Long-term Complications Associated with Implant-supported Complete Fixed Dental Prosthesis

by

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Abstract

Rehabilitation of edentulous patients with Implant-supported Complete Fixed Dental Prosthesis (ICFDP) is a well-documented treatment option. This dissertation assessed the relation between the rate of biological/mechanical complications and the type of metal framework alloy, length of cantilever extension.

The results showed that long-term clinical outcomes of ICFDP were favorable. While 30% of patients experienced biological complications, 66.6% of the prostheses needed to be repaired during follow-up period. The risk of prosthesis failure and mechanical complications was significantly higher in silver-palladium frameworks as compared with palladium-silver or type IV gold alloys.

The length of cantilever was not correlated with the amount of marginal bone loss. The rate of marginal bone loss around anterior implants was higher than that of posterior implants associated with cantilever segments. The treatment improved the patients’ quality of life and 96% of patients would undergo the same treatment again if required.
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1.0. Introduction

Clinical use of osseointegrated dental implants has improved the quality of life in partially and completely edentulous patients for more than three decades (Brånenmark et al., 1977). Many long term follow-up studies have shown excellent survival rate of dental implants (Lindquist et al., 1996; Lekholm et al., 1999; Roos-Jansåker et al., 2006; Astrand et al., 2008). In contrast to survival rate which is primarily based on implant terminal failure, the concept of “success” in implant-related treatments represents a wider and more realistic range in clinical performance of implant-retained prostheses. Occurrence of biological and mechanical- technical complications may not directly result in implant failure; however, such complications decrease the level of patients’ satisfaction and impose time/financial burden on clinicians (Attard et al., 2005; Kreissl et al., 2007). Long-term success of implant-retained prostheses is influenced by a variety of factors such as quality and design of implants and superstructure, adequacy of surgical and prosthetic techniques, oral hygiene and maintenance, host response and choice of framework and prosthetic components (Zitzmann and Marinello, 2002; Esposito et al., 1998).

Biomechanical patterns of occlusal force distribution and stress transfer from prosthesis through implants to supporting bone can greatly affect the rate of biological and mechanical complications associated with implant supported prostheses (Lekholm et al., 1986; Jenm, 1993). The distribution of these forces is influenced by a variety of different factors such as the amount and quality of bone, number and position of the implant retainers, the design of the prosthesis and cantilever lengths, and also mechanical properties of the metal framework and prosthetic components (Benzing et al., 1995; Patterson et al., 1995; Hobkirk and Havthoulas, 1998).
The stiffness of a metal alloy in the prosthesis cast framework has been identified as an important factor for a more desirable transfer of masticatory forces from the prosthesis to supporting implants and alveolar process (Hulterström and Nilsson, 1991; Watanabe et al., 2000). Beyond rigidity, other required qualities of cast alloys include biocompatibility in the oral cavity, corrosion/tarnish resistance, thermal properties, melting range, compensation for solidification, reasonable level of fabrication complexity and precision of fit of prosthesis to the implants. Type III gold dental alloy coupled with acrylic material was used as the material of choice in the original implant treatment protocol and has continued by many to be used for cast frameworks (Adell et al., 1981). Over the years, primarily due to financial reasons, a number of other alloys were tested in the laboratories as alternatives to gold alloy. Mechanical properties of framework alloys can potentially change the long-term outcomes of the treatment by potentially causing biomechanical and biological complications.

1.1. Metal Alloys in Dentistry

A metal alloy used for fabrication of superstructure framework in implant-retained fixed prostheses needs to provide a suitable combination of biocompatibility, resistance to corrosion, castability, density, stiffness, and low cost. Application of dental alloys using the lost-wax casting technique in dentistry started in mid-1900 when Taggart introduced the lost-wax technique on the fabrication of small cast gold inlay restorations (Taggart, 1907). The wide application of metal alloys for casting inlays in the dental field made it necessary to classify dental alloys on the basis of their specific characteristics. An early classification concept described four groups with slightly different mechanical properties (Coleman, 1926). The four alloy types were labeled as Type I (soft), Type II (medium), Type III (hard), and Type IV (extra
hard). At the time, the chemical composition and the metal content of alloys were regarded as important factors in the field of clinical application of dental alloys. Thus, casting alloys’ “Types” were classified based on a compositional system. In this gold-based classification, the gold content for groups I to IV ranged from 83 to 75 wt %. The hardness of these alloys, which are all solid solutions, is influenced by the solution hardening effect. Type IV alloys can also be further hardened by heat treatment procedure. This makes type IV gold strong and rigid enough to bear mastication forces as the metal framework of long span fixed dental prostheses (FDP) and partial removable dental prostheses (RDP).

In the following years, palladium mainly replaced expensive platinum in those alloys while the content of gold was slightly reduced. As the composition of dental casting noble alloys became more diverse over decades, more inclusive classifications were developed in order to comprise both gold-based and non-gold-based alloys. One such classifications divided dental alloys to “high noble” (≥ 60 wt % noble metals and ≥ 40% gold), “noble” (≥ 25% noble metals), and “predominantly base metal” (< 25% noble metals) (ADA, 1984). Further reclassification subdivided the “high noble” group into four types based on their yield strength (proof stress at 0.2% offset) and elongation percent for each type of alloy (ANSI/ADA Specification No. 5 for Dental Casting Alloys, 1998).

This current classification (Table 1.1) specifies requirements for dental casting alloys used as dental restorations and appliances (Craig and Powers, 2002). Yield strength as the main mechanical property used in this classification system, and essentially represents the maximum ability of an alloy (a metal framework) to endure mechanical stresses before the plastic
deformation happens and the shape is permanently changed. The second mechanical property (i.e. elongation %) predicts the main event following the plastic deformation of an alloy and reflects the capacity of an alloy to withstand mechanical stress causing plastic deformation before it results in the ultimate fracture. Alloys with low elongation percent are relatively brittle which is not desirable in most cases.

Table 1.1) Classification of high noble dental alloys based on mechanical properties, ANSI/ADA Specification No.5

<table>
<thead>
<tr>
<th>Type</th>
<th>Hardness</th>
<th>Yield S. (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Soft</td>
<td>&lt; 140</td>
<td>18</td>
</tr>
<tr>
<td>II</td>
<td>Medium</td>
<td>140-200</td>
<td>18</td>
</tr>
<tr>
<td>III</td>
<td>Hard</td>
<td>201-340</td>
<td>12</td>
</tr>
<tr>
<td>IV</td>
<td>Extra-Hard</td>
<td>&gt; 340</td>
<td>10</td>
</tr>
</tbody>
</table>

The application of types I and II gold alloys (high noble) has been limited to small inlay/onlay restorations due to their low yield strength. Modern tooth-colored direct restoration; however, has to a large extent eliminated the need for direct gold cast restorations. Types III and IV on the other hand, have been in service for full-metal and metal ceramic crowns and bridges for a long period of time. According to the periodic table of the elements, there are eight elements as noble alloys: gold, platinum, palladium, rhodium, ruthenium, iridium, osmium and silver. Silver, however, is not considered as a noble metal in dentistry due to its instability and reactivity in oral cavity environment which may cause localized tissue response or systemic side effects (Braemer, 2001; Geurtsen, 2002). The common physical property among the other seven noble metals is
their tarnish and corrosion resistance. In dental standards, gold, platinum and palladium are considered as the main metals in dental casting alloys. Most of the high noble alloys are used in fabrication of metal-ceramic prostheses since they form a thin surface layer of oxide facilitating the chemical bond (covalent bond) between metal and ceramic. High noble alloys available in market may be divided into different subdivisions such as Au-Pt-Pd, Au-Pd-Ag, Au-Ag-Pt, Au-Pd-Cu-Ag etc. (Craig and Powers, 2002).

When comparing the composition of type I to IV alloys in table 1, it is noticed that the hardness of high noble alloys increases as the nobility of alloys declines and the noble content of the alloy is replaced with base metal constituents. This phenomenon can be directly attributed to “solid solution strengthening” process. Historically, dental gold alloys contain as many as four other main constituents (platinum, palladium, silver and copper). These metallic atoms commonly replace the gold atoms in their ordered-set (lattice) positions (substantialion solid solution strengthening), which impedes the dislocation motion within the microstructure of gold alloys. Also, it is known that the presence of metallic atoms such as copper in a super-saturated solid solution can result in “precipitate hardening” due to the emergence of a second phase through age-hardening procedure and phase transformation (Uzuka et al., 1981). This type of heat treatment is occasionally used in type IV alloys in order to achieve high yield strength values up to 450 MPa. However, non-noble metals are prone to corrosion. Therefore, there will be a counterbalance between corrosion-resistance properties and the hardness achieved through hardening procedures. A detailed description for the complicated hardening mechanisms and their effects on the physical properties of dental casting alloys is beyond the scope this research project (Anusavice, 2003).
The main constituents of commercial “high noble” and “noble” dental casting alloys (ADA compositional classification) are very similar. Nonetheless, noble metals may contain a number of different metals, which makes them a rather diverse group. The silver content of most “noble” alloys is markedly higher that of high noble alloys (Craig and Powers, 2002). Therefore, higher amount of palladium in noble alloys is required since palladium counteracts the sulfide tarnishing effect of silver and prevents porcelain discoloration in metal ceramic prostheses. X-ray photoelectron spectroscopic analysis has shown that an enriched layer of palladium below the silver sulfide layer can markedly decrease the thickness of tarnishing sulfide layers (Lang et al., 1982; Suoninen et al., 1985). At the same time, addition of palladium offsets the unfavorable mechanical properties of silver in low-gold noble alloys. While silver decreases the melting range and considerably raises the percent of elongation and ductility of the alloy, palladium elevates the melting range and increases the hardness and tensile strength of the alloy. One may consider four subclasses for noble alloys: 1) Au-Cu-Ag-Pd; 2) Pd-Cu-Ga; 3) Pd-Ag; 4) Ag-Pd. (Wataha, 2002).

Unlike to the other subdivisions in noble alloys, Au-Cu-Ag-Pd alloy shows relatively low solidus temperatures. Low solidus temperature makes this alloy unsuitable for metal-ceramic prostheses and it may be attributed to the low amount of Pd (only 5%) in this alloy. Generally speaking, noble alloys possess yield strength and modulus of elasticity values higher than those of high noble alloys due to high content of palladium (Wataha, 2002). Different variations of high-palladium alloys with more than 75% Pd have been introduced from this group over the past three decades. High-palladium alloys are used for metal-ceramic restorations, all-metal restorations, implant-retained prostheses (Carr and Brantley, 1991), and potentially for
removable partial denture framework (Asgar, 1988). The strengthening mechanisms for high-palladium casting alloys are complicated. Substitutional / interstitial solid solution strengthening due to the presence of different solute elements in palladium’s face-centered cubic (fcc) crystal structure (Mezgar et al., 1988), additional strengthening from the dendritic (coring) structure or inter-dendritic constituents, presence of harder secondary phases (Odén and Herø, 1986) and the eutectic constituent in fine-grained alloys (Brantley et al., 1999) are considered as the main mechanisms of improving the yield strength values of this class of alloys.

Palladium-silver and silver-palladium alloys, introduced in the 1970s, have been used for full-cast restorations, metal-ceramic prostheses and superstructures of implants supported prostheses. The composition of these alloys forms a diverse range of systems from those mainly silver based to those with higher amounts of palladium. This has caused confusion in the dental literature since there is no standardization in the terminology when the names of these two different groups of alloys are addressed in dental metallurgic articles (Goodacre, 1989). While Ag-Pd alloys contain 70% Ag and 25% Pd, Pd-Ag alloys demonstrate an almost reversal composition of Pd (60%) and Ag (30%). Palladium and silver are completely soluble with each other in the solid state and form a continuous series of solid solution without any phase transformation, as shown in the Pd–Ag binary alloy diagram in Figure 1.1 (Craig and Powers 2002).

Small percentage of low melting point metals such as In and Sn is added to these alloys in order to facilitate metal-ceramic bonding. At the same time, the added elements improve castability of the alloy by increasing molten metal fluidity (Anusavice, 2003). It has been shown that the
presence of such small amounts of In and Sn changes the single-phase binary system of 
palladium and silver solid solution alloys into a multi-phase non-equilibrium phases and micro-
segregation system which contains precipitates following porcelain baking heat treatment 
(Vermilyea et al., 1996). It should be noted that heat treatment hardening cannot be performed 
for simple solid solution binary palladium silver alloy systems since further phase transformation 
will not be achieved. Therefore, Sn and In play a key role in micro-structural changes during 
annealing heat treatment of silver palladium alloys (Guo et al., 2003). Annealing procedure of 
Pd-Ag is accomplished through a staged aging process when primarily a meta-stable ordered 
face-centered tetragonal (fct) phase based on Pd₃In is formed within the grains. At this stage the 
coherency strain and hardening of the alloy is due to the coherency strain between the meta-
stable fct structure and the fcc crystal structure of the matrix (Hisatsune et al., 1990).

![Figure 1.1) Phase diagrams for binary combinations of silve-palladium (Craig and Powers, 2002)](image)

*Atomic percentages: bottom line - Weight percentages: top line. L: liquidus; S: solidus.*
Although Ag-Pd and Pd-Ag alloys are virtually a continuum of the same casting alloy, their mechanical properties and clinical performance are quite different. In general, the silver based alloy (Ag-Pd) is currently less common in dentistry and exhibits inferior yield strength, hardness and modulus of elasticity along with a far more tendency towards corrosion. Because of its high silver content, Ag-Pd forms a thin layer a tarnishing silver sulfide leading to a green hue in porcelain (Wataha et al., 1998). Also, it has been demonstrated that Ag-Pd alloys exhibit less resistance to corrosion and sulfide tarnish as the concentration of silver increases in the system. Corrosion process in Ag-Pd initiates from grain boundaries and propagates into the grains (Vaidynathan and Prasad, 1981).

Since its introduction in 1970’s, Ag-Pd has been applied for metal-ceramic restoration; but, the inherent hydrodynamic instability of the alloy has limited its application to mostly full-metal restorations. It must be noted that the density of Ag-Pd alloy is considerably lower than that of gold alloys. This causes a lower “g-force” generated by the molten alloy during the casting process. For this reason, casting Ag-Pd alloy is considered a technique sensitive procedure in which the casting temperature and mould temperature have to be closely controlled. On the positive side, Ag-Pd alloys are cheaper, show rather low sag tendency and also very easy to be soldered.

Unlike silver-palladium, Pd-Ag has achieved widespread popularity as a dental casting alloy. A part of this popularity can be attributed to its superior mechanical properties which make it suitable for multi-unit bridges. During 1990’s and due to high demand for palladium in automotive industry (Anusavice, 2003), the price of this alloy soared and its consumption in
dentistry dropped. Since the price of Pd is currently much lower than that of gold, high-palladium alloys have regained their popularity in the field of prosthetic dentistry. The low intrinsic cost of these alloys combined with their lower density make them a good economic alternative for traditional gold-based alloys; however, there are a few technical difficulties related to their casting process. The most highlighted problem associated with the use of high palladium dental alloys is the high melting point of palladium (over 1400° C) which results in high melting ranges of the Pd-Ag alloys containing more than 60% Pd. Obtaining good clinical fit of these alloys with such high solidus temperature heavily depends on precise compensation for casting shrinkage. Moreover, atmospheric gases instantly incorporate with the liquidus state of Pd-Ag alloys and interact with their metallic ions (Huget and Civjan, 1974). This phenomenon, in the absence of well-designed sprue arrangements can cause a high rate of porosity in the castings investment. Thus, successful fabrication of Pd–Ag casting alloys requires strict adherence to dental laboratory procedures.

1.2. Implant Superstructure Frameworks

In the original prosthetic framework introduced by Brånemark, gold alloy framework needed to be soldered to gold alloy cylinders. The superstructure was next connected to transmucosal abutments using gold screws (Brånemark et al., 1977). Early attempts to find a clinically reliable alternative to gold alloy frameworks for implant-retained prostheses include using silver-palladium alloy (Ag–Pd) (Leung et al., 1983; Cox and Zarb, 1985), chromium-cobalt (Cr-Co) (Chao et al., 1988) and later titanium (Bergendal and Palmqvist, 1999) frameworks. Zarb and Symington (1983) reported acceptable clinical characteristics of Ag-Pd alloy as an option for fabrication of implant superstructure framework and described this alloy's ability to withstand
occlusal loading. Nevertheless, an alloy with higher modulus of elasticity can distribute masticatory forces more evenly among implants with less cross-sectional thickness of framework (Chao et al., 1988; Hulterström and Nilsson, 1994). It would appear that high moduli alloys are capable of distributing the imposed loadings uniformly over the osseointegrated implants. The elastic modulus of a cobalt-chromium alloy is typically 200 to 220 GPa, approximately twice as high as gold or Silver-Palladium alloys (90-95 GPa) routinely used for metal frameworks. Compared with gold alloys, Co–Cr alloys are harder and present a lower specific weight (density), good tarnish and corrosion resistance, lower cost and higher modulus of elasticity (stiffness). However, Co–Cr alloy exhibits less detail definition, has a higher melting point, is more difficult to finish/polish and shows greater casting shrinkage which makes it necessary to use special casting equipment and investment materials (Goodacre, 1989; Hulterström and Nilsson, 1994).

1.3. Long-term Outcomes of Implant-supported Complete Fixed Dental Prostheses

The impressive long-term success of implant-supported Fixed Dental prostheses in edentulous patients reached already 30 years (Adell et al., 1981). In this classic article, the authors reported that marginal bone loss around implants supporting fixed complete dentures after one year of loading ranged from 1.3 to 1.5mm for maxilla and 0.8 to 1.4 mm in mandible with an annual 0.1 mm of bone loss thereafter. Considerably high cumulative survival rate of the placed implant (over 80% in maxilla and over 90% in mandible) have since been corroborated by other investigators (Lindquist et al., 1996; Ekelund et al., 2003; Lekholm et al., 2006; Jemt and Johansson 2006; Astrand et al., 2008).
When assessing the long-term outcomes of dental implant treatments, clinicians are more concerned about implant survival rate, prognosis of prosthodontic treatment and the incidence of biological/mechanical complications. One the other hand, patients consider physiological, functional and social impacts of treatment, cost effectiveness and benefits from the rehabilitative treatment as the most crucial factors. While in earlier years radiographic measurements of bone loss was considered as the main prognostic criterion to evaluate the success of implant treatment (Alberktson et al., 1986), Buser et al. (1991) introduced alternative evaluation criteria using quantitative patient-oriented methods to measure the success rate. One may conclude that developing reliable evaluation criteria to assess clinical and psychological outcomes of treatment cannot be possible without merging the above mentioned approaches (ADA, 1993). This means that evaluation of long-term outcomes of implant-supported prosthodontic treatments cannot be solely limited to the success rate of implant integration. A review of the literature shows that incidence of soft tissue and bony complications along with the long-term prosthetic stability of the restorations can significantly affect the success of the treatment (Berglundh et al., 2002; Bryant et al., 2007). Therefore, high rates of biological and technical complications affiliated with implant-retained prostheses cannot be ignored.

Biological complications may be defined as inability of host tissues to establish or to maintain osseointegration. These complications are generally divided into early (pre-osseointegration) and late (post-osseointegration) complications where the former refers to a failure to establish osseointegration while the latter involves the breakdown process of otherwise established osseointegration. Incidence of early complications due to excessive surgical trauma, patient-mediated impaired healing process, premature loading and infection (caused by systemic or
iatrogenic factors) interferes with the osseointegration process, and eventually leads to the early failure of the affected implants (Esposito et al., 1998). Late implant failure which is caused by a disruption of the bond between implant and the surrounding bony structure occurs after loading the osseointegrated implant with prosthesis. Occurrence of late failures has been attributed to overloading the implant, chronic bacterial infection (peri-implantitis), and unfavorable immune host response to either implant or the toxic ions released from implants (delayed hypersensitive reaction) (Esposito et al., 1998).

One important factor determining the prognosis of an implant-retained prosthesis is the integrity of the implant-tissue interface at the crestal alveolar bone around the implant (Alberktsson et al., 1986; Smith and Zarb, 1989). Recording the marginal bone loss over time is a valuable predictor of the long-term clinical performance of implants since the gradual bone loss can eventually result in implant failure. Long-term follow-up studies suggest that Brånemark titanium implants, placed according to the original surgical/prosthetic protocols, show a reasonable amount of marginal bone loss of approximately 2 mm after 15 years with a 0.1 mm of yearly resorption following the first year (Lindquist et al., 1996; Attard and Zarb, 2004). In a systematic review (Bryant et al., 2007) including randomized controlled trial (RCT) studies with follow-up periods of at least one year and consecutively treated cases in prospective or retrospective studies with follow-up periods of at least five years, it was concluded that the bone loss for maxillary fixed complete dentures during the first year of function ranged from 0.02 to 0.55 mm and thereafter showed an average annual value of 0.0 to 0.2 mm. The respective values for mandibular fixed complete dentures varied from 0.09 to 0.80 mm and from -0.14 to 0.13 mm (Bryant et al., 2007).
The effect of oral hygiene on crestal bone loss has been reported by Linquist and coworkers (1996). They found an average of 0.6 mm increase in marginal bone loss over a ten-year period when patients with poor oral hygiene were compared to those with good hygiene. It has been hypothesized that microbial colonization of the implant surface located near the level of alveolar bone crest may initiate an inflammatory process in peri-implant tissues resulting in an increased rate of marginal bone loss (Adell et al., 1981; Jansen et al., 1997; Broggini et al., 2006) and higher risk of peri-implantitis (Quirynen and Van Steenberghe, 1993; Persson et al., 1996). In order to eliminate the effect of bacterial leakage and consequential bone loss, manufacturers have introduced internal connection and platform switching concepts; however, both flat-to-flat and internal conical connections show some degrees of bacterial microleakage at the implant-abutment connection interface (Quirynen and Van Steenberghe, 1993; Steinebrunner et al., 2005; Harder et al., 2010). Interestingly, lower proportions of motile organisms and spirochetes are detectable in fully edentulous patients rehabilitated with fixed implant supported prostheses showing decreased levels of pathogenic species when compared with partially edentulous patients (Mombelli et al., 1988; Mombelli and Mericske-Stern, 1990; Denser et al., 1997; Quirynen et al., 2002). This suggests that other factors such as the prosthesis design and its mechanical properties along with occlusal forces may play important roles in marginal bone loss phenomenon in fully edentulous patients treated with implant-retained prostheses.

The effect of different biomechanical aspects of implant treatment on the clinical outcomes of implant-retained prostheses has been assessed by many investigators (Skalak, 1983; Lindquist et al., 1988; Rangert et al., 1989; Naert et al., 1992; Jemt and Book, 1996). Occlusal force has been widely regarded as an influential factor affecting the rate of marginal bone loss or loss of
osseointegration in dental implants (Adell et al., 1981; Lindquist et al., 1988; Quirynen et al., 1992; Naert et al., 1995). It has been theorized that mechanical stress/strain beyond the physical limits of hard tissues can cause both initial and long-term bone loss around implants (Misch and Bidez, 1994). Based on this theory, Misch and Bidez proposed the concept of “implant-protected occlusion” which promotes reduced occlusal forces on implant prostheses through different methods including smaller tables of occlusion in order to protect the implants. Although several animal studies attempted to demonstrate the direct correlation between occlusal overload and the rate of bone loss in dogs (Hoshaw et al., 1994), monkeys (Isidor, 1996; Miyata et al., 1998) and rabbits (Duyck et al., 2001), other animal model studies did not indicate a causal association between occlusal overloading and crestal bone loss around osseointegrated implants (Ogiso et al., 1994; Wehrbein et al., 1997; Hürzeler et al., 1998; De Pauw et al., 2002).

Meanwhile, longitudinal clinical studies did not indicate any established relation between the bone loss around implants and occlusal wear or clinching habits (Carlson et al., 2000; Engel et al., 2001). There are also a few in vivo studies reporting increased marginal bone levels due to “new bone formation” under certain loading conditions (Gotfredsen et al., 2001; Melsen and Lang, 2001) and following long-term periods of function (Henry et al., 1993; Naert et al., 1999). A more recent systematic review including only studies with at least 5 years of follow-up periods (Aglietta et al., 2008) revealed that there was no correlation between the presences of cantilevered segments and the rate of marginal bone loss in implant-retained fixed dental prostheses with cantilever extensions (ICFDPs). The authors concluded that “no detrimental effects on bone levels were observed around implants in the proximity of cantilever extensions”. Other systematic reviews confirmed this conclusion (Zurdo et al., 2009; Greenstein and
Cavallaro, 2010). In another systematic review, Salvi and Brägger (2009) expressed their surprise to see the negligible and clinically insignificant effect of technical/mechanical risk factors such as overloading, non-axial loading, and biomechanical stress on the level of bone surrounding dental implants. One would assume that excessive experimental loading may lead to progressive bone loss and ultimately implant failure; however, it is difficult to find a direct relation between occlusal overload and the loss of osseointegration in patients.

While the scientific evidence to identify the effect of occlusal overloading on the marginal bone surrounding implant seems contradictory and unclear, it is well-known that adverse occlusal forces can cause mechanical complications in superstructures and implant components (Sones, 1989; Goodacre et al., 1999; Schwarz, 2000; Goodacre et al., 2003; Salvi and Brägger, 2009). Burghgardt and colleagues (2002) in a systematic review of longitudinal prospective studies showed that mechanical complications related to implant components and superstructures were more frequently reported than biological complications. Mechanical complications occur after the prosthodontic treatment following initial successful osseointegration and may be attributed to incompatibility of mechanical properties of the implant-prosthesis assembly and biological factors. An evaluation of the underlying factors causing mechanical complications and their potential consequences can contribute to a better understanding of the criteria affecting the success rate of implant treatments.

Historically, mechanical complications represent a wider range of interpretations when compared to implant survival rate which simply defines the end point of implant failure (Bryant et al., 2007). Thus, the literature depicts an inconsistent view for the rate of different technical
complications mostly due to variable definitions of events, visits and occasions requiring prosthetic maintenance. In classic articles, only the total disintegration of implant from the surrounding bone and complete loss of prostheses were considered as a failure. Therefore, no information is reported on prosthetic complications such as abutment/prosthetic screw loosening and/or fracture, acrylic/porcelain tooth fracture, acrylic resin base fracture, metal framework fracture and damages to the opposing dentition/prosthesis in this group of papers (Babbush et al., 1986; Cox and Zarb, 1987; Alberktsson et al., 1988; Adell et al., 1990; Buser et al., 1991; Buser et al., 1997). Adell et al were the first investigators reporting on mechanical complications following a long-term observation. They faced with 4.9% fractures of bridges, 1.5% fractures of prosthetic screws and 3.0% fractures of abutment screws. All of the mechanical complications were attributed to under-dimensioning components and/or inadequate stress distribution (Adell et al., 1981).

Goodacre and co-workers (2003), in an attempt to summarize clinical data regarding different types of complications associated with implant treatments, reviewed the literature from 1981 through 2001. They combined the raw data of each particular complication from all studies reporting that complication and calculated the mean frequency value for each complication in order to depict the occurrence trend of various complications. It was concluded that aside from loss of retention in overdentures, “esthetic veneer fracture (resin)” is the most frequent complication in implant prostheses (22%) while the frequency of prosthetic/abutment screw loosening and fracture ranged from 2 to 7%. Interestingly, the rate of metal framework fractures (3%) was slightly higher than that of abutment screw fractures (2%). As it is expected, implant fracture was a very rare incident (1%). In contrast to the above mentioned paper, Bryant and
colleagues in their systematic review (2007) stated that they were not able to analyze mechanical complications and the maintenance required for the implant-retained dental prostheses in detail due to the lack of consensus in reporting prosthetic problems. They defined general categories, including the rate of (1) continuous prosthesis stability, (2) prosthesis failures or remakes and (3) a need for major modification, in order to assess prosthetic treatment success. It was concluded that the rate of continuous prosthesis stability was generally high, ranging from 88 to 100% in minimum five years of follow-up. However, the other two measures rendered highly variable results (Bryant et al, 2007).

One of the most interesting long-term studies to review the mechanical complications associated with implant treatments is “Toronto Study” (Cox and Zarb, 1987; Zarb and Schmitt, 1990; Attard and Zarb, 2004). The first follow-up reports on this study (Cox and Zarb, 1987; Zarb and Schmitt, 1990) do not present much detailed data about the mechanical complications encountered over the observation period; however, they bring up a few interesting points. It was noted that the clinical and laboratory restorative techniques adopted from conventional prosthodontics need to evolve based on a careful scientific scrutiny in order to minimize the frequency of the mechanical complications. One of the most striking results of this first North American prospective study is the markedly high rate of metal framework fractures which occurred in 26.5% (13 out of 49) of the prostheses. This is in a clear discrepancy with the previous results (Adell et al., 1981) which demonstrated only 5% of any prosthetic fractures. In order to explain such a high rate of framework fractures, the authors (Zarb and Schmitt, 1990) pointed out the inherent susceptibility of cantilevered segments in implant-retained fixed dentures. They recommended an increased cross-sectional region of metal framework and a
maximum length of 20 mm of cantilevered segments. They also addressed the inadequacy of mechanical properties of the silver-palladium alloy which had been used originally (Albacast, Pennwalt Jelenko, Armonk, N.Y.; 68% Ag, 26% Pd and 5% In+Zn) as the metal framework in the study (Zarb and Symington, 1983). Actually, the dramatic result conflicts with the general statement made by the authors in this paper that “Silver-palladium possesses physical properties that parallel those of type III gold alloys, with yield strength properties in the same general range” (Zarb and Symington, 1983, p.272). In response to the specific mechanical complication, a different type of silver-palladium alloy (Palliag M, De Gussa, Teterboro, N.J.; 58.5% Ag, 27.4% Pd, 10.5% Cu, 3.5% Au+Zn) with superior mechanical properties was adopted to fabricate new prostheses (Cox and Zarb, 1987; Zarb and Schmitt, 1990).

In order to assess the effect of metal alloys’ mechanical properties on the clinical performance of implant-supported complete fixed dental prostheses, a prospective study (Murphy et al., 2002) attempted to compare the mechanical complications in prostheses fabricated with gold alloy (Chicago IV: 65% Au, 14% Ag) frameworks versus those of similarly designed prostheses made with silver-palladium alloy (Palliag M: 58.5% Ag, 27.4% Pd) frameworks. Over a five-year follow-up period, no metal framework fracture was observed while 11 and 13 incidents of screw-loosening were reported for gold and silver-palladium framework groups, respectively. Only two denture teeth fractured from the frameworks in each group. The authors concluded that the clinical performance of both alloys, despite differences in mechanical properties, was very similar over 5 years. However, it is noteworthy that the length of cantilevered segments in this study was kept as short as maximum 10 mm. It is not clear how the clinical performance of those alloys would have been if longer cantilever segments would be incorporated in the
prosthetic design. Also, considering fatigue factor, it will be interesting to see the clinical outcomes of the two groups after longer periods of follow-up. No further follow-up report has been published from the authors since 2002 (Murphy et al., 2002).
2.0. Rationale and the Purpose of the Study

Limited available bone for implant placement makes cantilevered prostheses an inevitable option. However, the clinical performance of cantilevered implant-retained frameworks can be unfavorably affected if the metal framework is fabricated from an alloy with inferior mechanical properties and/or poor solder joints, or where the cross-sectional thickness of the framework is inadequate. An excessive cantilever length, especially in patients with parafunctional habits, will make the matter even worse. It has been speculated that the presence of cantilevered segments can significantly amplify the magnitude of forces exerted on the adjacent implants due to bending moments (Skalak, 1983; Osier, 1991; Patterson et al., 1995). It is thought that distal side of the nearest implant to the cantilever arm is subjected to the highest amount of loads (Skalak, 1983; Sertgöz and Güvenen, 1996). The biological response of bone to this extra load is yet to be clear since the evidence on the contribution of prosthetic components in marginal bone loss is inconsistent. However, it can be hypothesized that overloading and unfavorable restorative factors increase the rate of mechanical complications over long periods of function, particularly due to fatiguing factors. Mechanical complications take place when the occlusal forces exceed the proportional limit (permanent deformation) or the ultimate strength (catastrophic fracture) of the materials (metal alloy and acrylic resin).

Rangert et al (1989), using a simplified model, showed that in the case of distally cantilevered fixed implant-retained complete dentures, masticatory forces are absorbed by the cantilever arm while the most distal implant is subjected to compression forces as the fulcrum (“see-saw” effect) and the mesial implant will be under tension forces [Figure 2.1].
The mechanism of force dissipation in the above mentioned model is related to the length of the cantilever arm, mechanical properties of the cantilever and the thickness of the cantilevered segment. By decreasing the length of cantilever arm and increasing the cross-sectional thickness of the framework, the rate of mechanical failures can be efficiently controlled. Nonetheless, it is necessary to use metal alloys with favorable mechanical properties. Lack of support from a framework with insufficient mechanical properties (low modulus of elasticity and low yield strength) results in an unfavorable distribution of the occlusal load, bending moment of the system, and eventually fracture of the metal framework from the weakest point. Even if occlusal force does not go beyond the proportional limit of the metal alloy, it may be high enough to reach the ultimate strength of the acrylic resin base and veneering resin teeth. In this case a fracture in the acrylic components of the prosthesis will be expected. Therefore the risk of biological and mechanical complications might be directly related to the mechanical properties of the metal frameworks’ alloy.
The purpose of this study is to quantify the post-insertion biological and mechanical complications related to the prosthetic treatment of edentulous patients treated with implant-retained fixed dental prostheses in patients treated in a prosthodontic specialty clinic. Over the years in the prosthodontic specialty clinic, the type and range of alloys have changed. Thus, it is also aimed to compare the performance of implant-retained fixed complete dentures made from a silver-palladium alloy metal framework versus that of other types of alloy frameworks.

2.1. Null Hypotheses

1) There is no biological and mechanical complication rate difference between implant-supported fixed dental prostheses (ICFDPs) with silver-palladium alloy framework and those made from other types of alloy framework.

2) There is no correlation between the amount of marginal bone loss around implants supporting ICFDPs and the length of cantilever segments of the ICFDP.
3.0. Materials and Methods

3.1. Patient Selection

Patients in this retrospective study were those with edentulous mandible, treated at the IPU Centre (University of Toronto, Canada) from 1980 to 2000. A total number of 30 patients were included in the study. All implants for these patients were placed before the year 2000. The protocol was submitted to the Research Ethics Board of the University of Toronto (U of T) in order to obtain ethics approval prior to commencing the study. All patients signed a consent letter prior to clinical examinations according to University of Toronto, Faculty of Dentistry policy (Appendix B).

3.2. Implants Surgery and Prosthetic Components

Patients included in this study had received Brånemark implants (Standard, MKII, MKIII or MKIV: Nobel Pharma/Biocare AB, Gothenburg, Sweden) to retain “Implant-supported Complete Fixed Dental Prostheses” (ICFDP). In total, 153 implants were placed for 30 patients. In three patients, 6 implants were placed to provide greater support for ICFDPs since the occlusal forces for these patients were expected to be more than average. The remaining 27 patients received 5 implants each to support their prostheses. A two-stage surgical procedure according to the original Brånemark protocol was strictly followed. Four to six implants were placed into the body of the mandible in the region between the two mental foramina. The second-stage surgery was performed 4 to 6 months later by exposing the implants and replacing the cover screws with titanium cylindrical transmucosal abutments. The length of the abutments was chosen based on the thickness of patients’ muco-periosteum. Titanium abutment screws were used to attach the
abutments to the implants (35 NCm). The After 4 weeks of soft tissue healing, the prosthetic phase started [Figure 3.1].

![Figure 3.1) Steps involved in second stage surgery: Replacement of the cover screws with transmucosal abutments](image)

(Adopted from: Adell et al., 1981)

Fabrication of ICFDP has been explained in details elsewhere (Zarb and Symington, 1983). In brief, a metal framework was fabricated on transmucosal abutment analogues on the master model. The metal framework was cast using different metal alloys as follows:

a) Silver-Palladium alloys (Modulus of Elasticity: 88 to 93 GPa) (Wataha and Messer, 2004):
- **Albacast**, Jelenko, New Rochelle, NY; (68% Ag, 26% Pd, 5% In+Zn)

- **Palliag M**, De Gussa, Teterboro, NJ; 58.5% Ag, 27.4% Pd, 10.5% Cu, 3.5% Au+Zn)

b) Palladium-Silver alloys (Modulus of Elasticity: 125 GPa) (Watha and Messer, 2004):

- **A37 NOBLE** palladium alloy (high palladium noble metal-ceramic alloy)

- **Degubond Ultra**, Degussa AG, NJ; (2% Au, 74.4% Pd, 12.5% Ag, 8.3% Cu)

c) Gold Type IV alloy, 58% Au (Modulus of Elasticity: 120 GPa) (Manufacture’s brochure):

- **Esteticor Implant 58**, Cendres & Métaux, SA; (58.5% Au, 29% Pd, 8% Ag, 4.5% Sn)

- **Stabilor G**, Degudent, Benelux BV, (58% Au, 5.5% Pd, 23.3% Ag, 12% Cu)

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>Commercial Brands</th>
<th>Principle Metal</th>
<th>Modulus of Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver – Palladium (Ag-Pd)</td>
<td>Albacast</td>
<td>Silver (58-68%)</td>
<td>88-93 GPa</td>
</tr>
<tr>
<td></td>
<td>Palliag M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palladium – Silver (Pd-Ag)</td>
<td>A37 NOBLE</td>
<td>Palladium (70-75%)</td>
<td>125 GPa</td>
</tr>
<tr>
<td></td>
<td>Degubond Ultra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold Type IV (Au Type IV)</td>
<td>Esteticor Implant 58</td>
<td>Gold (58%)</td>
<td>120 GPa</td>
</tr>
<tr>
<td></td>
<td>Stabilor G</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1 Type, composition and modulus of elasticity of the commercial metal alloys used in this study

After confirming the fit and passivity of the framework on the abutments, acrylic denture teeth and commercial methyl methacrylate were processed on the framework. Prostheses (ICFDPs) were attached to transmucosal abutments using small prosthetic gold screws (bridge screws).

3.3. **Recall Procedure**

A total number of 136 patients were invited by letter followed up by a phone call to attend an examination visit. Thirty patients (22%) replied to the invitation letters and agreed to attend a
recall clinical examination. The medical and dental histories were gathered using a questionnaire. Recordings were made of general and local factors which may affect the incidence of biological and mechanical complications associated with the implants and prosthetic superstructures. This included the occurrence of systemic disease since implant placement, regular medications used by patients, smoking status, dental treatment received since implant placement, recall frequency at the dental hygienist and the last dental examination appointment.

3.4. Collection of Data from Patients’ Charts

General information was gathered from the patients’ charts. Patients’ age, self-reported smoking habits and the number of cigarettes per day, medical history, medication intake, reason for tooth loss and the date of prosthesis insertion were recorded in “patient’s summary forms” (Appendix.1). Type of the alloy in frameworks, type, number and distribution of implants were retrieved from patients’ charts. All patients’ chart documentations were closely reviewed and different biological or mechanical complications during the follow-up period were recorded.

3.4.1. Bone Quality and Quantity:

Patients’ bone quality and quantity were recorded by the surgeon at the time of implant placement according to Lekholm and Zarb (1985).

3.4.1.1. Bone Quality: Patients’ alveolar bone quality was divided into four groups:

- Type I: Very dense bone composed of almost all cortical bone mass
- Type II: Coarse trabecular bone covered by a thick crestal layer of cortical bone
- Type III: Fine trabecular bone covered by a porous crestal layer of cortical bone
- Type IV: Primarily fine trabecular bone and often the absence of cortical bone
3.4.1.2. **Bone Quantity**: Bone quantity was divided into five categories:

- Type A: Virtually intact alveolar ridge
- Type B: Minor resorption of the alveolar ridge
- Type C: Advanced resorption of the alveolar ridge
- Type D: Initial resorption of the base of the dental arch
- Type E: Extreme resorption of the base of the dental arch

Figure 3.2 demonstrates different bone types according to Lekholm and Zarb (1985):

![Bone Types Diagram](image)

*Figure 3.2) a- Bone Quality ; b- Bone Quantity (Adopted from: Lekholm and Zarb, 1985)*

3.4.2. **History of implant loss (biological complication)**:

Period of service before failure was traced in months for each lost implant.
3.4.3. *History of peri-implant mucositis or peri-implantitis (biological complication):*

Any recorded incidence of inflammation and suppuration related to the gingival tissue surrounding implants in patients’ charts was gathered (Section 3.7.).

3.4.4. *History of various mechanical problems encountered following the insertion of superstructures (mechanical complications):*

Any history of mechanical complications such as prosthetic/abutment screw loosening/fracture and incidences of cracks, chippings and fractures in resin teeth, acrylic body and metal framework of prostheses was recorded. Loss of composite resin filling out screw access hole was excluded from the list of mechanical complications.

3.5. **Radiographic Examination**

Two sets of peri-apical radiographs were used to determine the amount of marginal bone loss at the interproximal sides of each implant. The baseline reference level of supporting bone was determined using radiographs taken immediately after implant placement at the day of “stage-one” surgery. These post-operation peri-apical radiographs were retrieved from patient’s charts and used as the reference. Peri-apical x-rays taken (long cone parallel technique) on the day of recall were used to evaluate and measure the supporting bone level for each implant. While parallel technique using a standardized jig is recommended to assess minute crestal bone level changes (Jacobs and van Steenberghe, 1998), it may not be possible to apply the paralleling technique without additional devices to ensure true parallelism. To avoid this problem, the height of the marginal bone on mesial and distal of each implant was recorded using the implant threads as a dimensional reference.
All Brånemark implants evaluated in this study (regular platform) had a uniform thread profile with standard pitch size of 0.6 mm. Therefore, the measurement was based upon the known distance between implant threads. The implant-abutment interface was considered as the reference point for the supporting bone level in each implant [Figure 3.3]. Ahlqvist et al. (1990) demonstrated that peri-apical x-rays can detect peri-implant bone loss when it exceeds 0.47 mm. This supports the use of the implant threads (0.6 mm) as a measurement scale. Reference bone levels on mesial and distal sides were determined by measuring the distance between implant platform (implant-abutment interface) to the most coronal thread where the alveolar crestal bone meets the implant surface. The average value was considered as the implant bone value [Figure 3.3].

![Figure 3.3](image-url)  
*Figure 3.3) Implant-abutment interface as the measurement reference and the dimensions of Brånemark implants*
3.6. Clinical Examinations

Through clinical examinations were carried out as a part of follow-up assessment of the clinical status of implants and superstructures in the group of patients included in this study. The clinical examinations for all subjects were performed in the Graduate Prosthodontic Clinic, Faculty of Dentistry, University of Toronto using identical methods for all patients. In examination session, implants and the supported prostheses were individually assessed to record the clinical criteria.

3.6.1. Detaching implant-supported complete FDP (ICFDP):

Following the removal of the composite resin and cotton pallet plugs from the screw access holes, the prosthetic screws were retrieved and collected in separate containers and disinfected using Lab-X disinfectant solution: Alcohol Anhydrous 70%; Ethylene glycol 5-10%, O- Phenylphenol 0.1% (Microbex, Division of Alliance H. Inc. Toronto, Canada). The prostheses were, then, disinfected and cleaned in an ultrasonic cleaner using the same disinfecting solution [Figure 3.4].

![Figure 3.4] Detaching ICFDPs after unscrewing the prosthetic screws
3.6.2. Plaque Index:

In order to evaluate patients’ modified Plaque Index (mPI), a four-point scale was applied. This four-point scale plaque index has been shown to be an effective scale in oral hygiene evaluation (Mombelli et al., 1987). The index had values between 0 and 3:

0 = No detection of plaque
1 = Plaque only recognized by running a probe across the smooth marginal of the implant
2 = Plaque can be seen by the naked eye
3 = Abundance of soft matter

Plaque accumulation score was calculated as an average for all implants supporting the complete fixed dental prosthesis (ICFDP).

3.6.3. Bleeding on Probing (BOP):

In the current study a simplified four-point scale, based on BOP, was adapted from Mombelli and coworkers (Mombelli et al., 1987) to measure modified Gingival Index (mGI) for each patient. mGI score was recorded for each implant according to the following scales when a periodontal probe (Click-Probe, Kerr, Kerrhawe SA, USA) was passed lightly (0.25 N) along mucosal margin adjacent to the implant:

0 = No bleeding
1 = Isolated bleeding spots visible
2 = Blood forms a confluent red line on mucosal margin
3 = Heavy or profuse bleeding

An average mGI was calculated for each implant and each patient.
3.6.4. Probing Depth (PD):

Probing depth (PD) was measured from the peri-implant mucosal margin to the bottom of the sulcus or pocket with a standardized penetration force of 0.25 N utilizing a specific periodontal probe (Click-Probe, Kerr, Kerrhawe SA, USA). Probing depth was measured at four sites (mesial, buccal, distal and lingual) for each implant to the nearest millimetre. An average DOP was determined for each implant and each patient.

3.6.5. Screw Loosening / Fracture:

All prostheses and implants were assessed to detect any sign of loose and fractured screws (abutment and prosthetic screws). In cases where fractured screws were identified, they were retrieved during the same clinical examination session.

3.6.6. Implant Mobility / Failure:

Stability of all implants was assessed separately by torquing the abutment screws which attach the transmucosal abutments to the respective implants. Any sign of mobility along with pain and discomfort was interpreted as a definitive sign of the terminal stage of osseo-disintegration and implant failure. In such a case, a free treatment consult was offered to the patient.

3.6.7. Opposing Dentition:

The antagonistic jaw relation facing ICFDP was recorded. Four categories formed the opposing dentition classifications:

Group I: Conventional complete denture

Group II: Natural dentition (with or without fixed/removable partial denture)
Group III: Fixed implant-retained prosthesis

Group IV: Tooth/implant supported overdenture

3.6.8. Digital Analysis:

In order to calculate the cantilever segments of the Implant-supported Complete Fixed Dental Prostheses (ICFDP), the intaglio surfaces of prostheses were scanned using a high resolution stationary scanner named 3Shape D810 dental laboratory scanner (3Shape A/S, Copenhagen, Denmark) [Figure 3.5].

![3Shape D810 dental laboratory scanner](image)

*Figure 3.5* 3Shape D810 dental laboratory scanner (3Shape A/S, Copenhagen, Denmark)

The scanner captured the reflected lights from the scanned object with its two 5-megapixel adjustable cameras. It employs a 3-axis rotation, translation and tilting mechanism to move the object when scanning [Figure 3.6].
The system provided a high level of accuracy with a maximum permissible error of 16 µm over 60 mm scan length and a maximum permissible probing error of 2 µm. The scanned surfaces were required to be covered with a masking opaque powder in order to eliminate reflections on the metal and acrylic surfaces during the scanning stage. The intaglio surfaces of Implant-supported Complete FDPs (ICFDP) were prepared according to the manufacturer's instructions with the VITA Powder before scanning the model. The white contrast VITA Powder was uniformly applied using Vita propellant spray. Then, the intaglio surfaces of the detached prostheses were scanned to generate the three-dimensional models [Figure 3.7]. After scanning, the powder could be easily removed with a small brush under running water.
Generating 3D Geometric Dimension and Tolerance (GD&T) mapping, the software allowed for a point-to-point distance three-dimensional measurement for any given region of interest. The three-dimensional linear length for the cantilever segments of prostheses were measured (mm) on the virtual model of the intaglio surface using Convince™ Premium software [Figure 3.8].
3.6.9. Replacing the Prostheses at the End of Clinical Examination:

All patients were offered a free implant hygiene session and prosthesis cleaning. At the end of examination sessions, abutment screws were torqued based on the manufacturer’s recommendation (35 Ncm). Prostheses were replaced on the transmucosal abutments and attached to the abutments using brand new prosthetics screws torqued according to the manufacturer’s recommendation (15 Ncm). Screw access holes were filled out with cotton and composite resin restoration.

3.7. Classification of Biological Complications

In order to classify the peri-implant lesions, the following clinical criteria were considered for peri-implant mucositis and peri-implantitis Roos-Jansåker et al., 2006b):

3.7.1. Peri-implant mucositis:

An inflammation of the soft tissues surrounding an implant in function with no marked loss of supporting bone:

- Depth of Probing (DOP) \( \leq 4 \) mm
- Presence of bleeding (BOP)
- Marginal bone loss of less than 1.5 mm

3.7.2. Peri-implantitis:

An inflammatory process affecting the supporting tissues around an osseointegrated implant with marked loss of marginal bone:

- Depth of Probing (DOP) \( \geq 4 \) mm
- Presence of bleeding on probing (BOP) or purulence
- Minimum 1.5 mm radiographic marginal bone loss and exposed threads

3.8. **Classification of Mechanical (Prosthetic) Complications**

Mechanical complications were assessed based on the following incidences:

- Implant fracture
- Metal framework crack/fracture
- Acrylic base and denture tooth crack/fracture
- Abutment and prosthetic screw fracture
- Abutment and prosthetic screw loosening

3.9. **Patient Satisfaction and Quality of Life Outcomes**

Prior to the recall appointment, self-administered questionnaires on Implant-supported Complete Fixed Dental Prosthesis (ICFDP) satisfaction were mailed to the patients (Appendix D). The patients were supposed to complete the questionnaires anonymously and submit them in closed envelops at the day of the recall appointment. The questionnaire consisted of the following items about the patients:

a) Reasons of losing teeth,

b) History of clenching and bruxism,

c) Willingness to have the same treatment if it would have been required,

d) Routine methods of oral hygiene maintenance and the oral hygiene devices of choice,

e) History of problems, repairs and complications related to the ICFDPs.
In another section of the questionnaire, the patients were asked to score the following characteristics of their ICFDPs according to a six-point grading scale (6=Perfect, 5=Good, 4=Satisfactory, 3=Unsatisfactory, 2=Poor, 1=Very Poor):

a) Esthetics: The appearance of the prosthesis
b) Chew Comfort: Ability of the patient to eat food (masticatory function)
c) Cleaning: Ability of the patient to keep the prosthesis clean (oral hygiene)
d) Expectations: Outcomes of the treatment as compared with patients’ expectations

3.10. Statistical Analysis

Statistical analysis was performed using SPSS 19 software (Version 19.0, Chicago, IL, USA). It included a descriptive analysis of recorded quantitative and qualitative data. Dependent variables were classified in four major categories: Implant survival rate (cumulative), marginal bone loss (continuous values in millimeter), incidence of biological complications (cumulative) and incidence of mechanical complications (cumulative).

To test the first null hypothesis comparing silver-palladium framework with the other two types of alloys, the statistical analyses included one-way ANOVA and post hoc multiple comparisons (Tukey’s) of the frequencies of various biological and mechanical complications (either recorded in patients’ charts or detected at the day of clinical examination) in three groups of alloys (a: Ag-Pd, b: Pd-Ag, c: Type IV gold alloys). The statistical unit was the number of complications. Mantel-Haenszel odds ratios (ORs) for prostheses to fail were calculated if terminal complications (i.e. framework fracture) or repeated complications occurred over the period of
observation compared with prostheses that did not have any record of terminal and/or repeated complications.

In order to assess the second null hypothesis, a Pearson Correlation Coefficient was used to assess the presence of a correlation between the average marginal bone loss around implants in each patient and the corresponding average cantilever segment of the metal framework in the same patient. Also, paired t-tests were used to assess whether significant differences in marginal bone loss occurred when comparing the most anterior implant and the implant adjacent to the longest cantilever segment on the posterior most part of the prosthesis. To compare the level of patient satisfaction on esthetics, function, cleaning and expectations of patients, Kruskal-Wallace tests were performed. The significance level for all of the aforementioned statistical tests was set at “p < 0.05”.
4.0 Results

4.1 Patients’ Age, Gender and Follow-up Period

A total of 153 Brånemark implants were placed in the edentulous mandibles of 30 patients to support 30 Implant-supported Complete Fixed Dental Prostheses (ICFDPs). Data related to the age and gender is summarized in table 4.1 for patients included in this retrospective study. The patients (n = 30) had a mean age of 54.2 years (a range of 28 to 74 years) at the time of implant placement surgery. The average age of the patients at the examination day was 73.2 (±11) years.

<table>
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<th>Age (years)</th>
<th>50-59</th>
<th>60-69</th>
<th>70-79</th>
<th>80-89</th>
<th>90-99</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Female</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td>7</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 4.1) Age and gender Distribution of the patients at the clinical examination day

In total, 8 male and 22 female patients were clinically examined at the recall appointment. The average follow-up period was 19 years (SD: 6.1 years) with a range of 12 to 32 years [Table 4.2].

<table>
<thead>
<tr>
<th>Years of Follow-up</th>
<th>Patients (n = 30)</th>
<th>Implants (n = 153)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 - 14</td>
<td>9 (30.0 %)</td>
<td>45 (29.4 %)</td>
</tr>
<tr>
<td>15 - 19</td>
<td>10 (33.3 %)</td>
<td>53 (34.6 %)</td>
</tr>
<tr>
<td>20 - 24</td>
<td>5 (16.7 %)</td>
<td>26 (17.0 %)</td>
</tr>
<tr>
<td>25 - 32</td>
<td>6 (20.0 %)</td>
<td>29 (19.0 %)</td>
</tr>
</tbody>
</table>
Seventy percent of the patients and 70.6% of the implants had a follow-up of 15 years or more after the stage one surgery. Thirty six percent of the implants and 36.7% of the patients had a follow-up of 20 years or more.

4.2. Patients’ Medical History

No general health problems of somatic character were reported for 9 patients (30%). However, ten of the patients (33.3%) reported inflammatory joint problems (Arthritis). Eleven patients were medicated for cardiovascular problems (36.6%), and 3 patients had other general health problems. While none of the patients had a history of taking intra-venous bisphosphonate products, four of them (7.5%) were taking one type of oral bisphosphonate medications for several years. Also, 14 patients (46.7%) reported daily usage of the one type of pain killer medication including ASA (Aspirin), Acetaminophen (Tylenol), Ibuprofen (Advil) or Mefnamic Acid (Ponston).

Patients’ smoking habit was categorized in 3 groups of “none-smoker”, “less than 10 cigarettes per day” and “more than 10 cigarettes per day” as demonstrated in figure 4.1. While 19 patients did not have a history of smoking and 7 patients smoked less than 10 cigarettes per day, 4 patients were considered heavy smokers since they smoked more than 10 cigarettes per day.
4.3. Distribution of the Opposing Dentition

Four different types of opposing dentitions occluding ICFDPs were observed in this study [Figure 4.2]. The opposing dentitions included 17 Complete Dentures (56%), 8 Implant-supported Complete Fixed Dental Prostheses (ICFDP) (27%), 3 Natural Dentition (10%) and 2 Implant-supported Overdentures (7%).
4.4. Types and Frequency of Occlusal Schema

The occlusal schema observed in the included patients in this study consisted of Bilaterally Balanced Occlusion (73%), Mutually Protected Occlusion (17%) and Group Function (10%). Figure 4.3 shows the frequency of different occlusal schema observed in this study.

![Occlusal Schema](image)

*Figure 4.3) Frequency of the types of occlusal schema in patients included in this study*

4.5. Implant and Prosthesis Survival

A review of charts revealed that only 5 implants (out of 153) were lost in 4 patients. In one of the patient’s who had received 6 implants, 2 implants failed before the prosthesis was made. Nonetheless, the prosthesis was made for this patient supported by 4 implants. Another patient, originally with 5 implants, lost one of the implants before loading and the prosthesis was made on the remaining 4 implants. In two other patients, each with 5 implants, two implants failed 1 and 3 years after loading with ICFDPs. The original ICFDPs were kept for these patients and they were loaded on 4 implants. None of the failed implants were at the most distal positions.
Therefore the original length of ICFDPs’ cantilever segments was maintained. At the end, 4 ICFDPs were loaded on 4 implants, 2 ICFDPs were loaded on 6 implants any 24 mandibles were restored with 5 implants (Table 4.3).

<table>
<thead>
<tr>
<th>Table 4.3) History of failed implants and modified ICFDPs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A Total of 152 implants</strong></td>
</tr>
<tr>
<td><strong>Early Failure (prior to loading)</strong></td>
</tr>
<tr>
<td><strong>Late Failure (1 &amp; 3 years after loading)</strong></td>
</tr>
<tr>
<td><strong>ICFDPs Followed Up</strong></td>
</tr>
</tbody>
</table>

None of the implants found to be mobile at the day of clinical examination (96.7% implant survival). As an important measure of success, the number of prostheses that remained in continuous function was recorded. Over the period of observation time, no prosthesis was lost because of implant failures; however, 16.7% of ICFDPs (5 out of 30 prostheses) had to be remade since the metal frameworks fractured after a few years of service. Also, 3 ICFDPs were remade due to repetitive mechanical complications including fractured acrylic teeth and flanges. This brought the cumulative failure rate of prostheses to 26.7% (8 out of 30 prostheses) over the years of follow up. No mobile, fractured or cracked prosthesis was found at the day of recall. Table 4.4 summarizes the number and percentage of failed and surviving prosthesis within 5-year periods of the observation time.
### Table 4.4) Rate of prosthesis failure over the course of observation

<table>
<thead>
<tr>
<th>Observation Time (Years)</th>
<th>Number of Failed Prostheses</th>
<th>Number of Censored Cases</th>
<th>Number of Surviving Prostheses</th>
<th>Interval Failure Rate</th>
<th>Cumulative Failure Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3</td>
<td>0</td>
<td>27</td>
<td>10.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>0</td>
<td>25</td>
<td>6.7%</td>
<td>16.7%</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>7</td>
<td>22</td>
<td>10.0%</td>
<td>26.7%</td>
</tr>
<tr>
<td>≥16</td>
<td>0</td>
<td>8</td>
<td>22</td>
<td>0.0%</td>
<td>26.7%</td>
</tr>
</tbody>
</table>

#### 4.6. Types and Distribution of Metal Frameworks

Reviewing the laboratory records in patients’ charts, the following categories of metal alloys were found to be used in ICFPD metal frameworks:

a) Silver-Palladium alloys: Alvacast, Pallag M

b) Palladium-Silver alloys: A37 Noble, Degubond Ultra

c) Gold type IV alloys: Esteticor Implant 58, Stabilor G

It was noted that the metal framework in 9 ICFDPs was cast with Silver-Palladium alloys (Ag-Pd). High palladium alloys (Pd-Ag) were used in casting 13 ICFDP frameworks while 8 superstructure metal frameworks were cast using type IV gold alloys. Figure 4.4 and table 4.5 summarize the related data.
Table 4.5) Distribution of cantilever segments (N=60) based on type of alloys and length of cantilevers

<table>
<thead>
<tr>
<th></th>
<th>&lt; 15 mm</th>
<th>15-20 mm</th>
<th>&gt; 20 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag-Pd</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Pd-Ag</td>
<td>19</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Gold Type IV</td>
<td>11</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

4.7. Plaque Index, Gingival Index (Bleeding on Probing) and Probing Depth
The data on the plaque index, bleeding on probing and depth of pocket at patient, implant and site (buccal, lingual, mesial and distal) is presented in table 4.6.
Table 4.6) Plaque index, bleeding on probing and probing depth at patient, implant and site levels

<table>
<thead>
<tr>
<th>Plaque Index (mPI):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Patient Level (n = 30):</td>
</tr>
<tr>
<td>Mean Implant Level (n = 148):</td>
</tr>
<tr>
<td>Mean Site Level (n = 592):</td>
</tr>
<tr>
<td>0.55 (0 to 2.45)</td>
</tr>
<tr>
<td>0.55 (0 to 3)</td>
</tr>
<tr>
<td>0.55 (0 to 3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bleeding on Probing (mGI):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Patient Level (n = 30):</td>
</tr>
<tr>
<td>Mean Implant Level (n = 148):</td>
</tr>
<tr>
<td>Mean Site Level (n = 592):</td>
</tr>
<tr>
<td>0.19 (0 to 1.25)</td>
</tr>
<tr>
<td>0.19 (0 to 1.25)</td>
</tr>
<tr>
<td>0.19 (0 to 2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth of Pocket (mm):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Patient Level (n = 30):</td>
</tr>
<tr>
<td>Mean Implant Level (n = 148):</td>
</tr>
<tr>
<td>Mean Site Level (n = 592):</td>
</tr>
<tr>
<td>1.94 (1.00 to 3.69)</td>
</tr>
<tr>
<td>1.94 (1.00 to 5.25)</td>
</tr>
<tr>
<td>1.94 (1.00 to 7.00)</td>
</tr>
</tbody>
</table>

4.7.1. Modified Plaque Index (mPI):

In 65.5% of the 148 surviving implants (86 out of 148) plaque accumulation was found on – at least – one of the buccal, lingual, mesial or distal surfaces of the implant (mPI > 0). It was observed that only on the surface of 8 transmucosal abutments (5.4%) the amount of accumulated plaques matched the definition of the fourth grade of modified plaque index (mPI = 3 : Abundance of soft matter). In 66 out of 148 surviving implants (44.6%), plaque was only recognized by running a probe across the surface of implant/abutment (mPI = 1). Nevertheless, plaque accumulation could be seen by naked eyes (mPI = 2) on the surfaces of 17 implants/abutments (11.5%). No plaque accumulation could be detected in 55 implants (37.2%). The mean value for mPI on the patient level was equal to 0.55. Figure 4.5 graphically depicts the distribution of mPI grades at implant level.
4.7.2. Modified Gingival Index (mGI), (Bleeding on Probing):

On the implant level, 100 out of 148 surviving implants (67.6%) did not show any bleeding on probing (mGI = 0). While only in 7 implants (4.7%) bleeding on probing formed a confluent red line on mucosal margin (mGI = 2), isolated bleeding spots were visible (mGI = 1) after probing 41 implants (27.7%). Nonetheless, heavy or perfuse bleeding on probing (mGI = 3) was not observed on any of the examined implants (0%). On the patient level, the average for modified gingival index (mGI) was 0.19. Figure 4.6 shows the frequency of different grades of mGI at implant level.
4.7.3. Probing Depth (PD):

The mean probing depth was 1.94 mm (SD: 0.72) at patient level. The average probing depth varied between 1.0 and 3.69 mm for the patients. The average probing depth at implant level showed a range of 1.0 to 5.25 mm. However, the measured depth for one of the implants reached to a maximum amount of 7.0 mm at the site level (mesial, distal, buccal and lingual).

4.8. Bone Quality and Quantity

Bone quality and bone resorption of the treated jaws were classified at the time of the first surgery according to the index described by Lekholm and Zarb (1985). No Type IV bone was recorded in patients’ charts; and only 2 patients had type I mandibular bone (6.7%). Nineteen patients (63.3%) had type II bone quality while 9 patients (30%) showed type III quality. The volume of the bone for each patient, recorded by the surgeon at the day of stage-one surgery, was retrieved from the patients’ charts. It was observed that none of the patients had type E alveolar
ridge, and type A ridge was only recorded for one patient. While 2 patients had type D alveolar ridge, it was noted that most of the patients’ alveolar ridges fell into type B (12 patients) and type C (15 patients) categories. Figure 4.7 summarizes the distribution of bone quality and quantity in patients included in this study.

*Figure 4.7) Distribution of bone quality and quantity in the patients according to Lekholm and Zarb (1985)*

### 4.9. History of Biological and Mechanical Complications

The history of complications related to the ICFDPs was recorded after reviewing patients’ charts and the clinical examination at the day of recall appointment. The history of complications is reported separately for biological and mechanical problems as it was explained and categorized in sections 3.4.3 and 3.4.4. In general, it was observed that 7 patients did not face any biological or mechanical complication over the period of observation (average of 16.4 ± 3.0 years). While only 5 patients had to solely deal with biological complications, 10 patients exclusively experienced mechanical complications. Also, 8 patients were involved in both biological and mechanical complications. The above mentioned results are graphically demonstrated in figure 4.8.

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4.9.1. Biological Complications (Peri-implant Mucositis and Peri-implantitis):

Following the clinical measurement of the probing depth and recording the bleeding on four sites (buccal, lingual, mesial and distal), it was observed that nearly one third of the implants (32.4%) had bleeding on probing at the day of recall appointment. The implants with bleeding on probing (n = 48) were categorized into three separate follow-up periods [Figure 4.9].
Figure 4.9) The prevalence of bleeding on probing in three different follow-up periods: a) 12 to 14 years; b) 15 to 19 years; c) 20 years or more.

It was observed that implants with “20 or more years” of follow-up had the highest percentage of bleeding on probing (22 out of 51 implants; 43.1%). Implants with “12 to 14 years” and “15 to 19 years” of follow-up showed a lower rate of bleeding on probing with 26.7% (12 out of 45) and 26.9% (14 out of 52), respectively. Comparing the frequency of bleeding on probing, Pearson Chi-Square test did not find a statistically significant difference among the three aforementioned follow-up periods ($\chi^2$ value = 4.070; $p = 0.131$). Table 4.7 shows the details and the validity of the Chi-Square test.
Table 4.7) Frequency of bleeding on probing in implants with different follow-up periods (Chi-Square, SPSS)

<table>
<thead>
<tr>
<th>Chi-Square Tests</th>
<th>Value</th>
<th>df</th>
<th>Asymp. Sig. (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Chi-Square</td>
<td>4.070</td>
<td>2</td>
<td>.131</td>
</tr>
<tr>
<td>Likelihood Ratio</td>
<td>3.997</td>
<td>2</td>
<td>.136</td>
</tr>
<tr>
<td>Linear-by-Linear Association</td>
<td>3.070</td>
<td>1</td>
<td>.080</td>
</tr>
<tr>
<td>N of Valid Cases</td>
<td>148</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. 0 cells (0%) have expected count less than 5. The minimum expected count is 14.59.

According to the criteria described in section 3.7.1 for peri-implant mucositis, 9 patients (30%) were diagnosed with peri-implant mucositis at the recall appointment. If peri-implantitis is defined as bone more than 1.5 mm with a pocket depth of ≥ 4 mm in the presence of bleeding on probing (section 3.7.2), only one of the patients (3.3%) would be diagnosed to have peri-implantitis at the time of the clinical examination. However, reviewing the patients’ charts revealed that the incidence of peri-implantitis was higher over the full length of the observation period. In total, 9 patients (30%) were found with a history of peri-implant mucositis and 3 patients (10%) were diagnosed and treated for peri-implantitis. Figure 4.10 graphically shows the incidence of the patients with a history of peri-implant lesions compared to those who did not developed any peri-implant lesions.
4.9.2. Mechanical (Technical) Complications (Prosthetic Complications):

A close review of the patients’ chart records suggests that 66.6% of the prostheses (20 out of 30) included in this study needed to be repaired or remade following the occurrence of different mechanical complications including loosening or fracture of screws, cracks or fracture of acrylic body and/or denture teeth, and also fracture of metal frameworks. Due to the uneven number of implants supported by 4 implants (4 ICFDPs), 5 implants (24 ICFDPs) and 6 implants (2 ICFDPs), no separate analysis was conducted to compare the rate of mechanical complications in ICFDPs supported with different numbers of implants. For 30 included prostheses, a total number of 58 mechanical incidences were recorded in patients’ charts. The frequency of these complications is presented in table 4.8.
Table 4.8) Distribution of prostheses with different types of mechanical complications

<table>
<thead>
<tr>
<th>Type of Mechanical Complication</th>
<th>Number of ICFDPs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No History of Mechanical Complications</td>
<td>10 (33.3%)</td>
</tr>
<tr>
<td>Acrylic Body and/or Denture Teeth Fracture</td>
<td>10 (33.3%)</td>
</tr>
<tr>
<td>Only Prosthetic Screw Loosening and/or Fracture</td>
<td>5 (16.7%)</td>
</tr>
<tr>
<td>Only Abutment Screw Loosening and/or Fracture</td>
<td>6 (20.0%)</td>
</tr>
<tr>
<td>Prosthetic and Abutment Screws Loosening and/or Fracture</td>
<td>3 (10.0%)</td>
</tr>
<tr>
<td>Metal Framework Fracture</td>
<td>5 (16.7%)</td>
</tr>
</tbody>
</table>

The results indicated that some of the patients had to deal with frequent complications while in other patients, if any complication occurred, it appeared as a none-repeated phenomenon. To assess the frequency of mechanical complications, the events were weighted as mean incidence values per 5-year periods. Where prostheses were lost and a new ICFDP had to be made, the number of mechanical incidences was calculated for the period of follow-up only up to the point that the prosthesis failed. It was observed that the average number of mechanical complications occurring every 5 years was 0.68 (95% CI: 0.44 to 0.92) incidence for each ICFDP included in this study.

4.9.2.1. Rate of Mechanical Complications in ICFDPs with Different Types of Metal Alloys:

It was of interest to ascertain if the incidence of mechanical complications (as evidenced by the occurrence of repeated complications) was associated with the types of metal alloys used in the superstructure. Therefore, ICFDPs included in this study (n = 30) were categorized into the following three groups based on the alloys of their metal frameworks:

Silver-palladium (Ag-Pd): (n = 9)
Palladium-silver (Pd-Ag): (n = 13)

Gold Type IV: (n = 8)

When comparing the mean incidence of mechanical complications (events/5-year follow-up) in these groups, it was noted that ICFDPs with silver-palladium frameworks (Ag-Pd) had the highest incidence of mechanical complications (1.08 events per 5-year follow-up period). This incidence for ICFDPs with palladium-silver (Pd-Ag) and gold type IV alloys were 0.65 (SE: 0.15) and 0.29 (SE: 0.25), respectively [Figure 4.11].

![Mean Incidence of Mechanical Complications](image)

*Figure 4.11* Incidence of mechanical complications in ICFDPs fabricated with different types of metal alloy frameworks per 5-year periods of follow-up

One-way ANOVA revealed a statistically significant difference in the incidence of mechanical complications between the groups (F=3.466, P=0.046). Levene’s test confirmed the homogeneity of the variances of the dependent variable (P=0.989). Tukey’s post hoc test provided further
information and demonstrated that significantly fewer mechanical complications occurred when ICFDP’s framework was fabricated with gold type IV alloy instead of Ag-Pd alloy (P=0.037). Nonetheless, no statistically significant difference was observed when comparing “Ag-Pd versus Pd-Ag” alloys (P=0.255) or “Pd-Ag versus Gold Type IV” alloys (P=0.425). Table 4.9 summarizes the One-way ANOVA test among the above mentioned groups.

Table 4.9) Post-hoc test: rate of mechanical complications in ICFDPs with different alloys (ANOVA, SPSS)

4.9.2.2. Risk of Prosthesis Failure in ICFDPs with Different Types of Metal Alloys:

As it was mentioned in section 4.5., a total number of 8 prostheses (26.7%) failed due to metal framework fracture or repeated mechanical complications. Comparing the rate of prosthesis failure among ICFDPs fabricated with different types of metal alloy, it was revealed that the risk of failure in ICFDPs with Ag-Pd frameworks was 44.4% (4 out of 9) over the course of follow-up. This risk for prostheses with Pd-Ag and Gold Type IV alloys were 23.1% (3 out of 13) and 12.5% (1 out of 8), respectively. Figure 4.12 depicts the rate of prosthesis failure in these groups.
Due to the small sample size, Freeman-Halton extension of the Fisher exact probability test using a 2 by 3 contingency was employed to evaluate the association between the frequency of ICFDP failure and the type of framework’s metal alloy. The result was $P=0.34$, indicating that the null hypothesis cannot be rejected. Therefore there was no significant difference in the frequency of ICFDP failure between prostheses fabricated with Ag-Pd, Pd-Ag and Gold Type IV alloy frameworks.

### 4.10. Radiographic Assessment, Marginal Bone Loss

At the examination day, crestal bone level was on average 2.2 mm (SD: 0.75) below the implant-abutment interface. The radiographic assessments demonstrated individual marginal bone loss variations from 0.6 to 5.8 mm. Table 4.10 presents the prevalence of implants according to the different levels of bone loss and the number of threads unsupported by the alveolar bone.
Table 4.10) Crestal bone position around the implants at the time of recall appointment among the patients examined

<table>
<thead>
<tr>
<th>Treads (Bone Level)</th>
<th>0 Thread (0 - 1.2 mm)</th>
<th>1 Thread (1.3-1.8 mm)</th>
<th>2 Threads (1.9-2.4 mm)</th>
<th>3 Threads (2.5-3.0 mm)</th>
<th>4 Threads (3.1-3.6 mm)</th>
<th>≥ 5 Threads (≥ 3.7 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Implants (%)</td>
<td>27 (18.2%)</td>
<td>40 (27.1%)</td>
<td>44 (29.7%)</td>
<td>20 (13.5%)</td>
<td>5 (3.4%)</td>
<td>12 (8.1%)</td>
</tr>
</tbody>
</table>

It was observed that one out of every four implants (25%) had 3 or more threads not supported by the alveolar ridge. The level of marginal bone in 45% of the implants was between the implant platform and the second thread of the implants; however, the bone level was noted to be lower than the second thread in nearly 30% of the implants.

4.10.1. Bone Loss of Anterior Implants versus That of Implants with Longest Cantilevers:

The average marginal bone loss around the most anterior implant for each patient was calculated; and, it was compared with that of the implant adjacent to the longest cantilever segment of ICFDP. While the most anterior implants showed 2.55 mm (SD: 1.21) bone loss, the implants close to the longest cantilever segment (posterior implant) demonstrated only 1.85 mm (SD: 0.48). The marginal bone loss results are graphically presented in figure 4.13.
A paired t-test was performed to investigate whether there was a significant difference in peri-implant marginal bone loss around the most anterior implant as compared with the implant adjacent to the longest cantilever segment of the prosthesis in the same patient (n = 30). It was observed that the amount of bone loss around the most anterior implant was significantly more than that of the implant adjacent to the longest cantilever segment of the ICFDP (P = 0.01) [Figure 4.14]. For the paired samples, a “mean of the differences” equal to 0.7 was observed with a standard error of 0.19. Also, 95% confidence level fell into an interval width of 0.31 to 1.07.
Figure 4.14) *A paired comparison of the marginal bone loss (mm) around the most anterior implant and the posterior implant closest to the longest cantilever segment for 30 patients*

### 4.10.2. Effect of Opposing Dentition on Marginal Bone and Mechanical Complications:

Analyzing the changes in marginal bone level with respect to the opposing dentition, no statistically significant difference was observed (Student t-test, $P = 0.48$) in average bone loss around the implants between the patients wearing conventional complete denture ($n = 17$) and those with an opposing dentition other than complete denture (i.e. natural dentition or implant-supported prostheses; $n = 13$). The average bone loss around the implants supporting ICFPDs opposing complete dentures was $2.27 \pm 0.85$ mm, and for those opposing natural dentition and/or implant-supported prostheses was $2.08 \pm 0.56$ mm. Figure 4.15 demonstrate the average of marginal bone loss in patients with denture versus those with natural dentition and/or implant-supported prostheses as their opposing dentitions.
Figure 4.15) Average marginal bone loss in ICFDPs opposing conventional complete denture versus those opposing non-denture (i.e. natural dentition and/or implant-supported prostheses)

The average rates of mechanical complications per 5 years in ICFDPs opposing complete dentures and that in ICFDPs opposing natural dentition and/or implant-supported prostheses were compared. It was observed that the incidence of mechanical complications was not significantly different (Student t-test, P = 0.88) for ICFDPs opposing complete dentures (mean: 0.69 incidences/5years, SD: 0.16) and those with natural teeth and/or implant-supported prostheses as the opposing dentition (mean: 0.73 incidences/5years, SD: 0.21)

4.11. Length of Cantilever Segments

The Length of the posterior cantilever segments of the prostheses for each patient was calculated as it was described in section 3.6.8.3. It was observed that the average length of the cantilever segments (n = 60) was 14.7 mm (SD: 3.54). The shortest and longest cantilever segments
recorded in this study were 7.4 mm and 22.9 mm, respectively. The distribution of the cantilever length is shown in figure 4.16.

![Distribution of cantilever length in ICFDPs](image)

*Figure 4.16* Distribution of the cantilever lengths in Implant-supported Fixed Dental Prostheses (ICFDPs)

### 4.11.1. Correlation between the length of cantilever section and the marginal bone loss:

In order to analyze whether the increased length of distal cantilever segments can result in higher amounts of marginal bone loss around the corresponding implants, the Pearson Product Moment Correlation test (Pearson's correlation) was performed (Figure 4.17).
As shown in Table 4.11, the Pearson’s r for the correlation between the length of cantilever (within the range of cantilever segments recorded in this study: 7.4 mm to 22.9 mm) and the marginal bone loss was 0.164 indicating that there is only a very weak relationship between the two variables. The significance value concluded that there was no statistically significant correlation between the marginal bone loss and the length of cantilever segments in ICFDPs (P = 0.21).
Table 4.11) Correlation between cantilever length and marginal bone loss (Pearson Correlation, SPSS)

<table>
<thead>
<tr>
<th>Bone Loss</th>
<th>Pearson Correlation</th>
<th>Sig. (2-tailed)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>.164</td>
<td>60</td>
</tr>
<tr>
<td>Cantilever Length</td>
<td>.164</td>
<td>1</td>
<td>60</td>
</tr>
</tbody>
</table>

A paired t-test did not show any significant difference when comparing the marginal bone loss around implants related to shorter and longer cantilevers for each ICFDP where one of the cantilevers was at least 1 mm shorter than the other one (P = 0.092 and 95% CI: -0.42 to 0.31).

4.12. Patient Satisfaction

All patients agreed to anonymously fill out the “patient satisfaction questionnaire” presented in Appendix D; and, all of the patients evaluated all statements. Responses to the questions from the “Patient Satisfaction and the Quality of Life” section (Section 3.9.) were overwhelmingly positive. Generally speaking, all of the 30 patients included in this study stated that they were satisfied with their implant-supported prostheses. All - but one patient - expressed that they have received the type of dental prosthesis they hoped for. The only patient, who did not find the provided prosthesis meeting her expectations, was hoping for an implant-supported prosthesis with better cleansability.

To assess the level of general satisfaction, patients were asked whether they would undergo the same treatment if required. Choosing from a multiple choice set of statements, 73% of patients
(22 out of 30) answered “Yes, Certainly” to the above mentioned question. While 23% of the patients (7 out of 30) chose the option “Yes, Probably”, only 4% of them (1 out of 30) probably would not undergo the same treatment if required. No patient chose the option “Absolutely Not” to answer the aforementioned question. [Figure 4.18].

![Pie chart](image)

*Figure 4.18* Patients’ categorized answers to the question “Would you undergo the same treatment, if required?”

### 4.12.1. Oral hygiene devices used by the patients:

While all patients used at least one of the oral hygiene devices to clean their ICFDPs, 25 of them reported using manual toothbrush. It was observed that a high number of patients used one of the interdental cleaning aids such as toothpicks (n=11), dental floss (n=6) and/or interdental brushes (n=18). The summary of the oral hygiene devices used by the patients included in this study has been illustrated in figure 4.19.
Figure 4.19) Percentage of patients using various types of oral hygiene devices

4.12.2. Patients Satisfaction with Their Prostheses:

Patients expressed their satisfaction regarding prosthesis esthetics, masticatory function and cleansability along with their expectations from their prostheses. Satisfaction scores were given by the patients, with: 6 = excellent, 5 = good, 4 = satisfactory, 3 = unsatisfactory, 2 = poor and 1 = very poor (section 3.9.). The results showed that patients believe the esthetics, function and general expectations from their prostheses can be considered as excellent/good while the cleansability of the prostheses cannot be assessed any better than good/satisfactory. Figure 4.20 shows the average scores given by patients to the above motioned aspects of ICFDPs.
The Kruskal-Wallace procedure was used to determine if there was a difference in the median patient satisfaction scores. It was determined that there is no statistically significant difference in median ratings for esthetics, function, cleansability and expectations scores.

*Figure 4.20* Satisfaction scores: Excellent=6, Good=5, 4=Satisfactory, 3=Unsatisfactory, 2=Poor, 1=Very Poor
5.0 Discussion

Oral rehabilitation of edentulous patients using implant-supported prostheses has been regarded as a successful and predictable approach equally by dental profession and patients (Coulthard et al, 2002; Strassburger wt al, 2004). The quality of the available scientific evidence that demonstrates high survival rate of different types of dental implants in direct functional contact with bone is compelling (Esposito et al. Cochrane database, 2007). Nonetheless, from the patients’ point of view, the function of a stable prosthesis during a complication-free long-term period matters much more than the survival rate of individual implants. While the reliability of osseointegration concept has been repeatedly shown, there are many complications associated with this treatment method. Any step in the prosthodontic procedure of restoring osseointegrated implants can possibly introduce structural, functional and cosmetic problems. Such problems dramatically reduce the level of patient satisfaction and adversely affect the overall clinical outcomes of the treatment. In this context, in order to control the occurrence of these problems, it is required to understand the predisposing factors causing common complications associated with implant dentistry.

Our limited knowledge about long-term clinical outcomes of rehabilitation with implant-supported prostheses becomes more critical when we notice that the management of tooth loss is not the same as treating acute diseases where our treatments can reverse pathologic conditions into the normal state. Therefore, clinical studies focused on “long-term” biologic, prosthetic and patient-oriented responses are required to enhance the efficiency of our approaches to the artificial replacement of missing dentition. As it was explained in the introduction of this dissertation, the long-term clinical outcomes of implant-supported complete fixed dental
prosthesis (ICFDP) have been vastly reviewed by different investigators; however, many aspects of this treatment modality are still unclear. For instance, the influence of design, composition, occlusal schema and passivity of the prosthesis on the rate of biological and mechanical complications is yet to be determined.

The principal objective of this retrospective study was to assess the long-term clinical outcomes of treating edentulous patients with implant-supported complete fixed dental prostheses (ICFDPs). Considering the high mean age (73 years) and general health problems of the original group of patients, it was not surprisingly that only 30 patients (treated between 1980 and 2000) could attend the recall appointments. Despite the practical difficulties with regard to the age and health of the patients, the superstructures were removed so that more detailed investigations could be carried out and more accurate results could be reported. Reviewing patients’ chart records, performing clinical and radiographic examinations and employing state-of-the-art digital devices, it was intended to assess the effect of various prosthetic and biological factors on the clinical outcomes of this modality of treatment and the associated patient satisfaction.

The cumulative survival rate of dental implants in this study was 96.6 % which is comparable with what has been previously reported for similar long-term studies in the literature (Adell et al, 1990; Carlsson et al, 2000; Astrand et al, 2008). Such a high individual implant survival rate for a long-term study can be considered very satisfactory. Several investigators have shown that implant survival rate can be markedly lower for maxilla; however, in the current study only mandibular ICFDPs were followed up. Considering the absence of mobility, marginal bone loss of less than 1.5 mm during the first year and less than 0.2 mm annually thereafter, and absence of
pain as the success criteria for osseointegrated implants (Albrektsson et al., 1986), only two more implants were deemed as “not successful” bringing the total success rate for implants in this study to 95.4%. On the other hand, the survival rate for the prostheses was not as positive. It was observed that the overall treatment result was negatively affected by the high rate of mechanical problems in a large percentage of ICFDPs. This resulted in a need for remaking the prosthesis in 26.7% of the cases. When reviewing the factors causing this high rate of prosthesis failure, it was noted that more than half of the remake cases were related to framework fracture at the cantilever segment. This is much higher than what has been reported elsewhere (Lindquist et al., 1996; Astrand et al., 2008). In a recent prospective study, Fischer and Stenberg, (2011) reported that only 9% of ICFDPs needed to be remade after 10 years of follow-up. Possible etiologies for higher superstructure mechanical failure rate in this investigation will be reviewed in further detail throughout this document where the prosthetic complications are discussed.

5.1. Marginal Bone Loss

In prospective studies, radiographs can be obtained at each recall time-point using standardized jigs to quantify the amount of bone loss over time. This can demonstrate the trend of alveolar bone changes as an important determining factor in success or failure of the treatment. In this retrospective study; however, the radiographs in patients’ charts (except for the x-rays taken at the day of first-stage surgery) were not at the same time-points. Therefore, the x-rays taken at the day of recall examination were compared only to the baseline (first-stage surgery) x-rays. Also, to solve the problem with the lack of standardization, bone loss was calculated based on the standard geometry and dimensions of the placed implants.
It is well known that marginal bone resorption associated with implant-supported prostheses is a continuous and inevitable phenomenon. Nevertheless, one of the most remarkable findings in this study is the small amount of bone loss that occurred during the course of observation. Considering the length of mean follow-up period (19 years), the average amount of bone loss (2.2 mm) in this study was well below the failure threshold previously defined in the dental literature (Albrektsson et al., 1986; Smith and Zarb, 1989). This result is more comparable to the amount of bone loss reported by Carlsson and coworkers (2000), and well in line with other investigations (Quirynen et al., 1992; Jemt, 1994; and Lekholm et al., 1999). With almost 0.1 mm bone loss per year, it is evident that this treatment modality with Brånemark osseointegrated implants can be considered quite reliable for life-long function. It should be mentioned that this amount of bone loss is twice as what was previously reported by Attard and Zarb (2004). They followed up a part of the same cohort of patients treated in the same clinic (IPU) between 1979 and 1984. They reported that the mean bone loss was equal to 0.05 mm per year. To explain such a difference, it may be hypothesized that the retrospective nature of the present study and the added range of included prostheses (fabricated from 1980 to 2000) have caused a higher mean annual bone loss.

Interestingly, it was observed that the amount of bone loss around the most anterior implant was significantly more than that of most distal implants. In agreement with Lindquist et al. (1988), Carlsson and co-workers (2000), and Attard and Zarb (2004), this result rejects the widely spread opinion about the causal association between the stress concentration around the most posterior implants and higher rates of marginal bone resorption. One may hypothesizes that the different nature of forces on posterior implants as compared with the central implant causes such a marked
difference. Laboratory studies have repeatedly shown that unlike the posterior implants, the most anterior implants are influenced by tensile stress (Rangert et al., 1989; Brunski and Skalak, 1992; Benzing et al., 1995). It is known that osseous structure tolerates compressive forces with less physiological and morphological changes (De Pauw et al., 1999; Duyck et al., 2001).

It was also of interest to determine the effect of cantilever length on the marginal bone loss since the correlation between marginal bone loss and overloading induced by cantilever segments is still unclear in the dental literature. According to the analyses, there was no correlation between the length of cantilever segment and the amount of marginal bone loss. This is in agreement with a recent meta-analysis about the effect of cantilever segments on the survival and success of implant-supported fixed dental prosthesis where it was demonstrated that the bone-level change observed in prostheses with and without cantilever segment was the same (Aglietta et al., 2009). Previously, Linquist and colleagues (1996) reported that the length of cantilever extensions failed to correlate significantly with marginal bone resorption in their cohort of patients after 15 years of follow-up. Regarding the overloading effects caused by cantilever segments, Shackleton and his colleagues (1994) described that overextended cantilever segments more than 15 mm induced more prosthesis failures as compared with cantilevers shorter than 15 mm; however, they emphasized that the reason for higher failure rate was not related to the loss of osseointegration or other biological complications. The results of the present study demonstrated that ICFDPs do not impose any detrimental effects on marginal bone levels around implants in the proximity of cantilever segments.
5.2. Biological Complications

Albrektsson et al. (1986) and subsequently Zarb and Smith (1989) did not consider including any measure of mucosal health in their proposed success criteria since they did not believe periodontal indices could be correlated to implant success. Nevertheless, it can be argued that the assessment of mucosal and osseous structures which support a failing implant not only helps us understand the failure mechanisms, it also facilitates a cause-related therapy by identifying the possible etiologies. For this reason periodontal parameters described in section 3.6 were measured in this study to identify “periodontal-like” diseases associated with implants.

Biological complications have been extensively assessed in the dental literature (Esposito et al. 1998; Berglundh et al., 2002; Goodacre et al., 2003). These complications, if not controlled, can threaten the survival of osseointegrated implants and jeopardize the function of prosthesis. In this study, the incidence of main biological complications, namely peri-implant mucositis (inflammation of marginal mucosa) and peri-implantitis (inflammatory marginal bone loss) was investigated.

The incidence of peri-implant conditions diagnosed as peri-implant mucositis and/or peri-implantitis can noticeably vary based on how these pathologies are defined and which reference parameters are employed. For this reason it is difficult to compare the results of this study to the other studies. As shown in figure 4.10, a large portion of patients included in study experienced peri-implant mucositis (30%) or peri-implantitis (10%). When these results are compared with studies that used the same type of implants and prostheses (MK Series, Brånemark implants supporting ICFDPs) a large discrepancy can be observed. Hemmings et al. (1994) and Eliasson
and colleagues (2000) reported that only 0 and 1.6% of the patients showed the signs and symptoms related to peri-implantitis. However, it should be noted that the aforementioned studies followed up the subjects for a much shorter period of time (5 years). In this regard, it can be hypothesized that the length of the observation period may play a role in increasing the rate of peri-implant lesions. A systematic review (Berglundh et al. 2002) revealed that the biological complications show a higher frequency of occurrence when subjects are followed up for 10 years as compared with 5 years. The data from section 4.9.1 supports this view where the prevalence of Implants with bleeding on probing in patients followed up for more than 20 years was markedly higher than that in patients followed up for periods less than 20 years (43% versus 26%).

In their cross-sectional studies, Fransson et al. (2005) reported that peri-implantitis was a frequent clinical finding in their group of patients and 28% of subjects had to deal with peri-implantitis during the observation period. In another retrospective study (Roos-Jansaker et al., 2006a), the incidence of peri-implantitis at patient-level was 16% after 9 to 14 years of follow-up. These rates of peri-implantitis are higher than what was observed in the current study (10%). Taking into account that the above-mentioned papers had a shorter follow-up period (average 8 to 10 years) as compared with this study, their higher rate of peri-implantitis becomes more notable. To explain the lower rate of peri-implantitis in this study as compared with the aforementioned papers, it is necessary to evaluate the etiological factors causing per-implantitis. It is safe to assume that plaque accumulation resulting from inadequate daily removal and/or improper design of the prosthesis can lead to inflammatory changes in the peri-implant tissues.
Several studies have shown that accumulation of microbial biofilms on the surface of dental implants acts as a key etiological factor in peri-implant diseases (Mombelli et al., 1987; Mombelli et al., 1990). The majority of the patients included in this study had acceptable plaque control level at implant sites.

As it was described in section 4.7.1, the average modified plaque index (mPI) at subject-level was equal to 0.55. According to the 4-point mPI used in this study (section 3.6.2), the average mPI at subject and implant-levels was evaluated somewhere between "no plaque detection" (value=0) and "recognition of plaque only by running a probe across the smooth marginal of the implant" (value=1). The original mandibular Brånemark “high water” prosthetic design employed in this study offers ease of access for oral hygiene. Therefore, the use of interproximal oral hygiene aids and floss was readily possible to control bacterial plaque accumulation. Needless to mention, the smooth surface of Brånemark machined implants and the polished surface of transmucosal abutments made it easier for the patient to keep the implant sites plaque-free.

Another important factor associated with the frequency of peri-implantitis is patients’ smoking habits (Baelum and Ellegard, 2004; Roos-Jansåker et al., 2006a). In this study’s patient cohort, smoking was not a common habit; and 63% of the subjects were non-smokers (19 out of 30). Fransson et al. (2008) reported that the frequency of peri-implantitis was approximately equal for smokers and non-smokers. More recently; however, Serino and Ström (2009) observed that the number of implants involved with peri-implantitis was higher in non-smokers compared with smokers. This unexpected result was attributed to the small number of smokers in the patient
cohort. In the present study, the subject frequency affected by peri-implantitis was higher in the non-smoking group; however, the average follow-up period for the non-smoking group was four years more than that for the smoking one. Thus, the higher rate of peri-implantitis in non-smokers can be related to the longer period of observation in this group of patients.

Generally speaking, peri-implant pathologies were a frequent clinical finding (40% of the subjects) in this cohort of patients. Nonetheless, it should be mentioned that these patients were not part of an oral hygiene reinforcement programme. Prevention of the recurrence of inflammatory disease involves ongoing plaque control. The risk of developing peri-implant lesions can be effectively controlled through a structured hygiene support program. In this study, it was not possible to report on the history of peri-implant lesions at the implant-level due to the incomplete and sometimes unclear records in patients’ charts after the clinical examinations during the follow-up years. Unfortunately, the chart records rarely provided any précised explanation regarding the proportion of affected implants and the severity of the disease for each patient diagnosed with peri-implant lesions.

5.3. Mechanical Complications

Mechanical (prosthetic) complications present an important aspect in determining the success rate of implant dentistry since they can dramatically decrease the level of patient satisfaction by affecting patient’s quality of life and wasting their time and financial resources. The fact that some of the similar long-term studies (Åstrand et al., 2008; Mertens and Steveling, 2010) did not identify and report on the details of mechanical complications which were encountered during the follow-up period, does not mean that mechanical complications are not important.
Berglundh et al. (2002), after systematically reviewing the literature, reported that more than one third of clinical studies did not report on mechanical (prosthetic) complications at all. Therefore, the long-term follow-up reports on superstructure outcomes in the literature are still limited. In the present study, records of mechanical complications were carefully assessed. As it was expected, most of the patients who needed frequent emergency appointments during the follow-up period, visited the clinic owing to mechanical problems related to their ICFDPs, and not in order to receive supportive therapy driven by biological complications. After a thorough review of patients’ charts, a total of 58 notes which were recorded on different mechanical complications in connection with the superstructures were found.

Concerning the prosthetic outcomes, a large portion of mechanical complications was associated with acrylic-related complications (chipping of acrylic teeth, fracture of acrylic body). As expected, the acrylic body of the superstructure is the weak link in an ICFDP. In the current study, 24 of the 58 mechanical incidences (41.4%) were in connection with acrylic flanges/teeth of ICFDPs. This is almost twice as high as the rate acrylic body fractures reported by Jemt where 21.5% of all recorded complications were related to acrylic denture tooth fractures over a 5-year observation period (Jemt, 1994); however, this is not surprising since an increased rate of acrylic fractures is expected when the observation period is longer. In accordance with similar studies (Johansson and Palmqvist, 1990; Carlson et al., 1994; Jemt, 1994), most of acrylic-related complications were easily repairable with minimum expense. It has been shown that mechanical factors such as the magnitude/frequency of masticatory forces and the prosthetic design of the restoration can cause fatigue and eventually fracture of the acrylic components of ICFDPs (Torbjörner and Fransson, 2004). It is also well-known that inadequate resin thickness
(i.e. less that 2 mm) over the underlying metal frameworks can dramatically increase the rate of acrylic fracture.

In this study, the number of acrylic-related fractures was the highest for ICFDPs superstructures with Ag-Pd framework. Six out of 9 (66.6%) superstructures fabricated with Ag-Pd alloys - at least once - had to be detached and sent to dental laborites for repairs owing to the fractures of the acrylic body and the denture teeth of these ICFDPs. On the other hand, only 23% (3 out of 13) of superstructures fabricated with Pd-Ag and 12.5% (1 out of 8) prostheses with Gold type IV framework experienced acrylic-related fractures. The high rate of mechanical complications in superstructures with Ag-Pd metal framework was not limited to the acrylic fractures. When the average number of different mechanical complications including acrylic-related fractures, screw-related problems and metal framework breakage (at the cantilever segments) per five-year follow-up period was calculated, it was observed that the average mechanical event per 5 years in ICFDPs with Ag-Pd framework had the highest value (1.08, CI 95%: 0.67 to 1.49). This was significantly (P=0.037) larger than that of superstructures with Pd-Ag (0.65, CI 95%: 0.35 to 0.95) and gold type IV alloys (0.29, CI 95%: -0.2 to 0.78).

To explain the significantly higher rate of mechanical complications in superstructures with Ag-Pd framework, it can be hypothesized that the considerably low modulus of elasticity in Ag-Pd alloys (88 to 93 GPa) (Wataha and Messer, 2004) is not adequate for ICFDPs. Thus, ICFDPs with AG-Pd frameworks experience a high range of prosthesis flexure under masticatory forces. When the metal framework is not adequately rigid and/or thick, it will undergo elastic deformation during masticatory function. Excessive flexure of the superstructure in turn can
result in loss of acrylic resin veneering (Hobkirk, 2003). This phenomenon is amplified where the prosthesis is designed with long cantilever segments. While flexures in metal frameworks in metal-ceramic prostheses can immediately result in ceramic cracks and fractures (owing to ceramics’ high modulus of elasticity and low fracture toughness), acrylic veneering is less likely to debond since it can dissipate the energy more readily by flexing. In vitro experiments (Skalak, 1983; Davis et al 1988; Graci et al 1991) indicate that acrylic resin, as a material with low modulus of elasticity, may be able to dissipate the impact of masticatory forces and decrease the effect of occlusal loads on the bone-implant interface. Nevertheless, both ceramic and acrylic are required to be adequately supported by the metal framework to withstand the masticatory forces in function. The frequency of fractures in superstructure may be significantly reduced by laboratory excellence and appropriate design; but, the high rate of these complications implies that even the most experienced clinicians and technicians are not able to completely avoid this type of problems.

Over the average 19 years of follow-up, 8 prostheses had to be remade. In three patients, unfavorable biomechanical factors led to repeated fractures of prosthetic/abutment screws and acrylic flanges/teeth, which made it necessary to fabricate new prostheses for these patients. The other 5 failed ICFDPs had to be replaced after the cantilever segments fractured at some point during the follow-up period. In harmony with the total rate of prosthetic complications, ICFDPs with Ag-Pd framework showed a much higher incidence of cantilever segment fracture. Four out of 9 (44.4%) Ag-Pd frameworks had to be remade with a stronger type of Ag-Pd (Pailliaq M, Section 3.2) after they fractured under occlusal forces. Metal framework fracture occurs because of inadequate metal thickness, porous cast metal, inadequate soldered connections and/or inferior
mechanical properties of the metal alloy. As it was addressed by Zarb and Schmitt (1990), who reported on the same cohort of patients, silver-palladium alloy cannot be considered as an acceptable choice of material for ICFDP metal frameworks when cantilever segments are part of the prosthetic design. The inferior clinical performance of Ag-Pd can be simply explained with the its low yield strength (250 to 300 MPa) as compared with heat treated type IV gold and high strength palladium-silver alloys (Craig and Powers, 2002).

Interestingly, the rate of mechanical complications per 5 years for ICFDPs with Pd-Ag framework was higher than that for ICFDPs with type IV gold frameworks (0.65 versus 0.29 incidences per 5 years of follow-up). It should be noted that the yield strength and modulus of elasticity of type IV gold and Pd-Ag alloys are quite comparable. This result may be explained by the higher laboratory skills and experience of the technicians in handling conventional gold alloys. One may expect that the lack of experience can potentially cause significant physical flaws such as porous cast metal and weak soldered connections in Pd-Ag frameworks. Such physical flaws in metal frameworks are readily translated into an increased rate of mechanical complications and substantially less than optimal level of clinical performance. For this group of patients, the estimated prosthetic failure rate per 100 ICFDP-years was 1.4 which is more than the results reported by other investigators (Aglietta et al., 2009). One plausible explanation might be that the wrong choice of material with Ag-Pd caused a higher rate of failure for ICFDPs in this study. Of course, in long-term studies similar to the current study more complications and possibly higher estimated failure rate per 100 ICFDP-years can be observed.
As it is summarized by Schwartz (2000), excessive occlusal force is often considered as one of the key factors causing mechanical complications and possibly prosthesis failure. Therefore, we may reasonably presume that the frequency of mechanical complications dramatically rises when patients who generate higher levels of functional or para-functional occlusal forces are included in studies. In an attempt to reduce the chair-time and cost involved with prosthetic maintenance, Jemt (1994) suggests that interocclusal appliances should be fabricated for patients who experience repeated ICFDP superstructure fractures. Nonetheless, there is practically no strict clinical parameter to make clinicians capable of categorizing the forces that can be exerted by patients as well as predicting which patients may develop bruxism. In order to compensate for this uncontrolled factor affecting the rate of mechanical complications, studies should include larger cohorts of patients. At the same time, the high rate of mechanical complications observed in this study emphasises the importance of routine lifelong checkup appointments to maintain the optimal clinical performance of ICFDPs for patients.

5.4. Patient Satisfaction

Objective clinical measurements may not be completely sufficient to evaluate the prosthetic outcomes of a treatment since the patient’s subjective viewpoints of the effect of prosthodontic treatment on oral health–related quality of life can be substantially different from clinicians’ evaluations (Vervoorn et al., 1991). It is well known that the problems of edentulism go beyond the dental function and it affects patients’ social interactions, professional life and emotional well-being. To restore patients’ confidence as well as the dental function, it is necessary to take patients’ subjective assessment of the treatment into the account and modify the treatment modulus accordingly. For this reason, Guckes and colleagues, (1996) added a patient-centered
aspect to the previous success criteria. This patient-centered assessment included physiological, psychological, and economic effects of the provided treatment on patients’ life.

In the current study, patient satisfaction was documented using a standardized assessment form. Generally speaking, patients were highly satisfied with the treatment and declared that they would certainly choose the same kind of treatment again, if required. While Feine and Lund (2006) considered comfort, masticatory function, phonetics and esthetics as the main variations governing general satisfaction of patients treated with maxillary ICFDP, the result of this study shows that accessibility for oral hygiene is the most critical factor affecting patient satisfaction after insertion of mandibular ICFDP. It was observed that patients’ satisfaction with their ICFDPs was rather affected by the level cleansability of the prostheses. Unlike esthetics, function and general expectations, patients’ assessments on oral hygiene accessibility was rated lower than the standard level of “good to excellent” level. The patients’ level of satisfaction on cleansability of ICFDPs was slightly above “satisfactory”. A score of 4.24 (CI 95%: 4.22 to 4.26) was recorded as the average satisfaction for cleaning (Satisfactory = 4; Good = 5; Excellent = 6). According to Levi et al., It is noteworthy that where patient satisfaction with one of the aspects of the treatment is rated below “good” or “excellent” the overall success of the treatment may be considerably jeopardized (Levi et al., 2003). This result confirms that ICFDP should be designed properly so that the ease of performing oral hygiene is readily provided for the patients.

This retrospective study documented a wide range of biological and mechanical complications occurring in Implant-supported complete fixed dental prostheses (ICFDPs) during the average follow-up period of 19 years. It was observed the average amount of marginal bone loss around
implants was minimal. The results also demonstrated that the length of cantilever segments does not influence the amount of bone loss. In fact, the bone loss in the most anterior implants (medial implant) was significantly more than that in the most posterior implants. Very few biological complications jeopardized the continuous stability of the ICFDPs. The majority of the problems recorded were related to the prosthetic components of the treatment (mechanical complications). Nevertheless, most of these mechanical problems were easy to resolve owing to the specific metal-acrylic design of ICFDPs included in this study. Retrievability of these detachable prostheses and the straightforward procedures to repair defects on the acrylic part of their superstructures have made this type of prostheses a successfully maintainable solution to treat edentulous mandibles.

5.5. Clinical relevance, strengths and weaknesses of the study

The clinical relevance of this study relies on the importance of understanding the effect of the mechanical properties of metal alloys employed to fabricate superstructure’s framework on the long-term clinical outcomes of ICFDPs. Dental practitioners and dental technicians need to understand that only metal alloys with superior mechanical properties should be used to fabricate the ICFDP frameworks. Failure to choose appropriate metal alloys with high module of elasticity and yield strength will result in higher rates of mechanical complications and potentially failure of the prosthesis. The second clinically relevant conclusion derived from this study revolves around the controversial biomechanical effect of occlusal forces on the cortical bone surrounding the implants adjacent to cantilever segments of ICFDPs. It is not clear how much load can be imposed on implants without jeopardizing the surrounding bone; however, the results of this study show that the most distal implants can withstand amplified occlusal forces
generated by the cantilever segments of ICFDPs within the range of 10 to 23 mm without experiencing any excessive marginal bone loss.

This study is one of the longest follow-up studies on the clinical outcomes of ICFDPs in edentulous patients. Therefore, the fatigue effect on the prosthetic components and long-term reactions of soft and hard tissues surrounding the implants could be reasonably evaluated. Detailed data about all of the patients included in this study such as medical/dental backgrounds, observations during implant surgeries, in-depth records of all clinical complications along with the interventions provided to control and fix the complications were readily available from patient’s charts. In the current study, all ICFDPs were unscrewed. This provided a better access for a more accurate assessment of peri-implantal tissue indices. Also, utilizing a digital dental scanner to measure the length of the cantilever segments of ICFDPs, made the measurements more consistent. In general, this study reviewed the whole aspect of the long-term clinical outcomes of mandibular ICFDs.

The main concern about the level of reliability of the evidence provided by this study is related to the retrospective nature of this study. The fundamental bias inherited in retrospective cohort studies can limit the degree of the reliability of the reported results. Another limitation of this study is related to the fact that the patients’ charts were used as the ultimate resource to record the biological and mechanical incidences. In some of the cases the clinical notes recorded by the clinicians were not fully clear in patients’ chart. Such a methodological limitation can affect the accuracy of the conclusions derived from the study. Meanwhile, the limited number of included patients (n = 30) may have decreased the statistical power. Of course, the results of this study
provide a better understanding about long-term outcomes of ICFDPs. Nonetheless, it should be noted that the two-stage original surgical protocol and machined (smooth surface) implants were utilized in this study. Thus, the conclusions derived from this study should be generalized with cautions since they may not fully apply to the current state of implant dentistry.

5.6. **Summary**

Rehabilitation of edentulous patients with implant-supported complete fixed dental prosthesis (ICFDP) was a successful treatment modality over an average follow-up period of 19 years. Two third of the ICFDPs required at least one intervention to have mechanical (prosthetic) complications fixed over the follow-up period. Implants with longer follow-ups showed higher rates of bleeding on probing. A mean value of 0.68 mechanical complication occurred per 5 years of service for each ICFDP. ICFDPs with Ag-Pd alloys showed the highest rate of failure and mechanical complications. Significantly higher bone loss occurred around the most anterior implants (medial positions) as compared with that around the most posterior implants. No correlation was observed between the length of cantilever (up to 23 mm) and the amount of marginal bone loss around the associated implant. Patients were highly satisfied with ICFDP; however, low cleansability of ICFDPs may be a concern.
6.0 Conclusions

1) Mechanical complications such as prosthetic/abutment screw loosening/fracture and incidences of cracks, chippings and fractures in resin teeth, acrylic body and metal framework of prostheses are frequently observed in edentulous patients who are rehabilitated with ICFDP. Nonetheless, these complications should be considered as manageable problems.

2) Mechanical properties of the metal alloys affect the rate of mechanical complications in ICFDPs. Metal alloys with high values of fracture toughness and yield strength are more suitable for ICFDPs. Unlike gold type IV and Pd-Ag alloys, silver-palladium alloy is not considered a good choice for ICFDPs since it results in a higher rate of mechanical complications in ICFDPs.

3) The amount of marginal bone loss was higher around the most anterior implants than that of the bone loss observed around the most posterior implants adjacent to the cantilever segments.

4) The length of cantilever segments (up to 22.9 mm) in ICFDPs does not increase the amount of the marginal bone loss around the adjacent implants.
7.0 References


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Faculty of Dentistry  Appendix A  Prosthodontics
University of Toronto

July, 2011

Dear patient

You are invited to participate in a clinical study at the University of Toronto, Faculty of Dentistry.

We wish to examine clinically the condition of all the implant retained bridges and retaining screws made in the implant prosthodontic unit (IPU) and the graduate prosthodontic clinic over the last three decades. We would like to document the status with clinical photographs and radiographs. Your detached bridge will be closely inspected for potential damages using a high-precision dental scanner and reattached using new bridge gold screws kindly donated by Nobel Biocare Canada. The worn bridge screws will be collected for further examinations in our laboratories.

The clinical examination will be conducted by a member of our staff or graduate residents in the graduate prosthodontics clinic. The bridge will be unscrewed, scanned and re-attached with new gold screws. Since screws when subjected to loads over time are work-hardened they become brittle and hence breakable. In case one or more of the screws retaining your bridge have broken we will attempt to remove the remaining screw pieces. You will be notified immediately if the clinical examiner finds anything of concern elsewhere in your mouth that requires the attention of your dentist. All fees will be waived. These would otherwise range between $200 and $800, depending on number of implants & gold screws and efforts required for any potential broken screw(s).

Your participation in this study will provide very valuable information that will be useful for treating future patients as well as manufacturing dental implant components. If you agree to participate in this study, please contact Mrs Heather Hyslop in the IPU patient manager office at 416-979-4930 ext. 4424. If we do not hear from you in four weeks, we will attempt to contact you to verify that our letter has been sent to the right address.

The principal investigator of the study is Dr. Asbjorn Jokstad, DDS, PhD. Professor and Head of Discipline of Prosthodontics.

Feel free to contact us for any questions or concerns by telephone at 416-979-4930 ext. 4423 / 4424 / 4309 at the Discipline of Prosthodontics, Faculty of Dentistry, University of Toronto, 124 Edward Street, Toronto M5G 1G6.

Thank you in advance for your participation in the study. Please read the attached document for further details about this clinical study.

Sincerely

[Signature]
Patient Information Document and Consent form

Retrospective analyses of patients with implant-retained complete fixed dental prostheses.

Principal Investigator: Dr. Asbjorn Jokstad, Professor and Head, Prosthodontics
Co-investigator: Dr. Babak Shokati, Prosthodontics resident.
Faculty of Dentistry, University of Toronto.
(416-979-4930 ext. 4309)

Introduction
You are asked to participate in the study titled above. The study will be conducted by one of the graduate residents (Dr. Babak Shokati) under the supervision of Dr. Jokstad, Professor and Head, Discipline of Prosthodontics, Faculty of Dentistry, University of Toronto. The following information has been provided to you in order to make an informed decision to participate in the study.

Purpose of the Study
The purpose of the study is to investigate the success of dental implant-retained restoration treatment. We will:
1. Request you to update your old Medical Health Questionnaire form kept in your patient chart, as mandated by the Faculty of Dentistry before admission to the Faculty of Dentistry clinics.
2. Solicit your satisfaction with the implant-retained prosthesis you received in our clinic a decade or more ago. We wish also to learn whether there have been complications or problems with the restoration. If needed, we hope you will allow us to contact your dentist to learn more about any complications or problems with your implant-retained restoration.
3. Examine the clinical condition of your implant-retained prosthesis and the soft tissue issues around the implants and the state of the individual implants in the graduate prosthodontic clinic (examiner: Dr. Babak Shokati, DDS, Prosthodontics resident), and
   - Closely examine your prosthesis after detaching it from implants
   - Replace the old prosthetic screws with new screws at no cost, and
   - Take clinical photographs of the local areas around your implants for detailed appraisal of aesthetic outcomes and soft tissue status, and
   - Take local digital radiographs of your implant(s) to determine bone quality and levels around the implants.

Your participating in this study will provide information that will be useful for treating future patients with implant-retained dental prostheses.

Risks
There will be only a small risk of prosthetic screw fracture (retaining prosthesis on implants). A standard protocol is routinely followed in cases such an incidence happens in dental clinics. There are no other known risks from participating in this clinical study. Digital radiography will be used, which employs lower exposure than conventional radiographs.
Appendix B

Confidentiality
All the information that will be collected from you will be entered in the Faculty of Dentistry Electronic Records Management System ("Axium") and kept strictly confidential. No information about you will be released to anyone without your written permission, unless required by law. You will be assigned a study subject number and all electronic data records will be maintained by subject number and not by name to preserve your confidentiality. Forms used in the study will be stored in a locked cabinet at the Faculty of Dentistry, University of Toronto. Only the study coordinator and principal investigator and the statistician will have access to all the forms and electronic data. Records of the study will be retained in a secure area for a minimum of five (5) years following the completion of the study, and will be destroyed thereafter.

The results of this study may be presented at scientific conferences, and/or published in scientific journals, without including any names or specific individual information.

Benefits and compensation
The examination will provide for you an opportunity to have your mouth assessed for free. Normally, the faculty fee for this service is: Oral examination of previous patient: $30; two periapical radiographs: $20; charging prosthetic screws: $250 = Sum. $300 (If needed, additional small radiographs will also be cost-free).

You will be advised immediately if the examining doctor finds anything of concern that needs to be rectified by your dentist.

Right to withdraw from the Study
Your participation in this study is voluntary. If you do not want to participate in the study, or if you reconsider your agreement you are free to do so. The decision you make will have no effect on your potential future oral care at the Faculty of Dentistry, University of Toronto.

Questions about the Study
If you have any questions about this study, please contact us by telephone: 416-979-4930 ext. 4424 / 4309 or via e-mail: b.shokat@utoronto.ca or a.jokstao@dentistry.utoronto.ca. If you have questions about your rights as a research participant, please contact the University of Toronto Office of Research Ethics by telephone 416-946-3273 or via e-mail: ethics.review@utoronto.ca.

I have read, or have been explained to me, the information about this study. I have had the opportunity to ask questions and have had them answered to me. I know that I can refuse to join the study, or quit the study at any time, without affecting the way I am treated at the Faculty of Dentistry, University of Toronto. I have by signed my name below agreed to participate in the above study and agreed to disseminate information about the above mentioned factors from my treatment record with the understanding that my confidentiality will be maintained and my identity will not be disclosed. I have received a copy of this Patient Information Document and Consent form.

<table>
<thead>
<tr>
<th>Your Name</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Witness: __________________________
**CLINICAL EXAMINATION & HISTORY OF RESTORATION**

Clinic: ______________________  Examination Date: ____/____/_______

### ESTHETIC PARAMETERS (MAXILLA ANTERIOR (1-4) ONLY)

1. Extraoral Analysis
   - Lipline: □ high  □ medium  □ low
   - Midline maxillary incisors compared to:
     a) facial midline □ symmetric □ non-symmetric
     b) dental midline □ symmetric □ non-symmetric

### OCCLUSAL PARAMETERS

1. Static Occlusion
   - H. Overjet: _____ mm
   - V. Overbite: _____ mm

2. Dynamic Occlusion
   - Occlusal Scheme
     right: □ Mutually protected Occlusion □ Group Function □ Bilateral Balanced
     left: □ Mutually protected Occlusion □ Group Function □ Bilateral Balanced
     right & left: □ Collapsed

   Occlusal Interferences
   □ Present  □ Absent

3. Opposing Dentition
   □ Natural (with/out FDP-RDP)
   □ Complete Denture
   □ Implant-retained complete FDP
   □ Implant/tooth retained overdenture

---

I confirm that I have carefully examined all entries on the Case Report Form for this patient.
All information entered is to the best of my knowledge, correct.

Investigator initials: ___  Date: ___/___/____

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RESTORATIVE STATUS

<table>
<thead>
<tr>
<th>Failure/Complication</th>
<th>Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the restoration missing (Failure)?</td>
<td></td>
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<tr>
<td>Is the restoration partially missing (Failure)?</td>
<td></td>
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<tr>
<td>Does the restoration show a complication?</td>
<td></td>
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</tbody>
</table>

CODES FOR COMPLICATIONS / FAILURES

Supra-construction:
1. Acrylic Veneer chipping/flaking  
2. Metal framework crack/fracture

Occlusal Screw:
3. Loosening  
4. Fracture
5. Loosen screw  
6. Fracture

Abutment Screw:
7. Fracture  
8. Loss due to trauma  
9. Loss due to peri-implantitis
10. Other ____________________________
<table>
<thead>
<tr>
<th>Measurement</th>
<th>Buccal</th>
<th>Mesial</th>
<th>Lingual</th>
<th>Distal</th>
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<tbody>
<tr>
<td>Presence/absence of supputation.</td>
<td>☐ Yes</td>
<td>☐ No</td>
<td>☐ Yes</td>
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<td>Mucosal margin: Bottom of the sulcus</td>
<td>mm</td>
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Faculty of Dentistry
University of Toronto

Appendix D

Prosthodontics

CLINICAL STUDY: Retrospective analysis of patients with implant-retained complete fixed dental prostheses.

Form 2/4. Patient Satisfaction, Status & Prosthesis history

Please use capital letters

Initials (No name): ______________ Date: ___ / ___ / ______

1. Can you recall the reason for the loss of your tooth/teeth replaced by the implant(s)
   - Gum disease
   - Decay
   - Cyst/Abscess
   - Fractured tooth
   - Orthodontics
   - Failed root-filling
   - Don’t know / Other reason (please specify): ______________

2. Do you grind/press your teeth during the day or night?
   - Yes
   - No

3. Are you satisfied with your implant-retained prosthesis?
   - Yes
   - No

4. Did you receive the type of dental prosthesis that you hoped for?
   - Yes, as I had wanted
   - No: (Please describe below):

                               __________________________________________________________
                               __________________________________________________________

5. How do you grade the implant-retained prosthesis characteristics below on a six to one scale (5=Perfectly, 4=Well, 3=Satisfactorily, 2=Unsatisfactorily, 1=Very Poorly):
   - Aesthetics: The appearance of the prosthesis pleases me.... Grade: _____
   - Chew comfort: I’m able to eat foods .... Grade: _____
   - Cleaning: I’m able to keep the prosthesis clean .... Grade: _____
   - Expectations: The prosthesis has met my expectations .... Grade: _____

6. Would you undergo the same treatment if required? (one box only)
   - Yes, certainly
   - Yes, probably
   - Undecided
   - Probably not
   - Absolutely not

7. What do you use for cleaning your implant-retained prosthesis? (Several boxes possible)
   - Manual toothbrush
   - Electric toothbrush
   - Water-Pik
   - Toothpick
   - Floss
   - Interdental brush

Page 1 of 2

I confirm that I have carefully examined all entries on the Case Report Form for this patient.

Investigator initials: _______ Date: ___ / ___ / ______

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8. Is the original implant-retained prosthesis still in your mouth?
   • Yes
   • No

9. Where have you had the follow-up examinations of the implant-retained prosthesis?
   • Private dentist
   • Faculty of Dentistry
   • Have not had any dental examinations since prosthesis placement
   • Other explanations

10. Do you have regular recalls with a dental hygienist? (one box only)
   • 3-4 times / year
   • 2 times / year
   • 1 time / year
   • less than 1 time / year
   • never

11. Have you ever had a need to repair your implant-retained prosthesis?
   • No
   • Yes
   When? __________________________________________
   Where? _________________________________________
   Why? __________________________________________
   Approximate Cost? _______________________________

12. Have you ever had any problems with your implant-retained prosthesis?
   • No
   • Yes,
   When? _________________________________________
   How often? _____________________________________
   Reason? ________________________________________

13. Have you ever had any complications with your implant-retained prosthesis?
   • No
   • Yes: (Several boxes possible)
   Implant:  • Inflammation  • Infection  • Pain/numbness
   Implant:  • Loosening  • Loss
   Denture:  • crack  • Fracture

Page 2 of 2

I confirm that I have carefully examined all entries on the Case Report Form for this patient:
All information reflects, to the best of my knowledge, correct.

Investigator initials: ___ Date: ___ / ___ / ___
Form 4/4. Prosthesis history from Patient Chart

I CONSENT THAT THE INVESTIGATOR TEAM OF THE CLINICAL STUDY: "Retrospective analyses of patients with implant-retained complete fixed dental prostheses" MAY REQUEST FROM MY DENTIST THE INFORMATION BELOW:

Signed: ___________________________ Date: ___/___/_____

Please use capital letters

Dentist name: ___________________________ Date: ___/___/_____

1. Is the original implant-retained prosthesis still in the patient's mouth?
   - [ ] Yes
   - [X] No
   - Date of failure: ___/___/_____

2. Has the patient ever had a need to repair their implant-retained prosthesis?
   - [ ] No
   - [ ] Yes
      - When? ___________________________
      - Where? ___________________________
      - Why? ___________________________
      - Approximate Cost? _______________

3. Has the patient ever had any problems with their implant-retained prosthesis?
   - [ ] No
   - [ ] Yes
      - When? ___________________________
      - How often? ___________________________
      - Reason? ___________________________

4. Has the patient ever had any complications with their implant-retained prosthesis?
   - [ ] No
   - [ ] Yes: (Several boxes possible)
      - Implant: [ ] Inflammation [ ] Infection [ ] Pain/numbness
      - Implant: [ ] Loosening [ ] Loss
      - Prosthesis: [ ] Crack [ ] Fracture

Date(s) of occurrence: ___/___/_____
(please also indicate complication) ___/___/_____
___/___/_____
___/___/_____

THANK YOU FOR YOUR COOPERATION
Please return form to: Discipline of Prosthodontics, Faculty of Dentistry, University of Toronto, 124 Edward Street, Toronto M5G 1G6.

Feel free to contact us for any questions or concerns related to this study by telephone at 416-979-4830 ext. 4423 / 4424 / 4309