# SUCCESS OF SHORT- VERSUS LONG- DENTAL IMPLANTS IN THE BICUSPID AREA: A RETROSPECTIVE STUDY

by

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D.M.D., University of Pittsburgh, 2002

M.D.S., University of Pittsburgh, 2013

Submitted to the Graduate Faculty of

the School of Dental Medicine in partial fulfillment

of the requirements for the degree of

Master of Science in Dental Medicine

University of Pittsburgh

2013

UNIVERSITY OF PITTSBURGH

SCHOOL OF DENTAL MEDICINE

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**SUCCESS OF SHORT- VERSUS LONG- DENTAL IMPLANTS IN THE BICUSPID AREA: RETROSPECTIVE RESEARCH**

Eyad Al-Khalifa D.M.D.

University of Pittsburgh, 2013

The placement and restoration of endosseous dental implants have become routine dental procedures that offer high success rates when suitable planning and protocols are followed. Anatomical considerations may exist, in the posterior region of both mandible and maxilla, that pose limitations, such as the position of the inferior alveolar nerve and the sinus cavity. Methods to increase vertical height of the posterior mandible or maxilla, such as autogenous bone augmentation, inferior alveolar nerve repositioning and sinus lifting, have shown high levels of morbidity. For patients with inadequate vertical height of the posterior maxilla and mandible, placement of short-length dental implants can be considered.

Prospective clinical trials have found excellent success rates for endosseous root-form dental implants of standard lengths, with success rates and survival rates of up to 98% across numerous studies (Buser 1997; Mangano 2010). Many studies have shown higher failure rates for shorter-length implants; recent reports have shown success rates comparable to longer-length implants (Misch 2006; Renouard 2006).

The purpose of this research is to determine the success rate of short implants placed in premolar regions, using statistical analyses of a retrospective review of the University of Pittsburgh School of Dental Medicine Electronic Health Record [EHR].

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# PREFACE

The author would like to express profound gratitude to his advisor, Dr. Pouran Famili, for her invaluable support and continuous guidance which enabled him to complete his work successfully. Author is highly thankful to Dr. Richard A. Bilonick, for his supervision and statistical analysis for this research work. It is a pleasure to the author to thank Dr. Ali Seyedain and Dr. Anitha Potluri for giving him thoughtful academic advice as a committee member for the thesis.

The author is indebted to his mother for her love, prayer and support throughout his life. Nothing one can say can do justice to how he feels about her support. Special thanks go to his two daughters, Acacia and Basma for their love.

Last but by no means least; it gives the author immense pleasure to thank his wife Aseel. His wife is his source of strength and energy. Without her support, this thesis would never have started, much less finished.

# 1.0 INTRODUCTION

The osseointegrated implant has been thoroughly investigated and its use reported in more than 1,000 published papers based on various animal and human models. Criteria for the evaluation of dental implant success are proposed. These criteria are applied in an assessment of the long-term efficacy of dental implants in current use, including short dental implants. Anatomical limitations very often represent a contraindication to implant therapy. After tooth loss, however, severely atrophic residual alveolar ridges are quite common, especially in patients who have been edentulous for a long period of time. Reduced alveolar bone height in posterior areas of the maxilla and mandible propose a great challenge for dentists and dental specialists who use implant therapy to replace a missing tooth, unless a procedure such as ridge augmentation or sinus floor elevation is performed. Although widely utilized, these techniques imply greater morbidity, longer treatment times and higher costs. The sinus cavity intruding into the maxilla and the close proximity of the alveolar nerve in the mandible are clinical situations where short implants may be considered a successful alternative treatment option.

This research is a retrospective review of existing medical records utilizing the University of Pittsburgh School of Dental Medicine Electronic Health Record, stored in its axiUm database [Exan® Las Vegas NV].

## 1.1 REVIEW OF THE LITERATURE: DENTAL IMPLANT

### 1.1.1 History of the dental implant

Early civilizations recognized the benefit of tooth replacement with different kinds of implants. The Mayan civilization has been shown to have used the earliest known examples of dental implants. Archaeologists have found a fragment of mandible of Mayan origin, dating from about 600 AD. This mandible, considered to be a woman in her twenties, had three tooth-shaped pieces of shell placed into the sockets of three missing lower incisor teeth. The idea of the subperiosteal implant was first proposed by Dahl in 1941 in Sweden, and was later patented by him in the USA in 1942. After various modifications by prominent clinicians such as Gershkoff, Goldberg, Linkow, Cranin, and more recently by Robert James (at Loma Linda), today the modern subperiosteal implant modality is used routinely, mainly in the United States, with very high success rates (90+ % over five years) and predictability matched only by the root-form implants. The modern subperiosteal implant modality was recognized by the National Institutes of Health (NIH) in 1988 as a major implant modality for the treatment of atrophied jaws. Golec et al. (1992) has shown that coating subperiosteal implants with hydroxyapatite may result in direct bone interface (a phenomenon called "biointegration" of HA) rather than attachment by a suspensory ligament. In 1952, in a modestly appointed laboratory in the university town of Lund, Sweden, Professor Per-Ingvar Brånemark had a lucky accident, or what most scientists would call *serendipity*. Much to his irritation, Dr. Brånemark discovered that it was impossible to recover any of the bone-anchored titanium microscopes he was using in his research. The titanium had apparently bonded irreversibly to living bone tissue, an observation which contradicted contemporary scientific theory. Dr. Brånemark subsequently demonstrated that under carefully controlled conditions titanium could be structurally integrated into living bone with a very high degree of predictability and without long-term soft-tissue inflammation or ultimate fixture rejection. Brånemark named the phenomenon osseointegration. The first practical application of osseointegration was the implantation of new titanium roots in an edentulous patient in 1965. More than thirty years later, the non-removable teeth attached to these roots are still in function.

### 1.1.2. Types of dental implants

The dental implant is a prosthetic device of allopastic material implanted into the oral tissues beneath the mucosa and/or periosteal layer, and/or within the bone to provide retention and support for a fixed or removable prosthesis.

**1.1.2.1 Subperiosteal implants** Subperiosteal implants were already introduced by Dahl in 1943. Of all currently-used devices, the subperiosteal implant has had the longest period of clinical trial. No specific animal research programs with subperiosteal implants appear to have been undertaken in the past decade. As shown below in Figure 1, these subperiosteal implants are not anchored inside the bone as endosseous devices, but are instead shaped to "ride on" the residual bony ridge. They are not claimed to be osseointegrated (Bodine 1980). The optimal outcome of subperiosteal implant therapy is represented by the long-term material of Bodine and Yanase (1959) whose ten-year report indicated success in the range of 66% ± 8%.

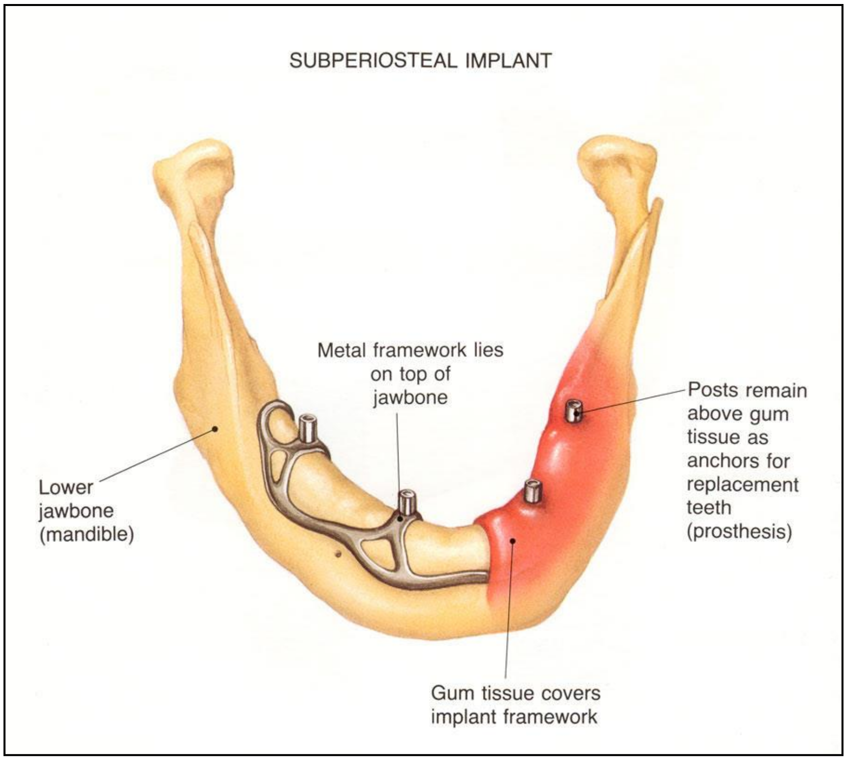


**Figure 1.** Subperiosteal Implant

**Source:** Taylor, Thomas D. Laney, William R. (1993). *Dental Implants: Are They for Me? (Educate Your Patients).* London: Quintessence.
*Reprinted with permission from Dr. Taylor, 05-03-2013*

### 1.1.2.2 The Transosteal, mandibular staple bone plate

Small and Kobernick (1969) inserted stainless steel threaded pins shown in Figure 2 that pass through the mandibles of edentulous dogs, and described tissue reactions over a period up to 12 months. Small 1985 presented some post-mortem evidence of osseointegration of the surgical implant screws, particularly in one case that was examined six years after insertion. Mandibular staple implants are indicated for insertion in the edentulous mandible with a minimal alveolar ridge height of 8 to 9 mm (Small 1985). In 1980 Small published a review of 1,516 cases, with rates of cumulative success at 94.6% for five to six years and 90.9% for 8 to 16 years. A total 395 among the 1,516 cases had retained the staples five years or longer. Gingival hyperplasia and/or infection about one or both transosteal pins was reported to be a complication in 10% to 15% of cases. Bone loss in 30 cases in the long-term follow-up (5 to 14 years, mean nine years) averaged only 0.78 mm.

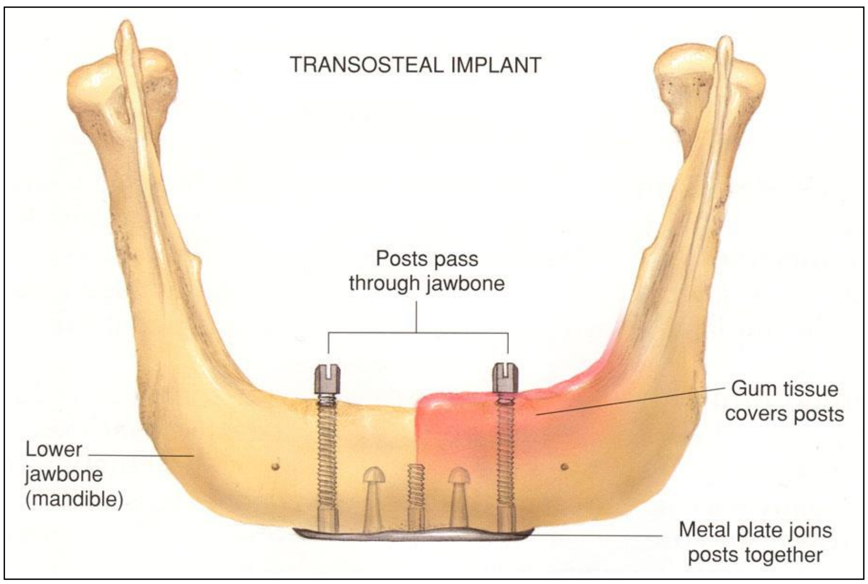


**Figure 2.** Transosteal Implant

**Source:** Taylor, Thomas D. Laney, William R. (1993). *Dental Implants: Are They for Me? (Educate Your Patients)*. London: Quintessence.
*Reprinted with permission from Dr. Taylor, 05-03-2013*

**1.1.2.3 The endosseous implants** The use of commercially pure titanium as an implant material was documented by Brånemark in 1977. His discovery of the osseointegrated implant led to the development of root-form endosseous dental implants as shown in Figure 3. They have become the standard in dentistry in the last 20 years. According to the FDA report *Class II Special Controls Guidance Document: Root-form Endosseous Dental Implants and Endosseous Dental Abutments*, "the root-form endosseous dental implant device refers to the fixture that is surgically implanted into the patient's bone. The root-form endosseous dental implant device is intended to be surgically placed in the bone of the upper or lower jaw arches to provide support for prosthetic devices, such as an artificial tooth, in order to restore the patient's mastication function."

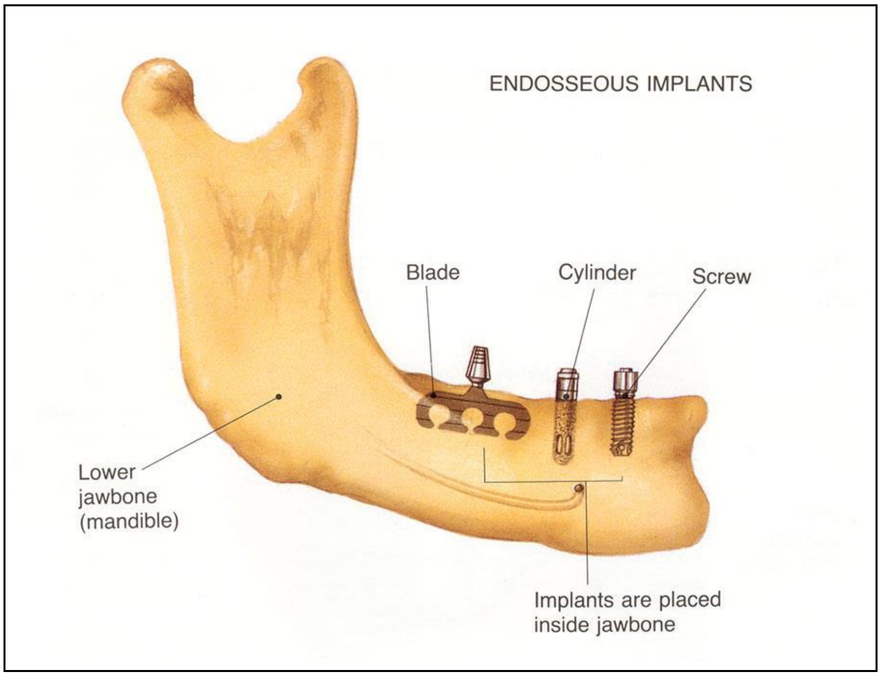


**Figure 3.** Endosseous Implant

**Source:** Taylor, Thomas D. Laney, William R. (1993). *Dental Implants: Are They for Me? (Educate Your Patients).* London: Quintessence. *Reprinted with permission from Dr. Taylor, 05-03-2013*

In 1981 Adell reported the success rate of 895 implant fixtures over an observational period of five to nine years after placement. Eighty-one percent of maxillary and 91% of mandibular implants remained stable. Brånemark and Albrektsson (1986) evaluated the outcome of all implants inserted during one year and then followed up for five years and found an implant success rate of 96.5% in the mandible. The great majority of all published papers have reported a positive outcome of endosseous implants in 90% to 100% of the cases.

## 1.1.3 Implant–tissue interface

**1.1.3.1 Implant-soft tissue interface** The implant-soft tissue interface is similar to that present in the natural dentition, as seen in Table 1, with a functional junctional epithelium containing basal lamina and hemidesmosomal attachments (Gould 1981,1984).

**TABLE1**

**Characteristics of the soft tissue interface**

| Feature | Tooth | Implant |
|---|---|---|
| **Sulcular epithelium** | + | + |
| **Junction epithelium** | + | + |
| **Basal lamina** | + | + |
| **Hemidesmosomes** | + | + |
| **Glycoprotein adhesion** | + | + |
| **Connective tissue fiber insertion** | + | - |

*Table 1 adapted from G.R. Bauman et al.(1993) The Peri-Implant Sulcus. *International Journal of Oral and Maxillofacial Implants* 8(3):273-280. *Reprinted with permission from the journal, 05-03-2013*

Meffert (1988) presented evidence supporting the concept that a viable biologic seal can exist between the epithelial cells and the implant. Kurashina 1984 described non-inflamed and inflamed peri-sulcular tissue at 27 dense hydroxyapatite (HA) implants in dogs, which closely parallels that observed about natural teeth in the same animal model:

1. *Non-inflamed:* In the connective tissue of the gingiva, a limited infiltration of inflammatory cells was noted. This field of inflammatory cells was the same area as that in the gingiva of neighboring teeth. Outside this area, numerous bundles of collagen fibers were seen and many of these fibers terminated perpendicularly to the interface with the implants, resulting in a saw-toothed pattern (Sharpey's fibers?). The epithelium on a lower level, adjoining the implant surface, was 2 to 5 cells thick. There was no cell differentiation between the subsequent superficial layers, no keratinization, and few or no papillae.
2. *Inflamed:* There were multiple bone resorptions at the alveolar bone crest. In some sections, islands of bone were seen lying at the interface with the implant, just above the alveolar bone. At the supra-alveolar level the gingival connective tissue showed a large field of inflammatory cells and disappearance of collagen fibers. Epithelial downgrowth lined the implant sulcus. The lowest level was always above the alveolar bone.

The most critical difference between periodontal and peri-implant tissue is the absence of Sharpey's fibers extending into the implant. Collagen fibers are non-attached and run parallel to the implant surface owing to the lack of cementum (Samachiaro 1986, Fukuyama 1986). However some reports have suggested that microscopic irregularities and porosities, such as would be found on plasma-sprayed titanium surfaces, may favor the appearance of fibers oriented perpendicularly to the implant surface (Buser 1992, Schroeder 1988).

**1.1.3.2 The implant-bone tissue interface** The relationship between endosseous implants and bone consists of one of two mechanisms: *osseointegration,* when the bone is in intimate contact with the implant, or *fibro-osseous integration*, in which soft tissues, such as fibers and/or cells, are interposed between the two surfaces. Brånemark et al. (1969) proposed the concept of osseointegration; the related concept *functional ankylosis* by Schroeder (1988) states that there is an absence of connective tissue or any non-bone tissue in the interface between the implant and the bone. Osseointegration refers to the direct contact of bone and implant at the light-microscope level. Sections viewed with electron microscopy have revealed a proteoglycan layer (containing calcified tissue) in direct contact with the titanium oxide surface implant. The proteoglycan layer is 40 to 200 Å thick (Albrektsson 1985). Meffert et al. (1987) suggested that only hydroxyapatite, and not titanium, was capable of true bonding to bone. Bagambisa et al. (1990) reported that an even carpet of multilayered osteoblasts covered the surface of HA implants, with bone infiltrating the porous surface. Hydroxyapatite was not osteoinductive but acts as a nucleation site for osteoid material. Bone formation occurred through epitaxial crystal growth.

## 1.2 IMPLANT PLACEMENT CONCERNS

Dental implant placement is no longer performed only by oral surgeons and periodontists; general dentists are also increasingly providing difficult surgical implant services. Dental implants may be used to replace single teeth, replace multiple teeth, or provide abutments for complete dentures or partials. It is essential to obtain appropriate information about the oral vital structures prior to implant placement. Knowledge of anatomy and its variations is essential to ensure precise surgical procedures to safeguard the patient's vital structures (Greenstein 2008).

### 1.2.1 Anatomic concerns

Prior to commencement of implant surgery, careful and detailed planning is required to identify maxillary and mandibular vital structures as well as the shape and dimensions of the bone, so the implants can be properly oriented and placed. During the planning phase of treatment, the recipient bed is routinely assessed by visual examination and palpation, as well as the available medical imaging modalities. When adequate occlusoapical bone height is available for endosteal implants, the buccolingual width and height of the available bone are the most important criteria for implant selection and success.

**1.2.1.1 Quality and Quantity of alveolar bone** Lekhom and Zarb (1985) classified the volume of remaining mineralized bone at the edentulous sites into five different groups based on shape, and the "quality" of the bone in the edentulous site into four types. (Please see Figure 4).

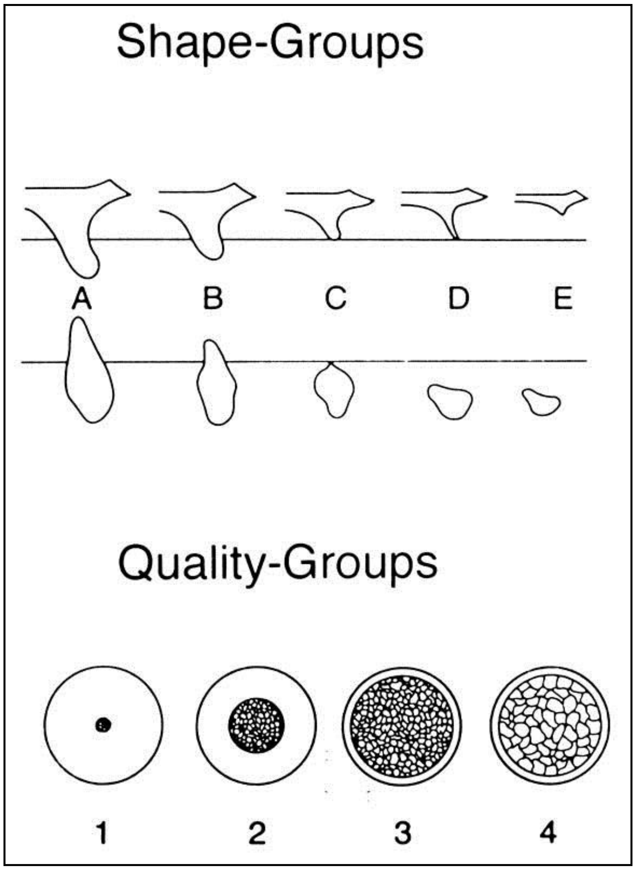


**Figure 4**. Classifcation of residual jaw shape and jaw bone quality

Source: Ulf Lekholm. Surgical considerations. *Journal of Prosthetic Dentistry* 79(1):43-48, 1998.
*Reprinted with permission from the journal, 05-03-2013*

(Detail for Figure 4):

## Shape Groups A-E

A. Virtually intact alveolar ridge

B. Minor resorption of the alveolar ridge

C. Advanced resorption of alveolar ridge to the base of the dental arch

D. Initial resorption of the base of the dental arch

E. Extreme resorption of the base of the dental arch.

## Quality Groups 1-4

1. Almost the entire jaw is composed of homogenous compact bone.
2. A thick layer of compact bone surrounds a core of dense trabecular bone.
3. A thin layer of compact bone surrounds a core of dense trabecular bone of favorable strength.
4. A thin layer of cortical bone surrounds a core of low density trabecular bone.

Bone quality types 2 and 3 are found much more frequently than types 1 and 4. Although variation in density exists in each region, quality 2 dominates the mandible and quality 3 bone is more prevalent in the maxilla (Truhlar 1997).

#### 1.2.1.2 Mandibular canal

The mandibular canal is one of the most important anatomical structures in the mandible, because it carries the inferior alveolar neurovascular bundle: the inferior alveolar nerve (IAN) and the inferior alveolar artery, vein, and lymphatic vessels (Tammisalo 1992). Rajchel (1986), studying 45 Asian adults, demonstrated that the mandibular canal, when proximal to the third molar region, is usually a single large structure 2.0 to 2.4 mm in diameter. Clinicians should be aware of variation in the course of the mandibular canal as it runs through the jaw, because the mandibular canal may present in different anatomical configurations in the vertical plane. According to Anderson (1991) the canal may run lower when it proceeds anteriorly, or may present a sharp decline, or drape downward in catenary fashion. Nortje et al. (1977), on panoramic radiographs, showed that the vertical mandibular canal position can be divided into four categories: 1) high mandibular canal (within 2 mm of the apices of the first and second molars); 2) intermediate mandibular canal; 3) low mandibular canal; and 4) other variations – these include duplication or division of the canal, apparent partial or complete absence of the canal or lack of symmetry. According to Gowgiel (1992), the neurovascular bundle from the mandibular foramen to the mental foramen is always in contact with, or in close proximity to, the lingual mandibular cortex. It has been shown that vascular and nerve bundles may be extremely close to the buccal cortex of the mandible in patients with broad and thick mandibular rami. Dario (2002) suggested that clinicians should consider obtaining a preoperative tomogram to avoid nerve injuries prior to implant placement above the inferior alveolar canal (Greenstein and Tarnow

2006, from Dario 2002). A mean incidence of neurosensory disturbance incidence after implant surgery was 6.1% (Goodacre 1999) to 7% (Goodacre 2003), with a range between 0.6% and 39%.

#### 1.2.1.3 Mental nerve and it's anterior loop

One of the most challenging regions to do implant placement in mandible is the area of the mental foramen region. This is because there are many variations with regard to the size, shape, location and direction of the opening of the mental foramen. The shape of the mental foramen can be round or oval: diameter ranges from 2.5 to 5.5 mm (Neiva 2004; Apinhasmit 2006; Yosue 1989). The position of the mental foramen was recorded as either in line with the longitudinal axis of a tooth or as lying between the two teeth. The mental nerve is at particular risk of iatrogenic injury because it arises from the asymmetric foramina and forms a concave loop anteriorly. In edentulous patients, the mental nerve may be very close to the bone surface or the top of the crest. Nerve injury may cause parasthesia (numb feeling), hypoesthesia (reduced feeling), hyperesthesia (increased sensitivity), dysthesia (painful sensation), or anesthesia (complete loss of feeling) of the teeth, the lower lip, or the surrounding skin and mucosa (Greenstein and Tarnow 2006, from Sharawy and Misch 1999). Bavitz (1993) measured anatomically and radiographically the anterior loop of the mental nerve in twenty-four cadavers (please see Table 2).

**TABLE 2**

**Measurement of the anterior loop from the mental foramen**

| | Anatomic measurement | Radiographic measurement |
|---|---|---|
| **Dentate** | Average 0.2 mm<br>Range 0 -1 mm | Average 2.5 mm<br>Range 0 – 7.5 mm |
| **Edentulous** | Average 0.0 mm | Average 0.6 mm<br>Range 0 – 2 mm |

*Table 2 adapted from Bavitz JB. An anatomical study of mental neurovascular bundle-implant relationships. *International Journal of Oral and Maxillofacial Implants* 8(5):563-567, 1993. *Reprinted with permission from the journal, 05-03-2013*

The most anterior position in which the mental nerve is commonly found is 1 mm forward or mesial to the most anterior aspect of the mental foramen (Bavitz 1993). Based upon Bavitz' finding, implants can be placed as close as one millimeter anterior to the radiographic mental foramen. Over-penetration occurs when the cortical portion of the alveolar crest places resistance on the drill. However, as it enters the marrow spaces, a drill may drop into the neurovascular bundle unless the surgeon has excellent control (Misch and Wang 2008). A safety margin of 2mm between the entire implant body and any nerve canal should be maintained (Greenstein 2008, from Greenstein and Tarnow 2006; Worthington 2004).

#### 1.2.1.4 Vasculature in the floor of the mouth

The arterial blood supply of the floor of the mouth is formed by an anastomosis of the sublingual and submental arteries. The submental artery (2mm average diameter) (Hofschneider 1999) is a branch of the facial artery. The sublingual artery (2 mm average diameter) arises from the lingual artery and is found coronal to the mylohyoid muscle (Martin 1993). Intraosseous hemorrhage is not a serious event, and control of the hemorrhage can be ensured by compressing the area with a directional indicator, an abutment, or the implant. A vascular wound may occur after detrimental surgical manipulations or tearing of the lingual periosteum, but in most cases it is attributed to perforations of the lingual cortical plate. Mechanical pressure exerted by the expanding hematomas displaces the tongue and floor of the mouth both superiorly and posteriorly (Kalpidis and Setayesh 2004). This occurrence may lead to extensive bleeding into the submandibular space, resulting in a life-threatening acute airway obstruction within the first few hours after surgery (Goodacre 1999).

#### 1.2.1.5 Maxillary sinus

The maxillary sinus is the largest paranasal sinus. It is pyramidal in shape. The base of the sinus lies vertically on the medial surface of the lateral nasal wall. The average volume of a fully developed sinus is about 15ml but may range between 4.5 and 35.2ml. The Schneiderian membrane, which lines the sinus, is adherent to underlying bone. The structures beneath the sinus consist of the alveolar ridge and maxillary posterior teeth (Small 1993). One or more septa, also referred to as Underwood’s septa, divide the floor of the maxillary sinus into several recesses and may thus cause various complications during sinus-lift procedures. The overall prevalence of one or more sinus septa is between 26.5% and 31% (Ulm 1995; Kim 2006) and is most common in the area between the second premolar and first molar.

It is well known that the sinus expands with age, and especially when posterior teeth are lost. The sinus cavity expands both inferiorly and laterally, potentially invading the canine region. This phenomenon is called pneumatization of the sinus. This finding is related to two phenomena:

1) The enlargement of the sinus at the expense of the alveolus after tooth extraction because of the increased osteoclastic activity of the periosteum of the Schneiderian membrane (Kraut 1989).
2) Increased pneumatization of the sinus because of the increase in positive intra-antral pressure (Smiller 1992).

The poor bone quality and inadequate bone volume in the posterior maxilla often presents specific problems for the placement of dental implants. To increase the amount of bone in the posterior maxilla, the sinus lift procedure (subantral augmentation) was developed in the mid-1970s (Linkow 1966). The sinus lift is a well-accepted technique to treat the loss of vertical bone height (VBH) in the posterior maxilla performed in one of two ways, either via a lateral window technique or (Summers 1994) by an osteotome sinus floor elevation technique with bone-graft material placed in the maxillary sinus to increase the height and width of the available bone. [Table 3. contains a guideline for sinus floor elevation.]

**TABLE 3**

**General Guidelines for Sinus Floor Elevation**

| Vertical Bone Height | Surgical Procedure | Implant Placement |
|---|---|---|
| **>/= 10 mm** | None needed | Immediate |
| **7 mm to 10 mm** | Sinus floor elevation via osteotome technique | Immediate |
| **5 mm to and 7 mm** | Sinus floor elevation via lateral window approach | Immediate |
| **1 mm to 4 mm** | Sinus floor elevation via lateral window approach | Delayed |

*Table 3 adapted from Georglos Tasoulis (2011), The Maxillary Sinus: Challenges and Treatments for Implant Placement. *Compendium* 32(1):10-20. *Reprinted with permission from the journal, 05-03-2013*

The most common intraoperative complication seems to be Schneiderian membrane perforation, occurring in 10-60% of all procedures (Ardekian 2006; Pikos 1999). The Schneiderian membrane could present a window for bacterial penetration and invasion into the grafted area (Zijderveld 2008). Failure to atraumatically elevate the Schneiderian membrane may result in graft migration or loss, exposure of the graft or implant to the sinus, and postoperative site infection. In addition to contaminating the recipient site, disruption of the mucosa may alter the normal mucociliary flow patterns, causing retention of secretions and infections around the foreign body (Ward 2008).

## 1.3 ROLE OF RADIOGRAPHIC EVALUATION IN DENTAL IMPLANT PLACEMENT

In dental practice, imaging is recommended for preoperative evaluation of the implant site, and postoperatively for the evaluation of correct seating of the abutment and further evaluation of bone loss under an implant maintenance regime. Radiography plays a vital role in diagnosis and treatment planning to place the implant.

Before attempting to treat a patient with an endosseous dental implant, dentists must determine jaw size, boundaries, and orientation of the vertical long axis of the jaw. In addition, internal anatomy should be visualized in three-dimensional perspectives, including the proximity of nasal fossae, neurovascular bundles, pneumatization of the maxillary sinus, soft tissue morphology, and bone quality. Imaging information will allow optimum placement of the implants and enhance the success, both short- and long-term, of all subsequent stages of the procedure.

### 1.3.1 Imaging modalities

The American Academy of Oral and Maxillofacial Radiology (AAOMR) (White 2001) has described the selection criteria for dental implant imaging. To assess the suitability of an implant site, the clinician must be able to visualize the mesial–distal view of the region of the arch where implant placement is being considered.

In many practices, digital radiographs have largely replaced conventional films. As a result, many dentists will find they are already familiar with the combination of rapid imaging and computer display that cone-beam units provide. Digital images will not fade and can be stored on a computer along with other patient information. They can be manipulated easily on a computer, where angles can be rotated, grayscale intensities can be adjusted, negative and positive can be reversed, and pseudo-color can be added to enhance contrast to facilitate immediate diagnosis. These are all major advances over trying to make a diagnosis by examining films by hand.

#### 1.3.1.1 2-D imaging: periapical and panoramic radiography

Periapical radiographs are images of a limited region of the mandibular or maxillary alveolus. Periapical radiographs are produced by placing the film intra-orally parallel to the body of the alveolus with the central beam of the X-ray device perpendicular to the alveolus at the region of interest, producing a lateral view of the alveolus. Unscreened radiographs provide high-resolution (more than 20 line pairs per mm) and sharp images, which allow accurate measurements in the horizontal direction, specifically measuring the proximity of adjacent tooth roots. These are well-suited for documentation and assessment of possible peri-implant bone resorption during follow-up and are considered superior to panoramic radiography in this respect (Strid 1985). With proper positioning techniques, periapical radiographs give minimum magnification and distortion and the reproducibility of these radiographs is high.

Panoramic radiography is a curved plane tomographic radiographic technique used to depict the body of the mandible, maxilla, and the lower one-half of the maxillary sinuses in a single image. Panoramic radiography allows complete visualization of the relationship of the maxillofacial structures within the focal trough, and provides information on the relative position of the inferior alveolar canal and the maxillary sinuses in relation to the crest of the alveolar ridge. It provides an approximation of bone height and vital structures and any pathological conditions that may be present (Strid 1985). The major disadvantages of panoramic radiography are an unpredictable distortion of the visualized structures and a low level of reproducibility.

Two-dimensional images cannot provide clinicians with information about the buccolingual cross-sectional dimension or the inclination of the alveolar ridge (Fredholm 1993).

**1.3.1.2 3-D imaging: Computed Tomography (CT)** Computed tomography (CT) was developed by British engineer Godfrey N. Hounsfield, who received a patent on computed tomography in 1972 and shared the 1979 Nobel Prize in Medicine for its invention with Allan M. Cormack. Hounsfield described computed tomography as a reverse of radar; whereas radar sweeps out to cover a landscape, computed tomography sweeps inward to cover the interior of an object or body.

Computed tomographic scanning for dental implant surgery planning has been well-described (Andersson 1987; Wishan 1988). Computed tomographic scanning, which allows exact preoperative analysis of the available bone volume and helps to determine the appropriate position, angulation, number, and length of the planned implants, is highly recommended (Schwarz 1990). This modality also gives a high-density resolution, and the soft tissues can also be visualized to some degree. The reformatted CT images provide axial, panoramic, and cross-sectional images that are all cross-referenced to one another (Schwarz 1987), allowing rapid correlation of the different views.

The American Academy of Oral and Maxillofacial Radiology recommends that any evaluation of the available bony architecture for diagnosis and planning of extensive implant-based oral rehabilitation include CT imaging (Almog 2006).

## 1.4 REVIEW OF THE LITERATURE: SHORT DENTAL IMPLANTS

Anatomic structures and ridge resorption limit the placement of a standard dental implant (Misch 1993). Posterior regions of the jaws usually have the least height of existing bone, since the maxillary sinus expands after tooth loss and the mandibular canal is 10mm or more above the inferior border of the mandibular body.

### 1.4.1 Rational for using short dental implants

Methods to increase vertical height of the posterior mandible, such as autogenous bone augmentation and inferior alveolar nerve repositioning, have shown high levels of morbidity (Das Neves 2006; Krogh 1994). For patients with inadequate vertical height of the posterior mandible, placement of short-length dental implants can be considered. The biomechanical rationale behind the use of short-length implants is that the crestal portion of the implant body is the most involved in load-bearing, whereas very little stress is transferred to the apical portion (Lum 1991) and the increase of implant length from 7 to 10mm did not significantly improve its anchorage (Bernard 2003). For an implant in bone of adequate density with a direct bone contact, the greatest magnitude of stress is concentrated in the crestal 5mm of the bone-implant interface (Misch 2005, Sevimay 2005). In Figure 5, a three-dimensional finite element (FE) analysis model was constructed to investigate the effect of four different bone qualities (D1, D2, D3, D4) on stress distribution in a single-unit crown. The figure shows maximum stresses in bone quality D4 at the neck of the implant and on the middle of the implant body. For bone qualities D1, D2, and D3, maximum stress was concentrated at the neck of the implant.

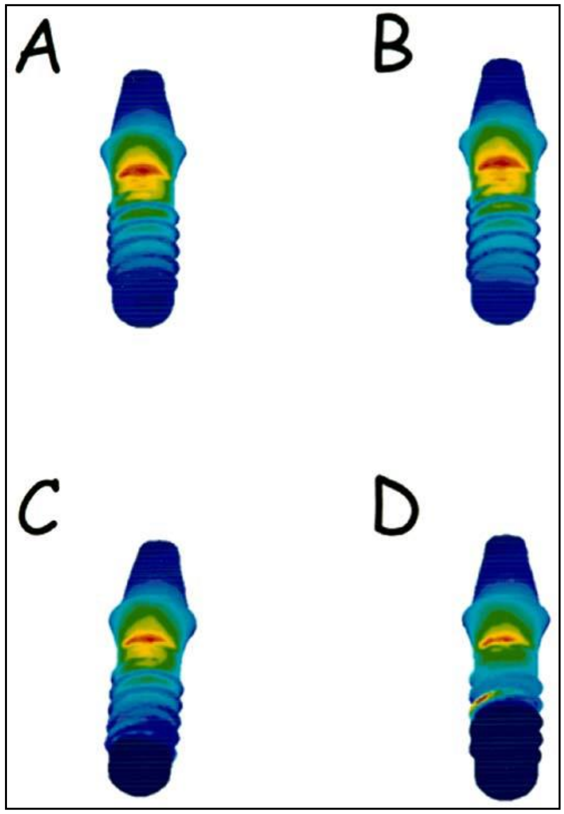


**Figure 5.** Distribution of stresses within implant and abutment

A = D1 bone 150 MPa; B = D2 bone 152 MPa; C = D3 bone 163 MPa; D = D4 bone 180 MPa

Source: Sevimay (2005). Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown. *Journal of Prosthetic Dentistry* 93(3):227-234 *Reprinted with permission from the journal, 05-03-2013*

### 1.4.2 Survival rates of short implants

A number of investigators have reported that shorter implants have a higher rate of loss as compared with longer implants of the same type and manufacturer (van Steenberghe 2000; Bahat 2000). However the development of implant design, surface structure and improved surgical technique have given reason to re-evaluate previous results, and recent clinical studies indicate that short implants may support most prosthetic restorations adequately. Survival rates around 95% are reported for the rehabilitation of partial edentulism and the severely resorbed maxilla (Tawil 2003; Renouard 2003) and 88% to 100% for the atrophic mandible (Stellingsma 2004). In 2006, Misch published a literature review of failure rates associated with dental implants less than 10mm long in the posterior of partially edentulous patients undergoing placement from 1991 to 2003. They reported that among 2,837 short implants, the survival rate was 85.3%. Misch and others have shown that most failures occur after prosthetic loading and that the failure rate is independent of implant length (Higuchi 1995; Misch 2005).

# 2.0 MATERIALS AND METHODS

## 2.1 STUDY POPULATION

Subjects were identified from a retrospective review of the existing dental records over a four-year period (from August 2008 to October 1, 2012) using the Electronic Health Record (EHR) of the University of Pittsburgh School of Dental Medicine.

## 2.2 CRITERIA FOR INCLUSION

All subjects were adult *(>age 18)* patients of record of the University of Pittsburgh School of Dental Medicine Department of Periodontics and Preventive Dentistry. Data were collected from the Electronic Health Record (EHR) of the University of Pittsburgh School of Dental Medicine (axiUm database, Exan Systems, Las Vegas, Nevada) from the time period from August 2008 to October 2012. All records were collected from implants placed in the bicuspid areas [tooth positions #4, 5, 12, and #13 (maxilla)] and tooth positions #20, 21, 28 and #29 (mandible) in generally healthy adult (ages 18-80) males or females. Records will be matched by implant type (NobelBiocare) and other relevant variables.

## 2.3 CRITERIA FOR EXCLUSION

Records from individuals reporting specifically diabetes, head/neck radiation, bleeding disorders, or any other medical condition that might contraindicate successful placement of dental implants were excluded. Records for implants placed in tooth positions other than bicuspid areas were excluded. Records for implants placed in individuals reporting osteoporosis were excluded.

## 2.4 BONE LOSS ASSESSMENT

Digital imaging software MiPACS dental enterprise viewer 3.1.1130 was used to capture periapical images that are used in this study. Periapical radiographs of shorter length and longer length dental implants were evaluated for the distance between the implant shoulder and the bone/implant contact point at the mesial and distal surfaces using a computerized image-analysis system, and the average value was obtained. 'Short' is defined as 10mm and less, and ‘long' is defined as greater than 10mm, most commonly between 11.5mm and 16mm in length. Measurements are caliberated for distortion by using measurement calibration tool within the software by using the actual measurement of the implant from subject chart.

## 2.5 SPECIFIC VARIABLES EXTRACTED FROM THE ELECTRONIC HEALTH RECORD

- Age
- Race
- Gender
- Implants placed in the bicuspid areas
- Length of implants
- Diameter of implants
- Periapical radiographs from the time of placement to the most recently available radiograph

## 2.6 STUDY DESIGN

Subjects used in this study were 75 patients (n=75) with a mean age of 59.4 years. A total of 115 implants (n=115) were placed in premolar areas (55 short implants and 60 long implants). Records included a subject identifier to identify all implants for a given subject. For subjects with multiple implants and thus multiple records in the dataset, the age, ethnicity, and sex were the same for each record for a given patient.

## 2.7 STATISTICAL ANALYSIS

Records of 75 subjects with a total of 115 implants were reviewed. The average age of the 75 subjects was 59.4 years with standard deviation 13.4 years. The median age was 62 years. The range for age was 22 to 87 years. There were 69 Caucasians, 4 African-Americans, 1 Asian, and 1 “other”. Twenty-seven subjects (27) were male and 48 were female. Seventeen variables were considered. They included age, sex, and ethnicity of the subject; treatment area, implant number, type, length, and diameter; the mesial measure of the placement of the implant; the distal measure of the placement of the implant; and the mean distance of the placement of the implant; the mesial measure of the placement of the crown; the distal measure of the placement of the crown; the mean measure of the placement of the crown; bone loss mesial, bone loss distal, and the mean measure of bone loss.

Table 4 shows simple summary statistics unadjusted for clustering of related measurements with subjects. Table 5 showed means with 95% confidence intervals adjusted for clustering using a mixed effects intercept-only model.

Figure 6 shows histograms for each quantitative variable. Figure 7 shows normal probability plots for each quantitative variable. Since bone density tended to be positively skewed a square root transformation was applied make the observations more normally distributed. Table 6 shows the results for fitting a mixed effects model to square root of mean bone loss as a function of implant diameter and length. The model is:

$$y_{ij} = \alpha + a_i + \beta_D D + \beta_L L + \epsilon_{ij}$$

where $y_{ij}$ denotes the square root of mean bone loss (mean.boneloss), $\alpha$ denotes the fixed intercept (the same for all subjects), $D$ and $L$ are the implant diameter and implant length, respectively; $\beta_D$ is the fixed slope for diameter, $\beta_L$ is the fixed slope for length, $a_i$ is the random intercept for subject $i$ (assumed Normally distributed with mean 0 and standard deviation $\sigma_a$, and $\epsilon_{ij}$ is a random error for subject $i$ and measurement $j$ (assumed Normally distributed with mean 0 and standard deviation $\sigma$). The maximum likelihood estimates for $\sigma_a$ and $\sigma$ were 0.195 √mm and 0.255 √mm, respectively.

According to the mixed effects model point estimates for the slopes, a 1 mm increase in diameter is expected to decrease the square root of mean bone loss by 0.0965 √mm and 1 mm increase in length is expected to increase the square root of mean bone loss by 0.000511 √mm. Plots illustrating the excellent model fit for each subject are shown in Figures 8 and 9.

Because the model was fitted to the square root transformed bone loss, Tables 7 and 8 were constructed to help show how mean bone loss is expected to change over the ranges of implant diameter and length, respectively, based on the estimated fixed effects. As shown in Table 7, as diameter increases, mean bone loss is expected to decrease from 1.15 mm to 0.86 mm as the diameter goes from 3.5 mm to 5 mm. This change, however, was not statistically significant.

Table 8 shows expected mean bone loss based on implant length. As length goes from 8 mm to 16 mm, the expected bone loss increases from 1.046 mm to 1.054 mm. The effect of length on bone loss, however, was not statistically significant. Although neither result was statistically significant, the diameter effect was much stronger than for length, based on the fixed slope point estimates.

Tables 9 a, b, c, and d show that of 115 implants placed, five failed. Tables 9 a, c, and d and show the naive marginal failure rates for patient age, implant length and implant diameter, respectively. Table 9 b shows the joint distribution of failures for length and diameter. The log of the probability for failure was modeled as a function of age, implant length, and implant diameter using a log-binomial (generalized) mixed-effects model with a random intercept to account for the nested implants within subjects:

$$\log(\pi_{ij}) = \gamma + g_i + \delta_A A + \delta_L L + \delta_D D$$

where $\pi$ is the mean failure rate for the $j^{\text{th}}$ implant for subject $i$, $\gamma$ is a fixed intercept (the same for all subjects), $g_i$ is a random intercept (assumed Normally distributed with mean 0 and standard deviation $\sigma_g$), $\delta_A$ is the fixed slope for age, $\delta_L$ is the fixed slope for length, and $\delta_D$ is the fixed slope for diameter. The observed failures $Y$ are assumed to be Bernoulli distributed with parameter $\pi$. The maximum likelihood estimate of the fixed intercept $\gamma$ was -14.084. The maximum likelihood estimate for $\sigma_g$ was 1.338.

Table 10 shows the fixed effects and random effects parameter estimates on the log scale. The subject-specific intercepts range from roughly -17 to -11 and this reflects the heterogeneity of the population. The relative risk was computed by exponentiating the parameter coefficients in Table 10. Table 11 showed that the relative risk for failing as a function of implant length was low and not statistically significant (p=0.56). The relative risks for failing as a function of implant diameter and age were also not statistically significant (p= 0.45 for diameter and 0.32 for age). The predicted probability of failure as functions of age, length and diameter based on the log-binomial mixed effects model are separately shown in Figure 10 and denoted by the green lines. These were compared with simple estimates of the probabilities using smoothing splines shown in red. It can be seen that the probabilities were estimated to be very small in addition to not being statistically significant. It should be noted that the naïve marginal failure estimates shown in Table 9 and the smoothing splines fitted in Figure 10 do not account for nesting of multiple implants for some subjects while the log-binomial mixed effects model does account for the nested data.

The R language and environment for statistical computing software [Version 2.15.2 by the R. Core Team 2012] with the `nlme` package [Version 3.1-108 by Pinheiro 2013] and the `lme4` package [Version 0.999999-0 by Bates et al., 2012] was used for statistical analysis and graphics.

## TABLE 4

**Simple summary statistics unadjusted for clustering of repeated measurements within subjects.**

| Statistic | N | Mean | St. Dev. | Min | Max |
|---|---|---|---|---|---|
| Age (yrs) | 115 | 59.373 | 13.443 | 22 | 87 |
| Treated area | 115 | 16.287 | 9.059 | 4 | 29 |
| Implant length (mm) | 115 | 11.604 | 1.899 | 8.000 | 16.000 |
| Implant diameter (mm) | 115 | 4.008 | 0.473 | 3.500 | 5.000 |
| Mesial distance shoulder implant/crestal bone at osteotomy (mm) | 115 | 0.161 | 0.318 | 0.000 | 1.690 |
| Distal distance shoulder implant/crestal bone at osteotomy (mm) | 115 | 0.403 | 0.484 | 0.000 | 2.150 |
| Mean or Average distance at osteotomy (mm) | 115 | 0.282 | 0.338 | 0.000 | 1.635 |
| Mesial distance shoulder implant/crestal bone with crown (mm) | 110 | 1.331 | 0.767 | 0.000 | 4.120 |
| Distal distance shoulder implant/crestal bone with crown (mm) | 110 | 1.626 | 0.877 | 0.000 | 4.930 |
| Mean or Average distance at crown placement (mm) | 110 | 1.478 | 0.763 | 0.000 | 4.500 |
| Mesial Bone loss (mm) | 110 | 1.163 | 0.717 | 0.000 | 4.040 |
| Distal Bone loss (mm) | 110 | 1.225 | 0.801 | 0.000 | 3.890 |
| Mean or Average Bone loss (mm) | 110 | 1.194 | 0.688 | 0.000 | 3.525 |
| Square-root Mean or Average Bone loss (mm) | 110 | 1.043 | 0.326 | 0.000 | 1.877 |
| Square-root Mesial Bone Loss (mm) | 110 | 1.023 | 0.342 | 0.000 | 2.010 |
| Square-root Distal Bone loss (mm) | 110 | 1.038 | 0.386 | 0.000 | 1.972 |

**TABLE 5**

**Means adjusted for nesting of implants within subjects using mixed effects models**

| Parameter | Adjusted Mean | Standard Error | 95% Confidence Intervals | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| Age (yrs) | 58.50 | 1.53 | 55.45 | 61.56 |
| Treated area | 16.30 | 0.98 | 14.36 | 18.25 |
| Implant length (mm) | 11.60 | 0.18 | 11.24 | 11.96 |
| Implant diameter (mm) | 4.01 | 0.05 | 3.91 | 4.11 |
| Mesial distance shoulder implant/crestal bone at osteotomy (mm) | 0.16 | 0.03 | 0.10 | 0.22 |
| Distal distance shoulder implant/crestal bone at osteotomy (mm) | 0.40 | 0.05 | 0.30 | 0.50 |
| Mean or Average distance at osteotomy (mm) | 0.28 | 0.04 | 0.21 | 0.35 |
| Mesial distance shoulder implant/crestal bone with crown (mm) | 1.30 | 0.08 | 1.14 | 1.46 |
| Distal distance shoulder implant/crestal bone with crown (mm) | 1.58 | 0.09 | 1.40 | 1.77 |
| Mean or Average distance at crown placement (mm) | 1.44 | 0.08 | 1.28 | 1.60 |
| Mesial Bone loss (mm) | 1.14 | 0.07 | 0.99 | 1.28 |
| Distal Bone loss (mm) | 1.19 | 0.08 | 1.02 | 1.36 |
| Mean or Average Bone loss (mm) | 1.16 | 0.07 | 1.01 | 1.30 |
| Square-root Mean or Average Bone loss (mm) | 1.03 | 0.03 | 0.96 | 1.10 |
| Square-root Mesial Bone Loss (mm) | 1.01 | 0.04 | 0.94 | 1.08 |
| Square-root Distal Bone loss (mm) | 1.02 | 0.04 | 0.94 | 1.10 |

**TABLE 6**

**Mixed effects model for mean bone loss as a function of implant diameter and implant length.**

| | lower | est. | upper | p-value |
|---|---|---|---|---|
| **Implant Diameter (mm)** | -0.2311 | -0.0965 | 0.0381 | 0.1603 |
| **Implant Length (mm)** | -0.0310 | 0.0005 | 0.0320 | 0.9743 |

**TABLE 7**

**Predictions for mean bone loss based on implant diameter**

| Diameter (mm) | Prediced Mean Bone Loss (mm) |
|---|---|
| **3.50** | 1.15 |
| **4.00** | 1.05 |
| **4.50** | 0.95 |
| **5.00** | 0.86 |

**TABLE 8**

**Predictions for mean bone loss based on implant length.**

| Length (mm) | Predicted Mean Bone Loss (mm) |
|---|---|
| **8** | 1.046 |
| **9** | 1.047 |
| **10** | 1.048 |
| **11** | 1.049 |
| **12** | 1.050 |
| **13** | 1.051 |
| **14** | 1.052 |
| **15** | 1.053 |
| **16** | 1.054 |

## TABLE 9a

## Implant failure by patient age.

| Patient Age (yrs) | Number of Implants | Number of Failures | Naïve % of Failures |
|---|---|---|---|
| **20 to 25** | 3 | 0 | 0.0 |
| **>25 to 30** | 0 | 0 | 0.0 |
| **>30 to 35** | 4 | 0 | 0.0 |
| **>35 to 40** | 7 | 0 | 0.0 |
| **>40 to 45** | 5 | 0 | 0.0 |
| **>45 to 50** | 6 | 0 | 0.0 |
| **>50 to 55** | 12 | 0 | 0.0 |
| **>55 to 60** | 19 | 1 | 5.3 |
| **>60 to 65** | 17 | 0 | 0.0 |
| **>65 to 70** | 20 | 2 | 10.0 |
| **>70 to 75** | 11 | 2 | 18.2 |
| **>75 to 80** | 8 | 0 | 0.0 |
| **>80 to 85** | 2 | 0 | 0.0 |
| **>85 to 90** | 1 | 0 | 0.0 |
| **Total** | 115 | 5 | 4.3 |

**TABLE 9b**

**Implant failure by implant length and diameter.**

| Implant Length (mm) | Implant Diameter (mm) | Number of Implants | Number of Failures |
|---|---|---|---|
| **8.0** | 3.5 | 1 | 0 |
| | 4.3 | 2 | 0 |
| | 5 | 0 | 0 |
| **10.0** | 3.5 | 18 | 0 |
| | 4.3 | 29 | 2 |
| | 5 | 5 | 0 |
| **11.5** | 3.5 | 6 | 0 |
| | 4.3 | 3 | 0 |
| | 5 | 0 | 0 |
| **13.0** | 3.5 | 20 | 1 |
| | 4.3 | 20 | 1 |
| | 5 | 3 | 0 |
| **16.0** | 3.5 | 4 | 0 |
| | 4.3 | 4 | 1 |
| | 5 | 0 | 0 |
| **Total** | | 115 | 5 |

**TABLE 9c**

**Naïve percentage of failures for implant length.**

| Implant Length (mm) | Number of Implants | Number of Dailures | Naïve % of Failures |
|---|---|---|---|
| **8.0** | 3 | 0 | 0.0 |
| **10.0** | 52 | 2 | 3.8 |
| **11.5** | 9 | 0 | 0.0 |
| **13.0** | 43 | 2 | 4.7 |
| **16.0** | 7 | 1 | 14.3 |
| **Total** | 115 | 5 | 4.3 |

**TABLE 9d**

**Naïve percentage of failures for implant diameter.**

| Implant diameter (mm) | Number of Implants | Number of Failures | Naïve % of Failures |
|---:|---:|---:|---:|
| **3.5** | 49 | 1 | 2.0 |
| **4.3** | 58 | 4 | 6.9 |
| **5.0** | 8 | 0 | 0.0 |
| **Total** | 115 | 5 | 4.3 |

**TABLE 10**

**Fixed effects and random effects parameter estimates for the log-binomial regression model.**

| Fixed Effects | | | | |
|---|---|---|---|---|
| | **Estimate** | **Std. Error** | **z value** | **Pr(>\|z\|)** |
| **(Intercept)** | -14.08373 | 8.84939 | -1.591 | 0.111 |
| **Age (yrs)** | 0.06478 | 0.06492 | 0.998 | 0.318 |
| **Implant Length (mm)** | 0.15451 | 0.27161 | 0.569 | 0.569 |
| **Implant Diameter (mm)** | 1.04989 | 1.37795 | 0.762 | 0.446 |

**TABLE 11**

**Relative risk estimates based on log-binomial regression model.**

| Explanatory Variable | Relative Risk | | | |
|---|---|---|---|---|
| | **Point Estimate** | **95% Lower Bound** | **95% Upper Bound** | **P** |
| **Age (yrs)** | 1.07 | 0.94 | 1.21 | 0.32 |
| **Implant Length (mm)** | 1.17 | 0.69 | 1.99 | 0.57 |
| **Implant Diameter (mm)** | 2.86 | 0.19 | 42.6 | 0.45 |

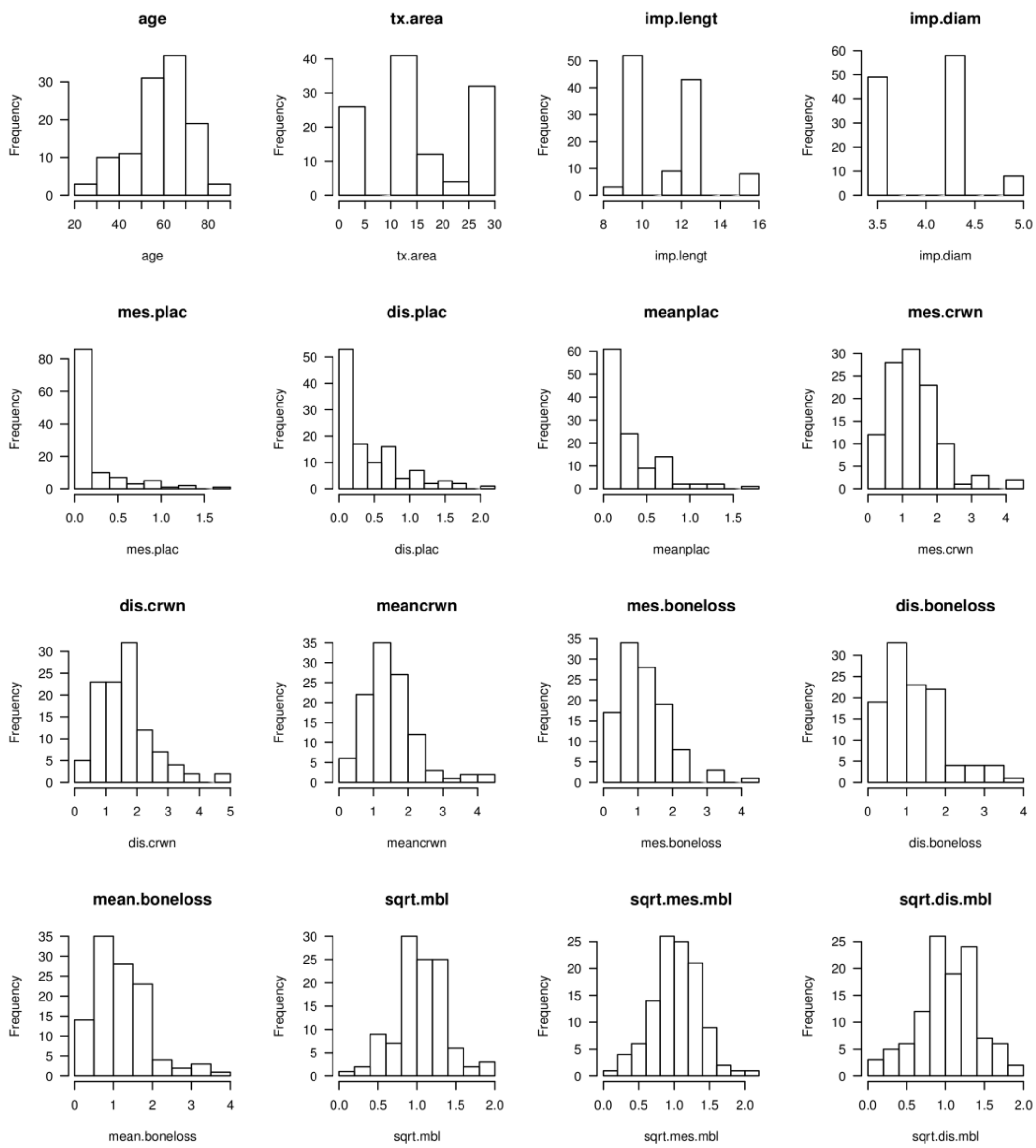


**FIGURE 6** Histograms for the quantitative study variables

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*Tx.area=Treated area; impl.lengt=Implant length; imp.diam=implant diameter; mes.plac= Mesial distance shoulder implant/crestal bone at osteotomy; dis.plac=Distal distance shoulder implant/crestal bone at osteotomy; meanplac= Mean distance at osteotomy; mes.crwn= Mesial distance shoulder implant/crestal bone with crown; dis.crwn=Distal distance shoulder implant/crestal bone with crown; meancrwn= Mean distance with crown; mes.boneloss= Mesial Bone loss; dis.boneloss= Distal Bone loss; mean.boneloss= Average Bone loss; sqrt.mbl= Square-root average bone loss; sqrt.mes.mbl= Square-root mesial bone loss; sqrt.dis.mbl= Square-root distal bone loss.

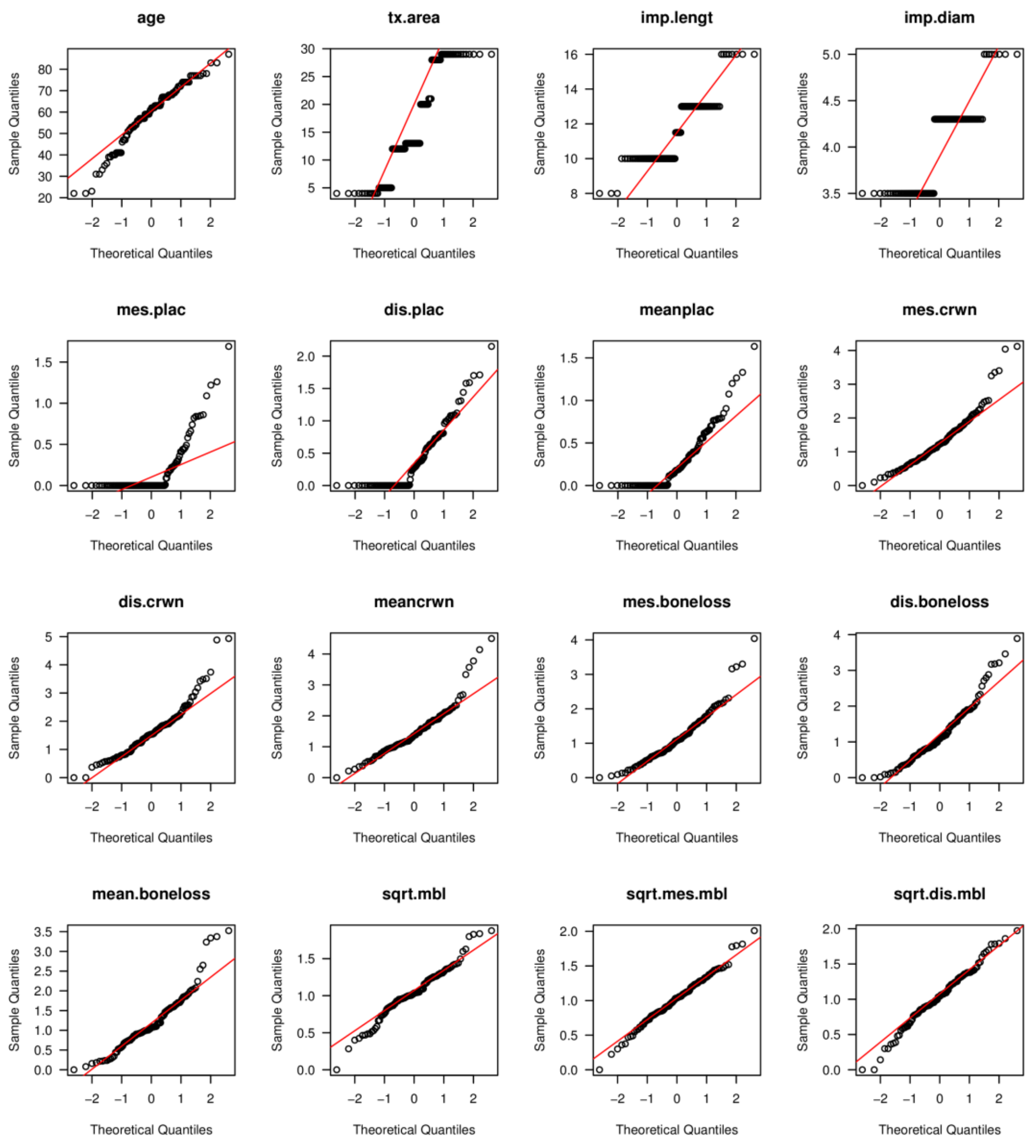


**FIGURE 7.** Normal probability plots for the quantitative study variables.

*Tx.area=Treated area; impl.lengt=Implant length; imp.diam=implant diameter; mes.plac= Mesial distance shoulder implant/crestal bone at osteotomy; dis.plac=Distal distance shoulder implant/crestal bone at osteotomy; meanplac= Mean distance at osteotomy; mes.crwn= Mesial distance shoulder implant/crestal bone with crown; dis.crwn=Distal distance shoulder implant/crestal bone with crown; meancrwn= Mean distance with crown; mes.boneloss= Mesial Bone loss; dis.boneloss= Distal Bone loss; mean.boneloss= Average Bone loss; sqrt.mbl= Square-root average bone loss; sqrt.mes.mbl= Square-root mesial bone loss; sqrt.dis.mbl= Square-root distal bone loss.

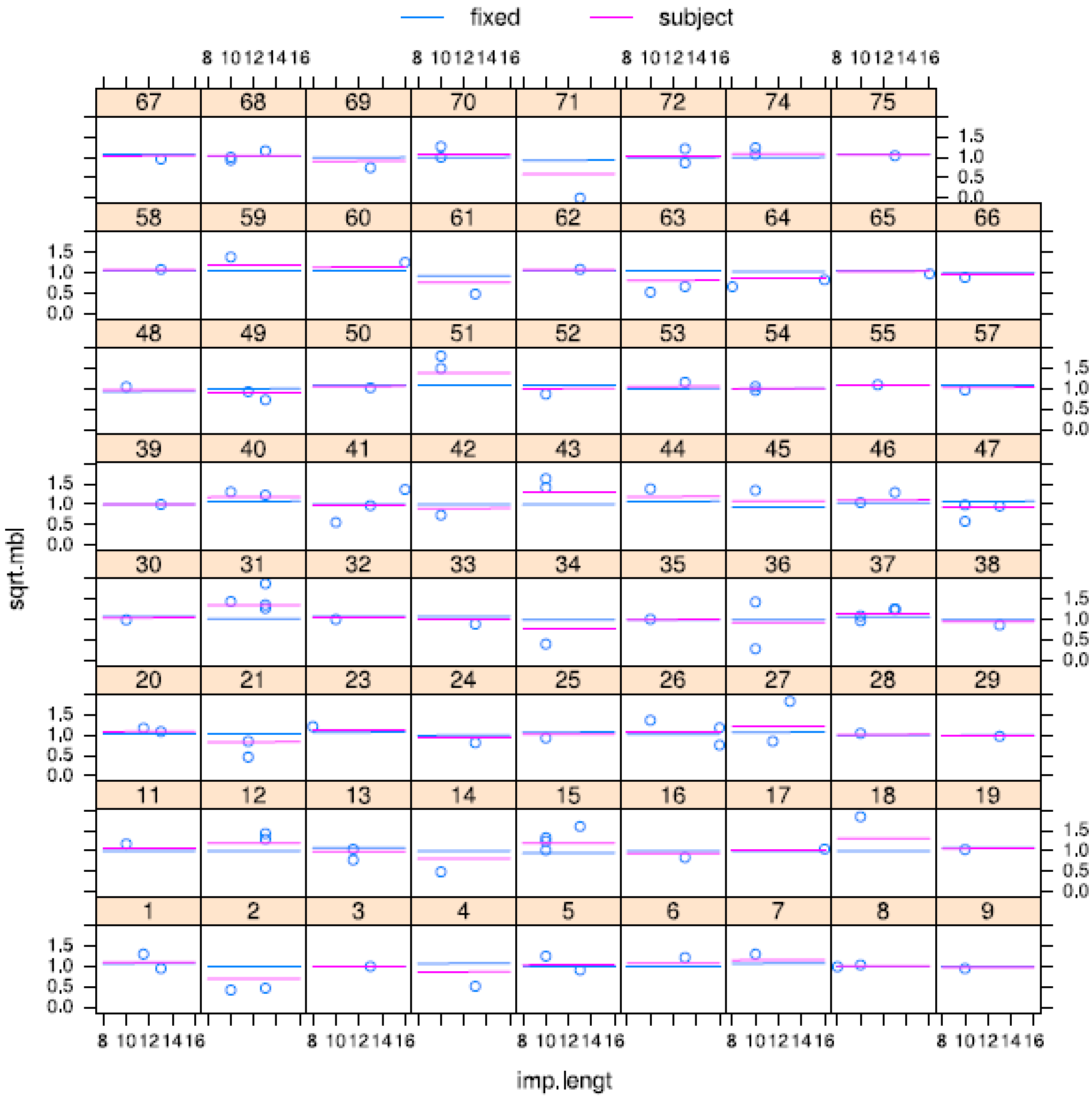


**FIGURE 8** Mixed effect model predictions for the square root of mean bone loss as a function of implant length (implant diameter equal to its mean value).

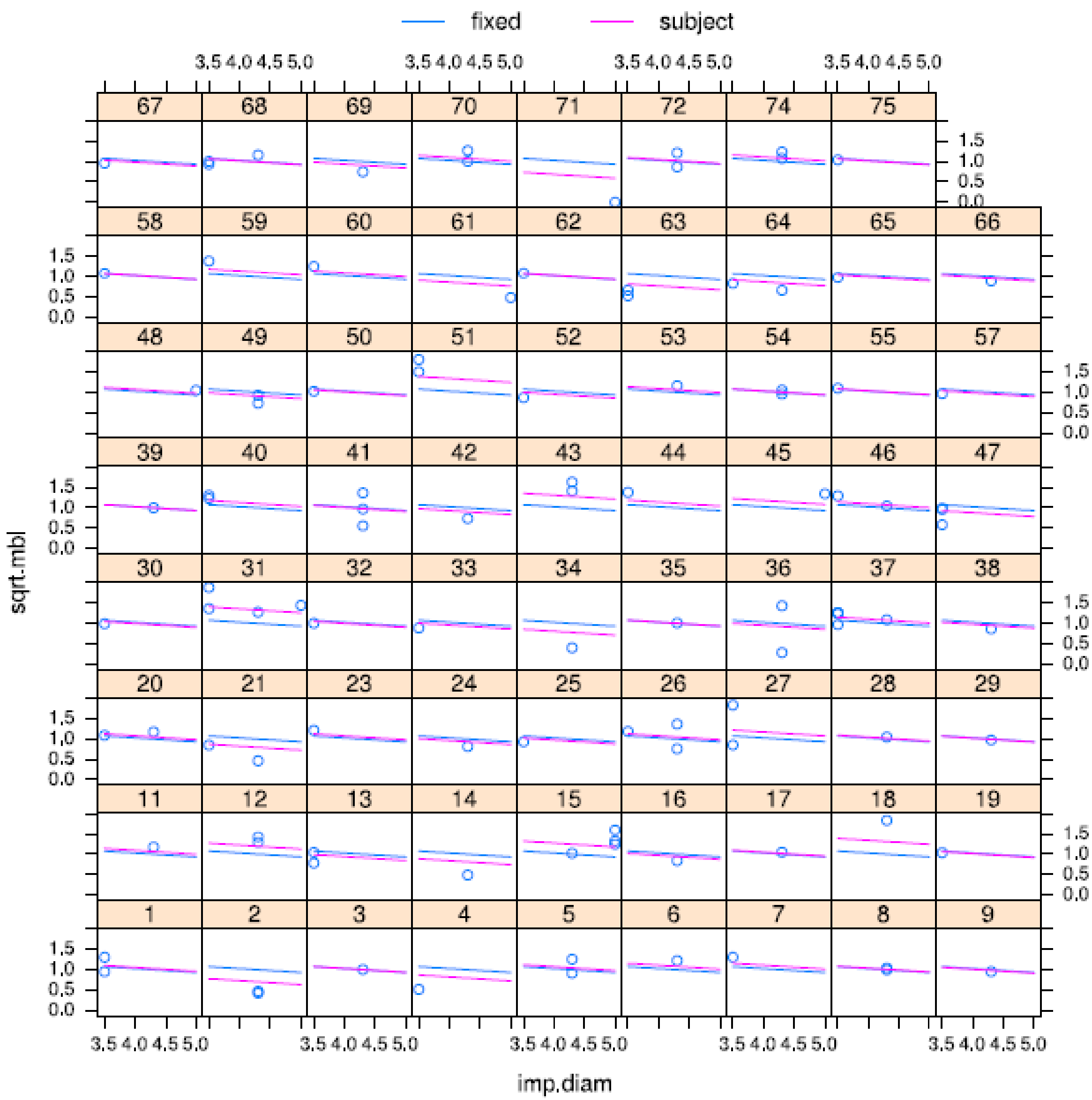


**FIGURE 9** Mixed effect model predictions for the square root of mean bone loss as a function of implant diameter (implant length equal to its mean value).

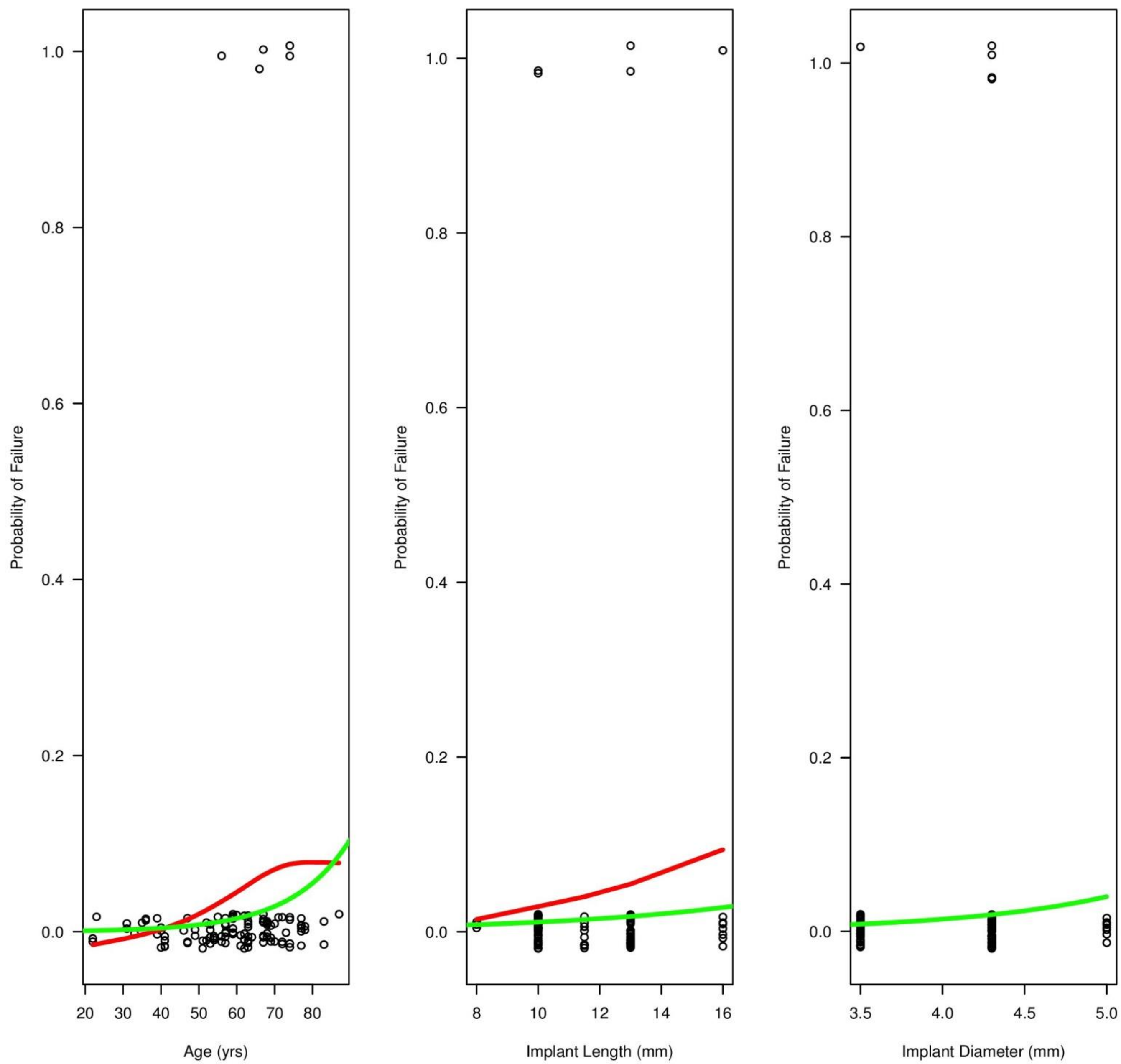


**FIGURE 10** Failure plots for age, implant length and implant diameter. Smoothing spline probability predictions are denoted by red lines. Log-binomial mixed effects model predictions are denoted by green lines. Due to the small number of levels for implant diameter, it was not possible to compute the smoothing spline predictions.

# 3.0 DISCUSSION

Criteria for successful integration of dental implants have been proposed (Albrektsson 1986). Of these, a lack of mobility is of prime importance as ‘loosening’ is the most often-cited reason for implant fixture removal. Adell (1981) reported success rates for 895 implant fixtures over an observational period five to nine years after placement. Eighty-one percent of maxillary and 91% of mandibular implants remained stable.

The results of this study showed that failures appear to relate somewhat with age, length, and diameter. Plots illustrating the excellent model fit for each subject are shown in Figures 8 and 9. Because the model was fitted to the square root transformed bone loss, Tables 7 and 8 were constructed to help show how mean bone loss is expected to change over the ranges of implant diameter and length, respectively, based on the estimated fixed effects. As shown in Table 7, as diameter increased, mean bone loss was expected to decrease from 1.15m to 0.86mm as the diameter goes from 3.5mm to 5mm. This negligible change was not statistically significant, although even if they were real, the estimated effects were small. As can be seen in Table 8, mean bone loss is expected to increase from 1.046 mm to 1.054 mm as implant length increases from 8 mm to 16 mm. Again, this change is not statistically significant. Even if it is real, the amount of change is likely to be negligible if the point estimate is accurate. However, all failure implants occurred before prosthesis connection, with similar results reported in Goodacre (2003). It is likely that bone quality and suitable surgical protocols play a more major role in short-implant prognosis than prosthetic features. The relative risk for this study regarding length was not significant ($p = 0.57$) and was comparable to results from clinical studies of short-length implants (Tawil 2003; Renouard 2003). It supports the hypothesis that short implants (8-10mm) might give similar long-term implant survival rates to longer implants used in larger bone volumes.

Das Nerves (2006) reviewed the results of 33 studies of 16,344 Brånemark-type implants, and assessed failure rates over time. Seven-hundred-eighty-six failures were reported, representing a failure rate of 4.8%. He also showed no correlation between implant length and implant success or failure, except in a single instance where machined-surfaced, hex-headed, countersunk implants were placed in poor-quality bone.

The results of this study showed five implant failures (Table 9b), with a total failure rate was 4.3%. And the total failure rate for short implants was 3.6%. As shown in table 9c, the failure rates of implants with lengths of 8, 10, 11.5, 13, and 16 mm were 0%, 3.8%, 0%, 4.7%, and 14.3%, respectively. This result was similar to result by Sun HL (2011). Table 9d showed the failure rates of implants with diameter of 3.5, 4.3, and 5.0 mm were 2.0%, 6.9%, and 0%, respectively. According to Morand and Irinalis (2007), the implant's diameter and extension should be taken into account, concomitantly, due to their interactive effects; the diameter is the most influent factor. The log of the probability for failure was modeled as a function of age, implant length, and implant diameter using a log-binomial (generalized) mixed-effects model with a random intercept to account for the nested implants within subjects. Table 11 showed the relative risk for failing as a function of implant length was low and not statistically significant ($p = 0.56$). Relative risks for failing as a function of implant diameter and age were also not significant ($p = 0.45$ for diameter, $p = 0.32$ for age). Figure 10 showed the failure plots for age, implant length, and implant diameter. Where possible, a smoothing spline (red line) was fitted to the observed failures. Failures were slightly “jittered” to help show multiple points at the same location on the graph. In addition, the log-binomial model predictions are shown (green lines). For each prediction curve, the other explanatory variables were fixed to their respective means. These probabilities for failure were estimated to be very small in addition to not being statistically significant. A 2009 retrospective study by Grant involved 335 implants 8mm in length placed in the posterior mandible in 124 patients (median age 56 years, 112 partially edentulous) between May 2005 and June 2007. The majority received fixed prostheses, while the remaining received individual restorations. Four implants (in two patients) failed to osseointegrate, and one implant fractured. Of the remaining 330, for up to two years post-placement, the survival rate was 99%. The investigators concluded that the placement of short implants was predictable and a suitable treatment for patients with reduced bone height in the posterior mandible.

All implants in this study received single-unit fixed restorations or multi-unit fixed bridge restorations and were placed in the premolar region. Data on the mean bone loss at the restored implant are also presented. The results of this retrospective research reveal that a statistically significant relationship did not exist between crestal bone loss and implant length. These results compare favorably with retrospective analysis of results from 247 dental implants with fixed prosthetics (crowns and bridges) by Draenert in 2011. The relative risk for failing implant length was not significant ($p = 0.57$). Also the relative risk for diameter and age were not significant ($p = 0.45$ and $0.32$).

For several researchers (Gentile 2005; Morand 2007), bone quality is a significant risk factor for failures due to lack of blood irrigation, overheating during implant drilling in dense bones, and lack of bone density in trabeculated bone. Goodacre (2003) considered that implants placed in poor bone quality areas showed failures rates 16% higher than those placed into greater bone density areas. One way of compensating the lack of bone quality would be to employ different techniques of implant surface treatment and machining. Although the results of this study showed no significant effects from age, implant length, or implant width on success, this remains a retrospective study. The topic needs well-organized prospective research looking at large sample sizes to confirm these results.

Short implants present a good alternative at posterior areas when the surgeon-operator is in close proximity to the sinus or the mandibular canal. But superior clinical judgment remains the key for successful implant treatment.

# 4.0 CONCLUSIONS

We concluded that short dental implants can be used in both jaws and could provide acceptable alternative treatment for rehabilitation of areas with deficient alveolar bone height or in areas in close proximity to the sinus, to avoid the necessity of lifting the sinus. According to the mixed-effects-model point estimates for the slopes, a 1mm increase in diameter is expected to decrease the square root of mean bone loss by 0.0965 √mm and 1mm increase in length is expected to increase the square root of mean bone loss by 0.000511 √mm. These effects were not statistically significant, although even if they were real, the estimated effects were small. As diameter increased, mean bone loss was expected to decrease from 1.15mm to 0.86mm as the diameter goes from 3.5mm to 5mm. And mean bone loss is expected to increase from 1.046 mm to 1.054 mm as implant length increases from 8 mm to 16 mm. This negligible change was not statistically significant. A larger study would be needed to better estimate the effects of implant length and diameter, but based on the data in this study, the effects appear to be small at best.

The relative risk for implant failure for each 1 mm of length was estimated to be 1.17 (95% confidence interval: 0.69 to 1.99) but was not statistically significant ($p = 0.57$). Based on the confidence interval, the relative risk is poorly estimated and the direction of the true effect is uncertain. The relative risk for implant failure for each 1mm of implant diameter was estimated to be 2.86 (95% confidence interval: 0.19 to 42.6) and was not statistically significant ($p = 0.45$). As indicated by the width of the uncertainty in this estimate is huge and thus inconclusive as to the real risk. A one year increase in age was estimated to increase the relative risk by 7% (1.07 with 95% confidence interval: 0.94 to 1.21) and was not statistically significant ($p = 0.23$). It is clear a larger study with many more subjects and implants, is needed to establish more precisely the true relative risks for implant failure.

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