performed 5 times more non-autogenous particulate grafting procedures than residents in Oral and Maxillofacial Surgery. The clinical significance of this is beyond the scope of this study and the literature remains divided over the necessity of such grafting. It does not appear to improve absolute survival, whether the implant remains in the mouth or not, but it may have an effect on the quality of implant survival through fortification of crestal bone levels. On a prospective cohort of 45

patients treated with guided bone regeneration techniques, Dorte Christensen[38] found 1.5 mm of crestal bone loss in 6.5% of implants placed more than 6 months after grafting while 14% of implants placed concomitantly with the graft showed the same levels of alveolar loss. Though the difference was not statistically significant, the author felt that a staged approach to grafting was safer means of preserving crestal bone height, allowing 6-8 months of osseous healing before attempting implant placement. On the other hand, Daniel Buser[39] reported encouraging results for rebuilding facial gingival contour in the anterior maxilla with implants placed simultaneously with a guided bone regeneration technique using a collagen membrane, deproteinized bovine bone mineral, and autogenous bone chips at the alveolar crest.

Entries within the Cochran Database address the subject of bone augmentation techniques for dental implant treatment. The most recent update by Marco Esposito[40] analyzed 13 randomized controlled trials and concluded that horizontal or vertical bone augmentation prior to implant placement is effective but a single superior technique could not be identified. Some recommendations were offered, such as using short implants instead of attempting vertical bone grafting in resorbed mandibles and the acceptability of bone substitutes in filling osseous defects. Also, the 2008 consensus conference in Stuttgart, Germany convened by the International Team for Implantology included a review by Ivan Darby[41] on the topic of alveolar ridge preservation. This review concluded that grafting to preserve alveolar ridge did not necessarily improve a site's capacity to receive a dental implant, even

though a variety of techniques have demonstrated preservation of ridge dimensions following tooth extraction. Furthermore, no data relating to aesthetic outcomes following ridge preservation have been reported.

Yet it may be for cosmetic reasons that the number of grafting procedures associated with Graduate Periodontics was higher. A possible explanation for the increased number of grafting procedures might be the higher number of implants placed in the anterior maxilla by this department (see Table 4). Residents in Graduate Periodontics placed 84 implants in this region compared to the 42 placed by Oral and Maxillofacial Surgery. Because tooth perception and display are most prominent in the anterior maxilla, grafting to satisfy the demands of aesthetics seems justified. Here, preservation of the alveolar foundation is often needed to support the gingival architecture.[42,43] The anatomic distribution of Graduate Periodontics particulate grafting placement included 46 sites in the anterior maxilla, 16 in the posterior maxilla, 7 in the anterior mandible, and 31 in the posterior mandible. The anatomic distribution of Oral and Maxillofacial Surgery's particulate grafting included only 10 sites in the anterior maxilla, 5 in the posterior maxilla, and 5 in the posterior mandible. The high number of particulate grafts in the anterior maxilla (46) may be justified by the high number of implants (84) placed in this region by Graduate Periodontics in order to satisfy aesthetic demands, but number of particulate grafts associated with sites in the posterior mandible (31) is more difficult to rationalize. Of course, there is no way to assess in this review whether truly aesthetic outcomes were realized as a result of these grafting procedures.

Further contemplation of the results on Table 4 show that Oral and Maxillofacial Surgery placed 123 implants in the posterior mandible and Graduate Periodontics placed 146. Excluding fractures, OMFS had 10 failures and PERIO had 4. Could the increased number of particulate grafts placed in the posterior mandible have reduced the number of failures? Additional research would be needed to evaluate the benefit of ridge preservation techniques in this region of the mouth where aesthetics have little sway in clinical decision making.

Considering the nature of this chart review, it is important to outline the limitations inherent to data collection from patient records in order to temper our interpretation of this study's results. While the selection criteria of picking charts with an appointment at the dental school within the last 12 months represents an attempt to include treatment courses with the greatest amount of follow-up information, it carries with it the problem of predisposing the results towards higher complication rates. Patients experiencing complications are more likely to require continued appointments for follow-up or re-treatment. It is also impossible to know whether all of the patient's care related to their implants and restorations was provided at the dental school. Neither can we know if all of the patient's visits to the dental school are included in the chart as entries can be omitted or lost. Even the entries that appear in the chart are suspect, as they are written with varying amounts of haste and thereby offer a considerable range and quality of detail. Furthermore, data extraction was performed by one investigator alone so classification and acceptance of data was done

unilaterally. There is also the potential for systematic errors in data association that arise from managing a large data set with an electronic spreadsheet.

It should be noted that the author exerted every effort to acquire the data in as unbiased and uniform a manner as possible. Although the data obtained from this review was rechecked and may be an accurate representation of the information available in the charts, the completeness of source information is still suspect. Some problems that exist with the data are that implant systems are lumped together in the analysis. Information regarding the manufacturing company, implant width, and length can easily be cross-checked with the implant program's database, the chart entry, the clinical computing system, and order forms on file; but the information about the implant's design, composition, or surface treatment is more challenging to obtain and was not sought for in this review.

Information regarding each clinician's status as a resident and department affiliation were initially identified with the implant program's database. This was then cross-checked with chart entries prefaced by department name as well as entries in the clinical computing system that provides operator identification numbers indicating resident status and department affiliation. Therefore, the departmental attribution of implants placed and failures recorded is judged to be sound. No attempt was made to differentiate the level of operator experience. There is no way of knowing whether the results contain a random mixture of operator experience or if the implants or their restorations were provided by residents in their first year of

experience, or even as their first experience, versus those in their final year of formal training.

Although none of the studies reviewed here (see Table 1) compared implant survival rates between different departments or disciplines at the same institution, components of these previous studies can be related to the results seen in this review. Kohavi's (2004) review technique was similar to the one used in this review in that patients were identified first through a university database and then selected. One difference is that Kohavi et al used a manual form for recording data from the chart before compiling the information in an electronic spreadsheet (Microsoft Excel 2002, Microsoft Corp, Redmond, WA). It is unclear how many investigators were involved in the collection, entry, and analysis of the data. Kohavi reported implant survival of 96.0% for a follow-up period of 12 to 24 months. This was a combined survival rate for all implants placed by faculty-student teams in Oral and Maxillofacial Surgery, Graduate Periodontics, and Graduate Prosthodontics.

Such survival was only slightly lower than the 1 and 2 year survival rates of 98.4% and 98.0% for the residents in Oral and Maxillofacial Surgery and Graduate Periodontics in this study (see Table 5). However, Kohavi also distinguished survival by implant type, with cumulative survivals for Branemark (Grade 1 titanium) at 94.9% and Taper-Lock (Grade 4 titanium) at 98.1%. The survival rate for Taper-Lock implants aligns well with the 2 year survival rate of 98.0% in this study, which includes a significant proportion of Screw-Vent implants (47.4% of all implants placed, see Table 26) which are manufactured by

the same company that produces Taper-Lock (Zimmer Dental Inc, Carlsbad, CA). Few restorative comparisons can be drawn between Kohavi's work and this study because of the limited follow-up time in Kohavi's review. The restorative providers are not clearly identified, but Kohavi did summarize the prosthetic utilization of implants, with the majority of implants, 165 of 303, being restored with FPDs and only a small number, 29 implants, restored with single crowns. This is quite the opposite of the prosthetic utilization frequencies in this review (see Table 13).

In terms of the number of records reviewed, total number of implants observed, and follow-up period, Clifford Starr's (2006) report of implants placed and restored by general dentistry residents corresponds well with this study. The methods used by Starr were also similar to those used by Kohavi and this study, in as much as an administrative database was referenced in order to identify and select records and an electronic spreadsheet (Microsoft Excel 2002, Microsoft Corp, Redmond, WA) was used to collect data. Starr evaluated the records of 263 patients with 790 implants and found that patients were treated with an average of 3 implants. These numbers are similar to the number of charts and implants reviewed here, 228 and 707, with the same average number of implants placed per patient. The follow-up time in Starr's report varied from 6 months to 7 years. A cumulative implant survival of 96.6% was given by Starr but it is unclear what interval of time this survival rate refers to, if any. It appears as though this is a percentage of all implants classified as surviving based on a calculation of implants failed (27) divided by all implants (790) placed. Because survival rates

were not produced with a life table analysis that censors the implant population per observation period for numbers exposed to the risk of failure, direct comparisons between Starr's survival percentage and the survival rates seen here is impractical.

Starr did account for the prosthetic utilization of implants but did not elaborate on the survival or complication rates of the restorations. Here FPDs represented the largest usage of implants placed, with 104 restorations occupying 35% (280) of the implants placed. A total of 227 single crowns used 29% (227) of the implants. Other restoration types used in significant numbers were 51 "removable complete dentures" occupying 19% (153) of the implants, and 25 "screw-retained fixed dentures" supported by 16% (126) of the implants. These results are different from the 50% (351) and 24% (168) usage of implants for single crowns and FPDs observed in this review. The prosthetic utilization results indicate a respectable level of case complexity being undertaken by the faculty and residents in the general dentistry residency program Starr evaluated. It is difficult to say whether the case complexity of the GPR at the University of Florida is comparable with that of the Prosthodontics program here, but it seems to offer an impressive opportunity for training general practice clinicians in both the placement and restoration of dental implants.

Maico Melo evaluated the survival rates of implants placed by Oral and Maxillofacial surgery residents covering the years 2002 through 2004. The aim of this study was a comparison of survival rates based on the residents' year in the training program. Melo produced Kaplan-Meier survival plots to demonstrate

survival rates achieved by residents at different levels of training and applied the Cox Proportional Hazards Regression to show that there was no significant difference in survival rates ($p = 0.89$) among residents years 1 through 4. The average number of implants per patient was 3.24, similar to this review, though the number of patients (54) and implants (175) were fewer. The survival rate Melo cites, 91% with 15 failures among 175 implants, seems comparatively low when held against the 6 and 12 month survival rates (98.5% and 97.9%) for implants placed by residents in the Oral and Maxillofacial Surgery program here (see Table 6). It appears the survival percentage Melo offers was arrived at using the same rudimentary calculation Starr employed. Nevertheless, because of the short follow-up period, a life analysis with statistical software would likely yield a result not far removed from the 91% already given.

Melo's study underscores a limitation in this review in that the level of experience for each of the residents placing implants was not accounted for. It is unknown what percentage of implants were placed by residents early or advanced in their training of if there was a disproportionality of experience among residents between departments. According to Melo's results, resident experience should not significantly affect survival rates, but the training experience provided by the programs here, especially between disciplines, are likely different from the one at Washington Hospital Center. Melo recognized the lack of prosthetic utilization data in his review and due to limited follow-up could not provide data for survival after functional loading. He did however summarize the average number of implants placed by residents in each training

year, with a higher average (4.16) being placed by residents in year 4 than those in year 1 (2.2). A comparison of survival rates based on anatomic location was performed by Melo and no statistically significant difference between sites in the maxilla or mandible was found ($p = 0.93$) with 7 failures in the maxilla and 8 in the mandible (see Table 1 in Melo). This result was reaffirmed in this study ($p = 0.5$) with 15 failures in the maxilla, and 17 in the mandible when failures due to implant fracture are excluded (see Table 4). This is in contrast with other reports that reveal higher failure rates in the posterior maxilla.[44,45]

The review led by Mats Kronstrom (2008) covers nearly the same time period as this study (1994-2004 vs. 1994-2008) and provides results for 166 implants in 95 patients. The clinicians placing implants were all experienced Oral and Maxillofacial Surgeons or Periodontists and the treatment plans and restorations were all performed by supervised undergraduate dental students. The survival rates were calculated using life table analysis. The 1 year survival was 95.4% and 5 year survival was 92.8%. This compares favorably with the 1 and 5 year survival rates (98.4% and 95.3%) seen in this study. It may also allude to satisfactory survival rates being attained by residents as compared to more experienced surgeons in Oral and Maxillofacial Surgery or Periodontics even when the implants are restored by other clinicians in training, but further research on this topic needs to be carried out.

The number of implants failing before prosthetic loading in Kronstrom's study was 4. Another 6 failed after. This is somewhat similar to the failure distribution pattern in this report where 13 were lost before and 26 after

restoration. These results follow those provided by Berglundh (2002) and Pjetursson (2004) where roughly half of implant failures occurred before restoration and the remainder occurred after. The relatively higher proportion of failures occurring after delivery in this study, a full 2/3 of failures occurred after loading, may be due to the selection criteria or the length of follow-up. For restorative context, Kronstrom gives an overview of the prothetic utilization of implants and provides details for some complications. Single crowns were used in the restoration of 64 implants while the remaining implants were restored with 7 FPDs and 33 ODs. These numbers do not directly compare with the treatments provided in Graduate Prosthodontics because the cases in Kronstrom's paper were screened for difficulty before assignment to dental students.

Likewise, prosthetic utilization was not presented in Andreana's 2008 retrospective study but the surgical placement of implants here was performed by residents in Advanced Education in General Dentistry (AEGD), Oral and Maxillofacial Surgery, and Graduate Periodontics. A total of 302 implants used in the treatment of 133 patients, however the numbers are not distinguished by department. A survival percentage of 97.5% is here again a proportion of all implants surviving per all implants observed in the study without regard to time. Because the review covers a substantial period, 1997-2004, the survival percentage of 97.5% does not collate directly with the survival rates given here. A particular value in Andreana's study is the information it provides relevant to the patients' medical histories and smoking status. Such considerations were

not included in this review. No statistical analysis was performed for Andreana's data, therefore the number and type of medical conditions listed simply provide context for discussion and are used to support Andreana's assertion that medically complex patients can be predictably treated with dental implants at the resident level.

Another review with results relevant to the performance of the Oral Surgery Residents in this study is Smith's 2009 article. This retrospective review presented data for 105 patients treated over a 6 year period with 236 implants by OMFS residents at the Royal Dental Hospital in Melbourne, Australia. Smith found the residents achieved a 94% 1 year survival rate and 92.8% 5 year survival rate. These rates are a little lower than the 97.9% and 95.4% survival rates for the same time periods for OMFS residents at the University of Minnesota. Regarding the restoration of these implants, 94 patients received at least one SC, 24 patients received FPDs, and 4 received ODs. The author mentioned that residents in the Graduate Prosthodontics and Implantology programs were providing the restorations but did not elaborate on the number of implants associated with the restoration types or the number of restorations provided by either restorative department. No information about restoration survival or complications were given. It was also uncertain whether all possible failures were included. Only failures that occurred before restoration were presented. The two "late failures" in Smith's review were placement failures that required removal and replacement to facilitate prosthetic restoration, thus it is possible that other failures occurred after loading that were not recorded in the

database available to his program. Placement failures were also observed in this study, two for Graduate Periodontics, one of which was replaced and another that was put to sleep, and one for Oral and Maxillofacial Surgery which was put to sleep. These were included in all failure calculations.

The only study here that reflects solely on the performance of Graduate Periodontal residents is the prospective clinical study carried out by Ricardo Vidal. The prospective nature and inclusion of radiographic bone measurements add value to this study, but its one year follow-up severely limits the applicability of its results. Vidal included 51 patients with 62 implants. The 100% survival rate is not far from the 1 year survival rate of 98.9% for implants placed by Periodontal residents in the current study (see Table 7). A total of 67 implants were identified as being immediately placed in he current study. Periodontal residents at the University of Minnesota performed 50 of these with 1 failure. Oral and Maxillofacial Surgery residents performed 17 with no recorded failures. The most useful evaluation of the implants in Vidal's study was the application of the Pisa Implant Health Scale to quantify the quality of surviving implants. This scale was not used for grading the quality of implant survival in the research presented here as it exceeded the scope of this study's design; however, it would be a useful criteria for further evaluating the survival quality of implants placed by residents in the two disciplines. The prosthetic utilization of implants in Vidal's review was limited to a description of single crowns and overdentures and the results of a patient satisfaction survey.

Although the Mikael Bonde's 2010 publication concerns itself with the outcomes of dental implants placed and restored by supervised dental students, it serves as an interesting comparison for the survival rates of the residents in this study who are only slightly more advanced in training. A total of 45 patients with 49 implants were included Bonde's review and all were recalled for clinical examination of the restored sites. A survival percentage of 94% was given for all implants included in the study. Survival rates over time were not provided. Considering the 3 failures that occurred among the 49 implants over a 10 year period, it is not unreasonable to view Bonde's results as comparable to those in this study. All implants were restored with single crowns which also had a study survival percentage of 94%. The conclusion Bonde reaches about the predictable success of implant treatment provided at this level only seems justified when referenced with the rigorous patient selection criteria and high levels faculty supervision outlined in the paper. Yet, it is at a level of experience not far from these dental students that many clinicians begin their implant training. The amount of faculty/mentor supervision of the residents in this study would be impossible to quantify, as would any difference in the level of supervision by department.

For comparing the survival rates to those in the larger arena of dental literature, the meta-analyses of Pjetursson (2004) and Jung (2008) can be appealed to. Pjetursson (2004) found a 5 year survival rate of 95.4% and a 10 year survival rate of 92.8% for implants supporting FPDs. Jung (2008) recorded a 5 year survival of 96.8% for implants supporting SCs. These rates are very

close to the overall 5 year survival rate of 95.3% observed for all implants placed by both surgical departments at the University of Minnesota. Excluding failures due to fractured implants, the 5 year survival rates for OMFS and PERIO are 95.4% and 96.9% respectively.

Of particular value in the current review is the restorative context that the implants were placed within. A significant majority of PERIO's implants (60%) were placed for restoration with SCs (see Table 16). OMFS placed a little under half (38%) of their implants for restoration with SCs (see Table 15) while nearly 30% of their implants were placed in association with advanced prosthetic restorations (LFDs, UFRs, & LFRs), an amount that doubles the 12.7% that PERIO placed for the same advanced restoration types. Both departments placed a nearly equal proportion of implants in association with FPDs (25.5% OMFS and 22.2% PERIO). It is difficult to provide a reason for the differences in case referral patterns between departments. The administration of a questionnaire to residents in Graduate Prosthodontics might be helpful for elucidating their rationale for referring implant cases to residents in one department or another.

It is also worth noting that most of the implant failures associated with OMFS occurred after prosthetic loading. This can be explained by the average number of observation months per implants by department. The average observation time for all implants placed by OMFS residents was 71 months. The average observation time for all implants placed by PERIO residents was 58 months. Because the average observation time for implants placed by OMFS

was 13 months longer, more time was available for an increased number of implants to be observed during the later years of prosthetic loading (see Table 8). This helps explain the slight divergence in survival rates between departments after the fifth year. The number of implants entering the 5-6 year observation interval was 172 for OMFS versus 131 PERIO (see Tables 6 and 7).

And while the implant survival rates achieved by both surgical departments is reassuring when compared to the dental literature, the survival rates for their subsequent restorations should be considered with caution. The 5 year survival rate for SCs was 83% and 89% for FPDs when all causes for restoration loss were considered (see Table 21). In Pjetursson's 2007 meta-analysis, the estimated 5 year survival rate for SCs was 94.5% with a confidence interval of 91.9-97.5%. For FPDs the 5 year survival estimate was 95.2%, with a confidence interval of 92.7-96.8%. In Jung's 2008 meta-analysis the 5 year survival rate for SCs was 94.5%, with a confidence interval of 92.5-95.9%. The 5 year survival rates for both of the major restoration types seen in this study, SCs and FPDs, were below the lower confidence thresholds presented in the literature. They were also below the lowest survival rates reported by all the articles Jung and Pjetursson analyzed. A rate of 89.6% for SCs after 5 years was reported by Scheller et al.[46]

The reason for these low restoration survival rates is unclear. They could be a reflection of poorly planned and fabricated restorations delivered by Graduate Prosthodontics residents. Or they may be a manifestation of the record selection process predisposing the results towards poor restorative

survival. After all, the charts were selected based on each patient having an appointment within the last 12 months, and patients with complications requiring restoration remake or maintenance would be drawn to the school with increased frequency. Whatever the case, these low restoration survival rates warrant further investigation either with an expanded sample of randomly selected charts or through prospective investigation.

Despite their low survival rates, the complication rates for these restorations compared relatively well to those published in the literature. Pertaining to SCs, Jung reported a 5 year rate of luting cement fracture (decementation) of 5.5% (95% CI: 2.2-13.5%). The 5 year rate for luting cement fracture in this study was 14% for SCCs, which is at the high end of Jung's confidence interval. Of course, the type of luting media and cementation techniques affect these results[47,48] and were not pursued further. Abutment screw loosening was 12% for all SCs in this study, which is comparable to Jung's 12.7% (95% CI:5.7-27%). The higher incidence of screw loosening seen between SCSs (35%) compared to SCCs (9%) in this study is likely due to mechanics and the lack of intervening luting media in SCSs.

Screw fracture had a 5 year event rate of 3% for all SCs in this study as compared to 0.35% (95% CI: 0.09-1.4%) in Jung. Porcelain chipping or fracture was recorded with a 5 year rate of 5% for all SCs in this study compared to 4.5% (95% CI: 2.4-8.4%) in Jung. Goodacre described complications as mean incidences for all implants in his 2003 article. The mean incidence calculation is based on number of events per total number of implants without regard to

prosthesis type or time to event. He reported the occurrence of 6% screw loosening, 2% abutment screw fracture, and 14% porcelain fracture. The mean incidence of these complications in this study are 5.7% screw loosening (40/707), 1.6% screw fracture (11/707), and 1.7% porcelain fracture (12/707). The discrepancy between porcelain fracture incidence will be addressed shortly.

For FPDs in this study the 5 year rate of screw loosening was 5%, for screw fracture, 2%, and for porcelain fracture, 1%. These may be compared with the cumulative 5 year complication rates in Pjetursson of 5.6% screw loosening, 1.5% screw fracture, and 8.8% porcelain fracture. The only noticeable difference here is in the rates of porcelain fracture for FPDs, 1% in this study versus 8.8% in Pjetursson. The small number of porcelain fractures associated with FPDs here also contributes to the low overall incidence of porcelain fracture observed, 1.7% in this study versus 14% in Goodacre. The unexpectedly low rate of FPD porcelain fracture in this study might be due to clinically unnoticed porcelain chipping or chipping that was notice but went unreported. This is unusual because the 5 year event rates for SC porcelain chipping/fracture correlate nicely with Jung's results, 5% here versus 4.5% in Jung.

Most prominent among the complication / maintenance events was the number of luting cement fractures observed among the 63 cement retained FPDs. The 5 year rate of 42.9% for FPDCs was much higher than the loss of retention rate given in Pjetursson of 5.7% (95% CI: 3-11%). The type of cement material may have contributed to this, as some form of Temp Bond (Kerr Corp,

Orange, CA) was used in the initial cementation of 39 of these FPDs. Although decementation is regarded as more of a maintenance issue, the high rate of its occurrence provides yet another reason for further investigating the survival and complication rates of these restorations. Future investigations may want to include restorative material types, opposing occlusion, occlusal scheme, and patient related factors such as parafunction.

In all likelihood the higher than expected 5 year event rates for decementation are due to the inclusion criteria while the lower than expected porcelain fracture rate for FPDs exposes a weakness inherent in retrospective reviews, namely their dependence on accurate observation and notation of events by other clinicians. Despite the shortcomings of this review, the overall implant survival rates appear to be accurate when compared with rates established in similar studies and the comparison of survival rates between departments seems reasonable. It would be interesting to see if a prospective study evaluating the quality of implant survival according to the Pisa Implant Health Scale would yield survival rates that differ in significance from those already obtained in this review.

Conclusion

Based on analysis of data obtained in this review, the null hypothesis is accepted and reiterated: there is no statistically significant difference in the survival rates of dental implants placed by residents in either the Oral and Maxillofacial Surgery or Graduate Periodontics programs at the University of Minnesota School of Dentistry. Within the limitation of this retrospective chart

review for dental implant placed and restored by residents between the years 1994 and 2008, the general objectives were fulfilled. First, the overall 5 year survival rate for all implants was determined to be 95.3%. Second, the 5 year survival rate for implants placed by resident in Oral and Maxillofacial Surgery was determined to be 95.4%. Third, the 5 year survival rate for implants placed by residents in Graduate Periodontics was determined to be 96.9%. Fourth, the restorative survival and complication rates for restorations provided by residents in Graduate Prosthodontics were established for the majority of restorations observed and included a 5 year survival rate of 83% for all single crowns and 89% for all fixed partial dental prostheses. Unexpected variances in the restoration survival and complication rates from values already established in the dental literature reveal the limitations of this review and indicate the need for further research. Although the accuracy of the restoration survival and complication rates is called into question by the nature of the inclusion criteria, the number of complication events demonstrates the importance of informing patients of anticipated, restoration specific outcomes in addition to the predictable implant survival rates.

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