Radiographic follow-up analysis of Brånemark® dental implants

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Abstract

Radiography plays an important role in clinical routine practice and in research projects evaluating dental implants, among them Brånemark® System. Presence of a peri-implant radiolucency has been used in studies as a criterion for implant failure without knowledge of its diagnostic accuracy. More precise determination, whether implants are osseointegrated or not, can be achieved if prosthetic constructions are detached to test implant stability. Such an approach is time-consuming and cumbersome. Hence, the accuracy in radiographic diagnosis of clinical instability has to be evaluated. Further, radiography is a commonly used diagnostic tool for monitoring marginal bone loss. Little is known about the observer variation. Long-term follow-up studies have shown conventional implant therapy to be a reliable procedure with few complications and minor average bone loss. Lately, studies have shown progressive bone loss in higher frequencies.

When testing accuracy in diagnosis of clinical instability in intra-oral radiographs, it was found to be as good as of many other radiographic procedures, *e.g.* caries diagnosis. Possibility of predicting instability, however, can be low in populations with low prevalence of implants showing loss of osseointegration.

Intra-observer variation was found to be the largest source of the total variation when studying inter- and intra-observer variability in radiographic bone level assessments. The number of radiographs in which individual implants were displayed had an influenced on intra-observer variation, while radiographic density and increased bone loss influenced the total inter-observer variation. Reliability can be improved by multiple readings by one observer or, even better, by letting several observers make several, independent readings, this limits the effect of a single observer who may be an outlier.

Marginal bone level was assessed in 640 patients with a radiographic follow-up of ≥5 years. The number of implants with a mean bone level of ≥3 mm below the fixture-abutment connection increased from 2.8% at prosthesis insertion to 17.2% after 15 years. Implant-based bone loss was as a mean 0.8 mm (SD 0.8) after 5 years, followed by only minor average changes. Mean bone loss on patient level followed a similar pattern. Disregarding of follow-up time, altogether 183 implants showed a bone loss ≥3 mm from prosthesis insertion to last examination, most of them in totally edentulous patients. Seventy of the 183 implants were found in 19 of the 107 patients. Hence, there seems to be a clustering effect. For the entire group of patients significantly larger bone loss was found the older the patient was at surgery and for lower jaw implants. Placement of the implant within the prosthetic construction, regardless of jaw-type, was found to be a predictor of a bone loss ≥2 mm with minor bone loss around implants placed in an end position. Other predictors were age and jaw-type. The number of intra-oral radiographs per examination, and more importantly, radiographic examinations can be reduced without jeopardizing good clinical management, a statement valid also for Brånemark® implants with advanced bone loss. To conclude, conventional implant treatment can still be regarded as a reliable and safe procedure.

Key words: cluster effect, dental implants, dependency, diagnostic accuracy, long-term follow-up, marginal bone level, observer variation, osseointegration, prediction.

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Contents

Preface

The thesis is based on the following papers, which will be referred to in the text by their Roman numerals (I – IV):

I Sundén S, Gröndahl K, Gröndahl HG.
Accuracy and precision in the radiographic diagnosis of clinical instability in Brånemark dental implants.
Clin Oral Implants Res 1995; 6: 220-226.

II Gröndahl K, Sundén S, Gröndahl HG.
Inter- and intraobserver variability in radiographic bone level assessment at Brånemark fixtures.
Clin Oral Implants Res 1998; 9: 243-50.

III Sundén Pikner S, Gröndahl K, Jemt T, Friberg B.
Marginal bone loss at implants: a retrospective, long-term follow-up of turned Brånemark System® implants.
Clin Implant Dent Relat Res, in press.

IV Sundén Pikner S, Gröndahl K.
Radiographic analyses of "advanced" marginal bone loss around Brånemark® dental implants.
Clin Implant Dent Relat Res, in press.

Introduction

The technique to install implants made of titanium to rehabilitate patients who have lost teeth has been in clinical use since the mid-1960s (Brånemark et al. 1977) and today more than 600 000 patients from all over the world have been treated with the Brånemark System® implants. The term osseointegration was coined by professor Brånemark to describe a direct and load-bearing union between a titanium implant and vital bone without ingrowth of fibrous tissue at the interface. In Dorland´s Dictionary (31th edition, 2007) osseointegration is defined as "direct anchorage of an implant by formation of bony tissue around the implant without the growth of fibrous tissue at the bone-implant interface".

Long-term follow-up studies are corner stones in clinical evaluations of medical and dental treatment modalities. In the field of dental implants, Adell and co-workers presented two classical long-term follow-up studies (Adell et al. 1981, 1990) that have been used to validate the use of osseointegrated implants to rehabilitate edentulous patients. In their study from 1990 they found that 95% of the maxillae and 99% of the mandibles had continuous prosthesis stability after 15 years. Since then, numerous follow-up studies on dental implants have been published, and today several studies cover 10 years or more for different patient categories (Brånemark et al. 1995, Lindqvist et al. 1996, 1997, Schnitman et al. 1997, Lekholm et al. 1999, Bahat 2000, Friberg et al. 2000, Snauwaert et al. 2000, Ekelund et al. 2003, Karoussis et al. 2004, Rasmusson et al. 2005, Jemt & Johansson 2006, Lekholm et al. 2006, Roos-Jansåker et al. 2006a, Örtorp & Jemt 2006, 2008).

Although implant therapy is regarded as a safe and reliable method complications do occur. Many authors have discussed different factors that may cause failures in implant treatment, but most likely implant failures have a multi-factorial background (Duyck & Naert 1998, Tonetti & Schmid 2000). Esposito et al. (1998) divided implant failures into four groups; biological failures (related to the biological process), mechanical failures of the components (fractures of implants, connecting screws, coatings and prostheses), iatrogenic failures (*e.g.* nerve damage, wrong alignment of the implant), and functional failures (phonetical, aesthetical, psychological problems). Further, they classified the biological failures as endogenous (systemic and local) and exogenous (operator- and biomaterial-related). Later, Esposito and co-workers (1999) defined biological failures as "the inadequacy of the host to establish or to maintain osseointegration". When an implant does not become osseointegrated it can be regarded as an early failure, in contrast to a late failure resulting from the loss of an achieved osseointegration under functional conditions.

Biological failures

Systemic factors such as age, genetics and general health have not been proven to be risk factors for implant survival (Esposito et al. 1998). Osteoporosis has been considered a risk factor for implant treatment but there is no scientific evidence to confirm that (Dao et al. 1993, Becker et al. 2000, Friberg et al. 2001). However, August et al. (2001) reported a significant higher failure rate in the maxilla for postmenopausal than for pre-menopausal women. Diabetes mellitus has also been considered a risk factor for implant failures (Shernoff et al. 1994, Morris et al. 2000). An additional factor associated with implant loss is smoking (Gorman et al. 1994, Wallace 2000, Bain 2003, Attard & Zarb 2004, Sadig & Almas 2004, Hinode et al. 2006, Jemt & Häger 2006). Wilson & Nunn (1999) found an increased risk for implant loss by a factor of 2.5 among smokers compared to non-smokers, while Roos-Jansåker et al. (2006a) could not find a statistically significant relation between smoking and implant loss.

Bone quality and bone quantity are local factors that influence implant failure rates (Engquist et al. 1988, Jemt et al. 1989, van Steenberghe et al. 1990, Friberg et al. 1991). Herrmann and co-workers (2005) found higher failure rates for implants placed in the maxilla, in bone of poor quality or reduced in volume. Fugazzotto et al. (1993), Snauwaert et al. (2000) and Roos-Jansåker et al. (2006a) also reported more failures for implants placed in the maxilla than for those placed in the mandible. In contrast, Strietzel et al. (2004) showed that mandibular implants had higher failure rates. The treatment protocol used will have an influence on the outcome with higher failure rates for treatment with overdentures and less for single tooth restorations (Berglundh et al. 2002). Also bone grafting, history of periodontitis and poor oral hygiene have a negative effect on the success rate (Esposito et al. 1998, Brånemark et al. 2001, Hardt et al. 2002, Karoussis et al. 2004, Jemt & Häger 2006, Roos-Jansåker et al. 2006a). However, according to Gotfredsen et al. (2008) implant treatment in periodontitis-susceptible patients is not contraindicated after successfully completed periodontal treatment.

The skill of the surgeon is of importance, as traumatic surgery can lead to soft tissue encapsulation of the implant resulting in an implant that will not become osseointegrated (Brånemark 1969). Drilling without adequate cooling may induce heat necrosis in the bone with implant loss as a consequence (Eriksson & Albrektsson 1983). Studies have shown that early failure rates for surgeons having placed <50 implants were twice as high as for those who have placed more implants (Lambert et al. 1997, Esposito et al. 1998).

According to Esposito et al. (1998) surgical trauma together with anatomical conditions are predominant factors for early failures, whereas overload together with poor bone quality and inadequate bone volume are the 3 major determinants for late failures. There is, however, no evidence that bruxism and clenching are associated with increased failure rates (Balshi et al. 1992). Most implant failures due to loss of osseointegration occur during the healing period and within the first two years of loading (Adell et al. 1981, 1990, Friberg et al. 1991, Jemt 1993, Bergendal & Palmqvist 1999, Jemt & Häger 2006, Jemt & Johansson 2006). Implant loss before loading has been reported within a range of 0.8% to 7.5%, and late loss from 2.1% to 11.3%.

Ongoing marginal bone loss is a factor affecting the outcome of implant treatment. If the marginal bone loss around an implant continues for several years, it may jeopardize the implant outcome (Snauwaert et al. 2000). If the bone loss is recognized and treated, the implant might be saved (Roos-Jansåker et al. 2007). Failures due to advanced marginal bone loss are rare.

Marginal bone loss during the first year of loading has been reported to be at most 1-1.5 mm and thereafter less than 0.2 mm on an annual basis (Adell et al. 1981, 1990, Ahlqvist et al. 1990, Lekholm et al. 1999, Hultin et al. 2000, Snauwaert et al. 2000, Ekelund et al.

2003, Attard & Zarb 2004, Jemt & Johansson 2006, Örtorp & Jemt 2006, 2008). Little is known about the bone loss during the healing period. Åstrand et al. (2004) started to radiographically monitor the marginal bone level at the time of implant insertion and found the bone loss between implant placement and prosthesis insertion to be several times higher than between prosthesis insertion and a 5-year follow-up.

Until the late 1990s the majority of studies showed that the average bone loss around implants in general was small. Lately, however, studies have been published demonstrating a more progressive bone loss around turned Brånemark implants (Fransson et al. 2005, Roos-Jansåker et al. 2006b). Fransson and co-workers (2005) found, among the same patients as in *Studies III* and *IV*, that 12.4% of the implants in 28% of the patients exhibited advanced bone loss. This meant that a bone level located at <3 threads at the 1-year follow-up was found at ≥3 threads 5-20 years later. When using a bone loss ≥1.8 mm as a threshold value, Roos-Jansåker et al. (2006b) identified 7.7% of the implants to suffer from progressive bone loss after 9-14 years from the 1-year control. Fransson et al. (2005) also used the 1-year follow-up as baseline, while others have used the time at abutment connection (Snauwaert et al. 2000). In the majority of studies the time at prosthesis insertion has been chosen as baseline.

Most reports on marginal bone loss present mean values, while frequency distribution data are rarely described. This makes the ability to interpret the incidence of pronounced bone loss limited. Only a few recent studies deal with this issue on a patient level in long-term studies (Lekholm et al. 1999, Ekelund et al. 2003, Fransson et al. 2005, Roos-Jansåker et al. 2006b, Jemt & Johansson 2006, Örtorp & Jemt 2006, 2008).

Some risk factors correlated with marginal bone loss have been identified: smoking (Haas et al. 1996, Lindqvist et al. 1996, Ekelund et al. 2003, Attard & Zarb 2004, Roos-Jansåker et al. 2006c), oral hygiene (Lindqvist et al. 1996) and presence of periodontitis at adjacent teeth (Hardt et al. 2002, Ekelund et al. 2003, Roos-Jansåker et al. 2006c). According to an extensive review made by Berglundh and co-workers (2002) the percentage of implants demonstrating bone loss of ≥2.5 mm was larger in studies on overdentures and fixed complete restorations than in studies including fixed partial restorations and single tooth replacements (4.8% and 3.8% versus 1.0% and 1.3%, respectively). It is known that, under experimental conditions, implants can fail due to excessive occlusal load (Isidor 1996). However, no direct relationship between overload and implant failure in humans have not been found (Esposito et al. 1998). Nevertheless, there seems to be a general consensus that excessive loading or undue stresses may induce bone loss (Proceedings of the 1996 World Workshop in Periodontics).

Mechanical complications

Even if biological failures are more severe than mechanical complications, the latter have to be taken into account. Unfavourable loading, fatigue, and prosthetic design are plausible reasons for mechanical failures (Attard & Zarb 2004). According to Lekholm et al. (2006) the most common mechanical complication is veneer material fracture and, secondly, loosening of components and fractures of abutment- and bridge-locking screws. Jemt & Johansson (2006), who studied the number of mechanical failures during a 15-year follow-up period on 76 consecutive patients with fixed prostheses in the maxillae, found only few mechanical complications, with veneer fractures being the most frequent.

Iatrogenic and functional failures

Osseointegrated and stable implants that cannot be used due to being malpositioned and implants that have to be removed because of violation of anatomical structures are referred as iatrogenic failures (Esposito et al. 1998). Another group of failures can be related to insufficient patient adaptation (*e.g.* phonetical problems).

Cluster and dependency

Although implant loss is relative rare investigators have found that some patients are affected more often than others, that is, implant failures tend to cluster in some patients (Weyant & Burt 1993, Hutton et al. 1995, Jemt & Häger 2006). In a multi-center study Herrmann et al. (1999) found that the risk for failure, even before loading, was higher for implants placed in the same patient/jaw in which an earlier failure had occurred. In a 3-year analysis of early failures of complete fixed implant-supported prostheses in the maxillae, Jemt & Häger (2006) found that bone quantity, reflected in fixture length, had a significant impact on implant failure rates. It has been speculated that these cluster patients have certain individual characteristics. However, evidence of the impact of systemic diseases on the success of implant therapy is scarce (Mombelli & Cionca 2006). If a same cluster effect exists with respect to bone loss around implants is not known.

When calculating success rates on an individual implant level, the statistical methods used in many studies are based on the assumption that the individual implants are independent (Herrmann et al. 1999). Adell and co-workers (1990) were the first authors to raise the subject of dependence between implants. Since then the question has been addressed by several authors (Mau 1993, Haas et el. 1996, Chuang et al. 2001, Attard & Zarb 2004). One method to overcome the dependency among implants is to randomly select one implant per patient, which turned out to be an accurate method from a statistical point of view (Herrmann et al. 2003). The first author to introduce the "one-implant-per-patient" technique was Mau (1993) followed by Cune et al. (1994) and Haas et al. (1996). If such a strategy is an advantage in studies on marginal bone loss is, to our knowledge, not known.

Criteria for success

Over the years many researchers have proposed criteria for success regarding oral implants. One of the oldest, and most commonly used criterion was proposed by Albreksson et al. (1986) and reviewed in 1993 (Albrektsson & Isidor 1993). Other's suggested success criteria are similar to those by Albrektsson and co-workers (1986) with only minor differences. Table 1 shows radiological criteria proposed by different authors.

Table 1. Different radiological criteria proposed by different authors

Proposal	Crestal bone loss	Peri-implant radiolucency
Schnitman & Shulman (1979)	Bone loss no greater than a third of the vertical height of the implantπ	No suggested criteria
Albrekstsson et al. (1986)	Vertical bone loss <0.2 mm annually following the implant's first year in service	No evidence of peri-implant radiolucency
Smith & Zarb (1989)	Mean vertical bone loss <0.2 mm annually after the first year in service	No evidence of peri-implant radiolucency as assessed on an undistorted radiograph
Albrektsson & Isidor (1993)	Average bone loss <1.5 mm the first year in service, and thereafter <0.2 mm annually	No evidence of peri-implant radiolucency
Wennström & Palmer (1999)	Maximum bone loss of 2 mm between prosthesis installation and the 5th year, with the majority of the loss occurring during the first year	No suggested criteria
Östman et al. (2007)	Success grade 1 <2 mm bone loss the first year in service	No radiographic signs of pathology
	Success grade 2 <3 mm bone loss the first year in service	No radiographic signs of pathology

Albreksson & Zarb (1993) suggested that each and every implant should be evaluated as a part of a four-grade scale representing success, survival, unaccounted for and failure. The success category includes implants that meet all of the success criteria according to Albrektsson et al. (1986), and the survival category are those attached implants that are not checked for mobility. The unaccounted for category includes all those patients who died or dropped out of the study, and the failure category includes all removed implants.

Methods to evaluate osseointegration

There are several methods to evaluate whether osseointegration has taken place or not. A simple method is to test implant stability by exerting a clockwise force on the abutment with a screwdriver. The implant can be considered osseointegrated if the implant is found to be immobile (Albrektsson et al. 1986). Another method is to tap the abutment with a metallic instrument. A high-pitched metallic sound will then indicate an integrated implant (Adell et al. 1985).

A number of authors (Olivé & Aparicio 1990, Teerlinck et al. 1991, Aparicio 1997) have reported the potential application of the Periotest in measuring implant mobility. The Periotest device (Siemens, Bensheim, Germany) is an electronic instrument originally designed for quantitative measurements of damping characteristics of the periodontal ligament to establish a numerical value for tooth mobility (Schulte et al. 1983). The device is, however, operator sensitive and its value as a clinical diagnostic method to measure implant stability has been questioned (Meredith 1997, Meredith et al. 1998, Lang et al. 2004, Becker & Gansky 2007).

Resonance frequency analysis (RFA) is another method, developed by Meredith et al. (1996), to evaluate implant stability and found to be of clinical value (Friberg et al. 1999a,b, Balleri et al. 2002, Östman et al. 2005, 2006). A small beam-like transducer (Osstell®, Integration, Diagnostics AB, Partille, Sweden) is attached to the implant or the abutment. The transducer can electronically make the implant to vibrate and the response is measured and registered. The technique is influenced both by the exposed length of the implant and the stiffness of the interface between the implant and the bone. Huwiler et al. (2007) found that even with a good initial implant stability, as measured with the RFA technique, implants might later on fail.

A clinically stable implant is characterized by the radiographic appearance of normal bone in close contact with the implant surface, while presence of peri-implant radiolucency is indicative of a non-integrated implant (Strid 1985). To make the presence of a soft tissue layer adjacent to the implant surface radiographically visible, it has to be wide enough to overcome the limitations imposed by the resolution of the radiographic system.

Methods to evaluate marginal bone level and its change over time

The examination of the bone tissue around implants has many features in common with the periodontal examination. The clinical examination must, according to Lang & Lindhe (2003), include parameters such as bleeding on probing, probing depth, and suppuration. All these assessments can reveal whether the mucosa around the implant is healthy or not. When probing a pocket around an implant, surrounded by an unhealthy mucosa, the probe goes beyond the sulcus and reaches closer to the bone than it does around a tooth (Schou et al. 2002). Under healthy conditions the pocket depth, for conventionally placed implants, ranges between 2-4 mm (Lang et al. 2004). Probing a pocket is often an arduous task since it is painful for the patient. Further, the assessed pocket depth depends on the pressure applied during probing which makes probing operator sensitive and unreliable. Lang and colleagues (2004) stated that peri-implant probing should be performed with a light force (*i.e.* 0.2-0.25 N) to avoid tissue trauma. Lekholm et al. (1986) found the presence of deep pockets not to be associated with an accelerated marginal bone loss. Clinical probing level and radiographic bone level have been compared to histological bone level around screw type implants in monkeys (Isidor 1997). The radiographic bone level was on average 0.1-0.5 mm, depending on type of implant, short of the histological bone level. The corresponding value for the probing level was much higher, 1.1-3.9 mm.

It has been suggested that the RFA technique can be used to measure the distance from the transducer to the first bone-implant contact. In a study by Meredith et al. (1997) a correlation of r=-0.78 between the effective implant length (length of transducer plus length of the abutment plus that part of the implant that is above the marginal bone level) and resonance frequency was found.

Radiography is the most commonly used clinical tool to asses marginal bone level at implants and its changes over time. The technique of choice is the intra-oral radiographic technique. The reason is that this permits individual adjustment of the X-ray beam angulation relative to each individual fixture. In addition, the high resolution in intra-oral radiographs provides possibilities to evaluate the bone level. All radiographs of implants should be taken with the film/detector parallel to the implant and the X-ray beam directed perpendicular to it. Threaded implants have the advantage of making it easy to determine whether the implant has been depicted with correct vertical irradiation geometry or not. An intra-oral radiograph, however, only illustrates clearly the mesial and distal marginal bone levels and early bone loss often occurs on the facial aspect of the implant (Spray et al. 2000, Cardaropoli et al. 2006).

To conclude, most techniques to study loss of osseointegration and marginal bone support require access to the implant itself. To achieve this, the prosthesis has to be detached. Because it would be both too costly and inconvenient to detach the bridgework at all postoperative clinical controls, radiography is regarded as the most feasible tool to use. Furthermore, removal of the prosthesis can cause additional wear of the components (Adell et al. 1990). When comparing bone levels and bone density differences in serial radiographs it is essential that a standardized, reproducible technique is used.

Radiography plays an important role, both in clinical routine practice and in research projects evaluating different treatment modalities in edentulousness, total and partial, according to the osseointegration principle (Brånemark et al. 1977). Presence of a peri-implant radiolucency has been used in many studies (*e.g.* Albrektsson 1988, Adell et al. 1990, Zarb & Schmitt 1990, Smedberg et al. 1993) as a criterion for implant failure without knowledge of its diagnostic accuracy. Albrektsson and co-workers (1986) suggested that, when evaluating the outcome of oral implant treatment, the individual implant stability should be tested. This is a pertinent requirement when smaller patient samples are evaluated or when strict research projects, *e.g.* evaluating different implant systems or implant surfaces/designs, are performed. It cannot be considered practical to detach all fixed prostheses and individually test the stability of each implant if larger patient populations are checked as in clinical practice. Hence, there has to be a difference in handling between daily clinical work and research projects. In epidemiological studies, it must be considered acceptable to use the radiographic diagnosis of osseointegration, presence or absence of a peri-implant radiolucency, provided that the radiographic technique in question is accurate and precise. The issue of radiographic detectability of non-osseointegrated implants has been discussed previously, and according to Worthington et al. (1987) and Zarb & Schmitt (1990) early signs of failures are subtle and, therefore, often radiographically invisible.

It has to be kept in mind that the purpose of the radiographic examination is not solely to diagnose loss of osseointegration. Radiography is also used to assess the status of the alveolar bone and to monitor whether the bone support has been changed since the last radiographic examination. Although the marginal bone loss as such may not serve as a criterion for success of an implant at a particular time, it has to be considered as a surrogate measurement in the perspective of the implant prognosis. Quirynen et al. (1992) indicated that an ongoing marginal bone loss eventually can compromise the successful outcome of the treatment. Since the beginning of the osseointegration era radiography has been used to evaluate implant bone level changes both in daily clinical work and in different research projects. The reliability of radiographic measurements of the bone level at tooth surfaces has been reviewed by Benn (1990), who concluded that current techniques are insufficient to measure true bone loss until it exceeds at least 1.0 mm of bone has been lost. He recommended the use of re-positionable film holders to standardise the irradiation geometry and very accurate, reproducible measuring techniques with an automatic computer-based measuring system. Obviously, there are differences between a tooth and a threaded implant. An implant offers the possibilities to use reliable reference points, such as the radiographic reference point used in earlier studies placed 0.8 mm apical to the fixture-abutment junction (FAJ) or the FAJ itself. Today FAJ is the most commonly used reference point. A threaded implant design will reveal if a strict paralleling technique has been used or not in serial examinations.

Regardless of diagnostic task, loss of osseointegration or marginal bone level changes, the diagnostic accuracy and precision may depend on the image quality and the observer who is reading the radiographs. This was the incitement to *Studies I* and *II*.

The background to *Studies III* and *IV* was the publication of the systematic review of the incidence of biological complications in longitudinal studies of at least 5 years made by Berglundh and co-workers in 2002. They reported that there was only limited information regarding the occurrence of implants exhibiting a bone loss of ≥2.5 mm. Shortly afterwards two Swedish studies were published demonstrating higher rates of implants showing progressive bone loss (Fransson et al. 2005, Roos-Jansåker et al. 2006b). Today, there is an ongoing debate whether the osseointegration technique can be regarded as a safe and reliable treatment alternative or if all implant-treated patients should be regarded as potential risk patient for peri-implantitis.

The term "peri-implantitis", introduced by Albrektsson & Isidor in 1993 at the 1st European Workshop at Ittingen, Thurgau, Switzerland, describes an inflammatory reaction with loss of supporting bone in the tissues surrounding an implant in function. Later, the term is used when combining data from probing and attachment level assessments (including bleeding/suppuration) and radiographic bone loss (Berglundh et al. 2002). According to Roos-Jansåker (2007) clinical signs of peri-implantitis are crestal bone loss, often seen as crater shaped defects, combined with deepening of the peri-implant pocket, bleeding and/or pus after probing, swelling and redness of varying degrees.

Observer performance

From studies in medical and dental radiology it is well-known that various observers may arrive at different results when examining the same radiographs, and that one and the same observer can contradict his or hers own findings at re-examinations (Lusted 1968).

Differences in level of education and experience among observers may result in the use of different diagnostic criteria among various observers. Attempts have been made to calibrate observers prior to investigations. In a study on radiographic diagnosis of periapical lesions, Molven (1974) found that it was possible to lower the number of disagreement cases, but that calibration does not solve the problem of discrepancies in criteria between observers, and Reit (1986) found the benefits of calibration programs to be limited. When studying reproducibility of and among observers judging both healthy and pathologic conditions, the prevalence of the pathological condition has a great influence on the results. Another factor of significance is the observer attitude (Goldman et al. 1972, Gröndahl 1979).

When interpreting postoperative radiographs in implant cases, the observer variability may also be influenced by, for example, the degree of bone loss, the jaw in which the implants are placed, time elapsed after implant loading, and the number of radiographs in which each implant is displayed. The quality of the radiographs, *e.g.* in respect to projection geometry and radiographic density may also have an influence on observer performance.

Evaluating a diagnostic imaging method

The result of a diagnostic method may be evaluated from many aspects; two of them being accuracy and precision (reproducibility) of the assessment. Accuracy describes the closeness of the results to the true value of the variable assessed, while precision indicates the closeness of the results from repeated measurements, either by the same or different observer/s. The optimum goal for a radiographic test, or any kind of diagnostic tests, is to be both accurate and precise (Wenzel & Verdonschot 1994). Unfortunately, it is not always possible to attain this goal. The lack of knowledge about the ”truth”, especially in clinical studies, causes problems in the determination of accuracy (Wenzel & Hintze 1999). Accuracy and precision in the radiographic diagnosis of loss of osseointegration can, however, be evaluated after removing the fixed restoration. The same possibility does not exist in radiographic bone level assessments. Although several studies have been concerned with longitudinal, radiographic evaluations of bone height changes at implants, relatively few have dealt with the precision of such assessments (Adell et al. 1990, Ahlqvist et al. 1990, Jemt et al. 1990, Quirynen et al. 1992, Thilander et al. 1994, Lofthag-Hansen et al. 2003, Fransson et al. 2005, Roos-Jansåker et al. 2006b). The precision of the observation becomes more important than the accuracy of the diagnostic technique when the aim of the study is to determine alterations occurring over a certain time period (Gröndahl 1979, Benn 1990). A low precision will express the variability in the assessment rather than a true change. With respect to radiographic assessment of the marginal bone level around fixtures no data on its precision are available in the literature.

A commonly used method to evaluate the accuracy for a diagnostic system is the Receiver Operating Characteristic (ROC) analysis. The ROC-value can be presented in different ways. The A_z-value (the area under the curve) is superior because it is less affected by the location or spread of the points that define the ROC curve (Swets & Pickett 1982).

Aims

The aims of the four studies included in the present thesis were to

- evaluate the diagnostic accuracy and precision associated with radiographic evaluation of clinical instability in Brånemark implants and to study the influence of image quality (*Study I*).
- evaluate inter- and intra-observer variability at bone level determinations from intra-oral radiographs of Brånemark implants and to study the influence of image quality (*Study II*).
- determine the influence on the observer variability of the degree of bone loss, jaw-type, and time elapsed after fixture loading (*Study II*).
- determine marginal bone level and its change around Brånemark implants over a long period of time in a large group of patients with different prosthetic constructions (*Study III*).
- assess the impact of gender, age, jaw-type, type of prosthetic construction and calendar year of surgery on bone level alterations (*Study III*).
- study advanced bone level changes as regards clustering effect, prediction and dependency (*Study IV*).
- investigate if the number of radiographs/radiographic examinations could be reduced without jeopardizing the clinical outcome (*Study IV*).

Study I

Accuracy and precision in the radiographic diagnosis of clinical instability in Brånemark dental implants.

Material and methods

Intra-oral film radiographs from patients with Brånemark turned implants, in whom failures of one or more implants were observed and the prosthetic construction had been removed and implant stability controlled, were used in this study. In addition, radiographs obtained immediately before abutment connection with clinical signs of implant failures were included. Lack of clinical stability was recorded when an implant was movable by light finger pressure or when it could be unscrewed without force. Implants without signs of clinical instability served as controls. Included in the control group were also implants from 5 randomly selected patients with complete fixed prostheses (3 upper and 2 lower jaws) radiographed 1 year after prosthesis insertion and in whom no clinical or radiographic signs of failures were observed during the subsequent 3 years.

Sixty-two implants (48 upper and 14 lower jaw implants) lacking clinical stability were identified, while the control group consisted of 158 implants (108 upper and 50 lower jaw implants). All radiographs of each patient (n=49) were interpreted by 8 oral radiologists, who were asked to decide whether or not a perifixtural radiolucency indicating an implant failure could be seen using a five-level ROC decision scale (Swets & Pickett 1982). The observers were not given information on the probability of presence of implant failures. The observers re-evaluated all radiographs 1 month after the first evaluation. Total observer variability was quantified using the observers´ individual A_z-values for the two readings. The intra-observer variability was calculated from the differences between the first and the second observation.

Of the 62 mobile implants 68% were visualized in one radiograph. The corresponding value for the 158 clinically stable implants was 73%. Remaining implants were seen in two radiographs. Implants were imaged in their whole length in 57% of the mobile implants and in 53% of the stable ones. Only 4 of the implant threads were seen in 13% of the mobile implants and in 8% of the stable. For 65% of the mobile implants the projection geometry used was perfect (clearly visible threads on both implant surfaces), the corresponding value for the stable implants was 74%. The radiographic density was as a mean 1.26 (SD 0.32) for the mobile implants and 1.29 (SD 0.37) for the stable ones.

Multiple linear regression analysis was used to investigate the possible influence of the factors mentioned above, including in which jaw the implants were inserted, on the accuracy in diagnosis.

Results

The diagnostic accuracy, expressed as A_z-values, was as a mean 0.844 (SD 0.036) at the first reading. The average A_z-value was slightly, but not significantly higher at the second interpretation. The multiple regression analysis failed to identify a particular factor that significantly influenced the diagnostic accuracy. The total observer variation in respect to A_z-values was 0.037 and the intra-observer variation was 0.005. Hence, the inter-observer variation was the largest source of the total variation.

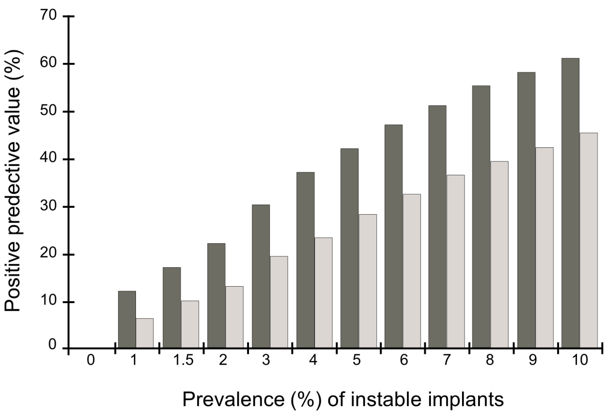


Fig. 1. Positive predictive values at different prevalences of clinical fixture instability. Black bars refer to values obtained when observers were definitely confident that a perifixural radiolucency was radiographically observed; gray bars refer to values when fixtures were included for which observers denoted probable presence of perifixtural radiolucency.

The mean true-positive rate at score 5 (definitely perifixtural radiolucency) was 18.0% and the mean false-positive rate 1.3%. The combination of ratings 5 and 4 (definitely plus probable perifixtural radiolucency) resulted in a true-positive rate of 37.5% and a false-positive rate of 5.1%. Based on these results, positive predictive values were calculated for prevalence of clinical implant instability varying from 0 to 10% (Fig. 1).

Conclusions

The results demonstrated that the diagnostic accuracy was at least as good as the diagnostic accuracy of many other radiographic procedures, such as proximal caries diagnosis and diagnosis of minor periodontal bone lesions (Dove & McDavid 1992, Furkart et al. 1992, Gürgan et al. 1994). However, the possibility of predicting clinical implant instability can be low in populations with low prevalence of implants showing loss of osseointegration.

Study II

Inter- and intraobserver variability in radiographic bone level assessment at Brånemark fixtures.

Material and methods

Radiographs from 30 patients who had been treated for total edentulousness (15 upper and 15 lower jaws) were evaluated. Intra-oral film radiographs had been taken at the time of prosthesis insertion and at subsequent 1- and 3-year check-ups using a paralleling technique. No implant was lost during the follow-up period.

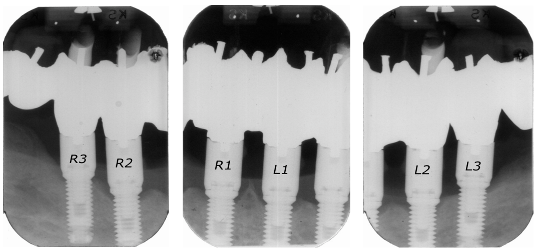


Fig. 2. Radiographs obtained at 1-year check-up in a typical lower jaw case with 6 fixtures marked R3 – L3 (R=right, L=left).

The majority (90.5%) of the 172 implants were imaged in one radiograph, the remainder in two. Most of them (82.2%) had been examined with optimal vertical projection geometry. Clearly visible threads on one side only were found in 13.9% of the implants, while the remaining 3.9% showed diffuse threads on both sides. The radiographic density varied between 0.61-3.39 optical density units with a mean value of 1.33 (SD 0.38).

The radiographs from each examination and patient were mounted in non-transparent frames on which the implants to be assessed were marked (Fig. 2). Six oral radiologists were asked to measure the distance between a reference point and the proximal marginal bone level at the mesial and distal side of the implant using a magnifying lens with 7x magnification and a measuring scale divided in 0.1 mms. The edge between the vertical and the conical part of the implant, *i.e.* 0.8 mm below the fixture-abutment junction, was selected as reference point. If an implant was displayed in more than one image, measurements were to be made in the image showing the largest distance. The observers did not know from which of the 3 examinations the images in question emanated. In all, 1032 implant surfaces were assessed by each observer. After approximately 1 month, all observers re-examined 180 implant surfaces, representing one implant from each patient and examination.

The distance between the reference point and the marginal bone level (RBl) at each implant surface was calculated as a mean value of all observers´ measurements. The average inter- and intra-examiner variances were calculated from the 6x1032 and 6x180 individual observations. Multiple regression analysis was used to study the influence of various factors on inter- and intra-examiner variances.

Results

For all observers the mean value between the reference point and the bone level increased with time after prosthesis insertion. However, differences between observers were found. At year 3 the result for one of the 6 observers (no. 6) was significantly different from all other, a difference that will be more obvious when calculating the bone loss over time. Between years 0-1 the reported bone loss varied between observers from

0.08 to 0.23 mm and between years 0-3 from 0.18 to 0.74 mm, with the largest bone loss reported by observer no. 6.

The RBl at individual implant sites, independent on when the examinations were performed, varied between 0.0-4.2 mm (mean of all observers´ measurements). From this distribution 3 subgroups were created, one with a mean bone loss of 0.0-0.99 mm (n=556), a second with mean bone loss averaging 1.0-1.99 mm (n=393), and a third with a value of >2.0 mm (n=83). Figure 3 demonstrates inter- and intra-observer variations within these 3 subgroups. The total inter-observer variation was 0.14 mm and the intra-observer variation, which is a component of the total inter-observer variation, was 0.08 mm. Hence, more than 50% of the total variation depended on variations within observers.

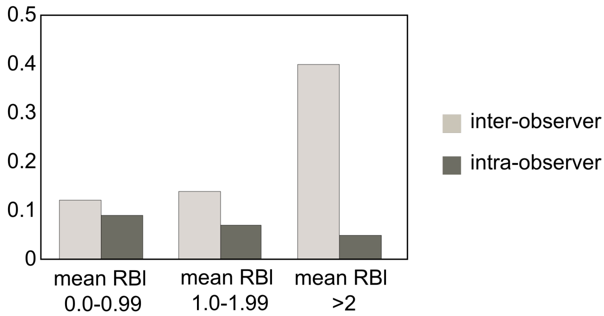


Fig. 3. Inter- and intra-observer variances for different RBl distances (in mm).

A multiple regression model was formed based on the inter- and intra-observer variation, respectively, with radiographic density, projection geometry, number of radiographs displaying the implant, time after prosthesis insertion, jaw, and bone level relative the reference point (RBl) as independent variables. The radiographic density had a significant influence on the total inter-observer variation, the darker the radiographs the larger the inter-observer variation. Inter-observer variation also increased significantly with increasing RBl values. A correlation was also found between inter-observer variation and time after loading, as well as between inter-observer variation and number of radiographs displaying the implant at each examination. An R-square of 0.14 indicated that only a small part of the total inter-observer variation could be explained by the factors studied. The only variable with a statistically significant influence on the intra-observer variation was the number of radiographs in which individual implants were displayed at each examination. The R-square value was even lower (0.06) in respect to the intra-observer variation.

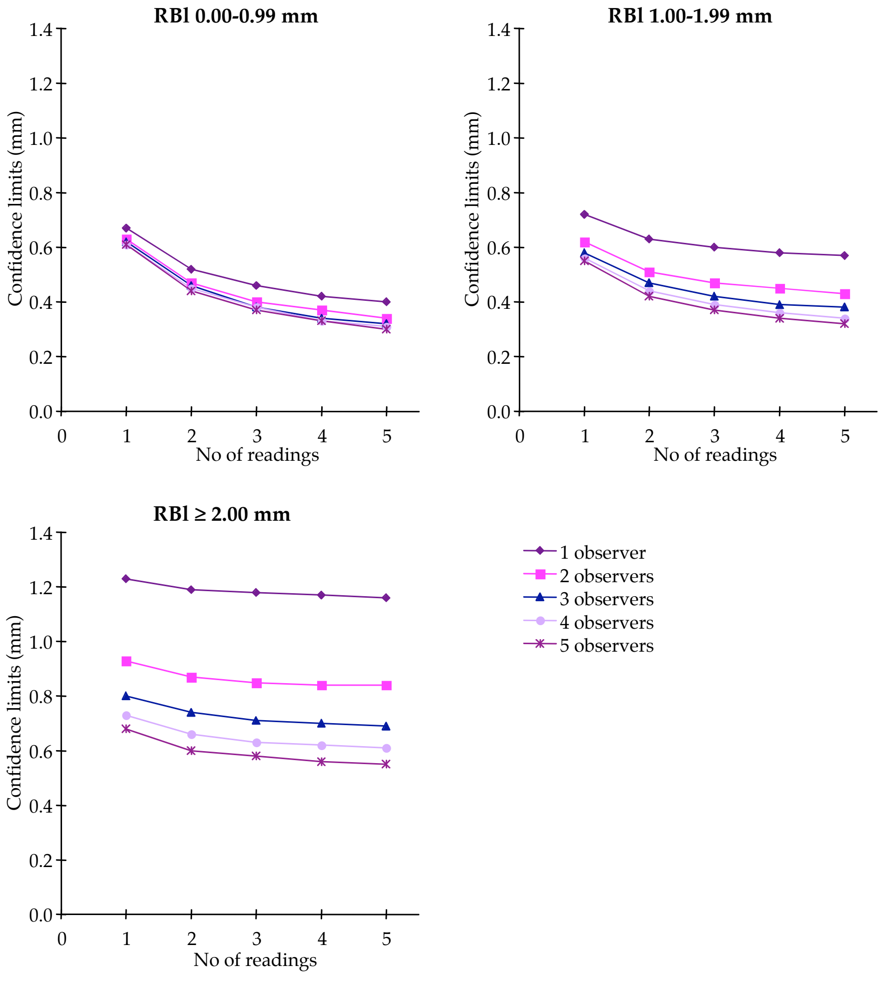


Fig. 4. Graph showing the decrease in 95% confidence limits as a function of number of observers, number of readings and RBl distances.

Knowledge of the mean standard deviation of the variances between and within the observers makes it possible to calculate confidence intervals for the assessment of the "true" distance between reference point and marginal bone level. Figure 4 shows the

95% confidence limits as a function of number of observers and numbers or reading/observers for different RBl distances. The values (in mm) have to be added and subtracted from obtained measurements to get a more correct estimate RBl distance. They demonstrate that better reliability is achieved if the number of observers is increased than if the number of readings by 1 or only a few observers is increased. Best reliability was attained by letting more observers make several, independent observations.

Conclusions

In the multiple regression analysis the radiographic density and the degree of bone loss showed the strongest effect on the inter-observer variation. Only 14% of the inter-observer variation and 6% of the intra-observer variation could be explained by the factors studied.

Albeit the relatively good precision in the observers´ assessments, calculated confidence values showed that measurement reliability could be improved by multiple readings by one observer and, even better, by letting several observers make several independent readings. It not only decreases the effect of the unavoidable variations between and within observers, it also makes it possible to avoid influence of measurement values from a single observer who might be an outlier.

Study III

Marginal bone loss at implants: a retrospective, long-term follow-up of turned Brånemark System® implants.

Material and methods

From the 1 716 patients who had attended an annual follow-up program during 1999 at The Brånemark Clinic, Public Dental Health, Göteborg, Sweden it was possible to identify 1 346 patients of which patients who had a documented function time in radiographs of at least 5 years were included in the study. All were treated with implant-supported (Brånemark System®, Nobel Biocare, Göteborg, Sweden) complete fixed, partial fixed or single-tooth replacements using turned Brånemark implants of various lengths. Patients with overdentures who later got a fixed bridge were included, while patients maintaining their overdentures were excluded. Further, patients who have had osseous grafting or other augmentation procedures were also excluded. The number of patients who fulfilled the inclusion criteria was 640 provided with 3 462 implants. Two hundred fifty-five patients were men. Totally, 393 were treated in the lower jaw and 330 patients in the upper jaw, and among these patients, 83 had received implant treatment in both jaws. Table 2 describes the distribution of upper and lower prosthesis by gender and type of bridgework.

Table 2. Distribution of upper and lower jaw prosthesis by gender and type of bridgework

	Upper jaw														
	None		Complete		1 Partial		2 Partial		Partial + Single		1 Single		2 Single		
Lower jaw	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Σ
None			61	51	28	35	18	15			11	16	8	4	**247**
Complete	150	69	23	21		1	3	1							**268**
1 Partial	32	17	3	2	2	2	4	1	1						**64**
2 Partial	28	12	4	5	2		4	1							**56**
Partial + Single		1	2												**3**
1 Single												1			**1**
2 Single	1														**1**
Σ	**310**		**172**		**70**		**47**		**1**		**28**		**12**		**640**

Intra-oral radiographs had been taken at The Clinic of Oral & Maxillofacial Radiology, lately a few radiographs have been taken at The Brånemark Clinic. Up to 2005 the examination was carried out with film, later different digital techniques have been used. Occasionally, when the patient could not tolerate an intra-orally placed detector the Scanora® scanogram technique (Soredex, Orion Corp., Helsinki, Finland) had been used. All radiographs from each patient were evaluated, even radiographs taken up to 2006. The distance between a reference point (fixture–abutment junction, FAJ) and the marginal bone level both on the mesial and distal surface of the implants was recorded using a magnifying lens (x7) to the closest 0.1 mm. If an implant was displayed in more than one image measurements were to be taken in the image showing the largest distance. The position of the implants in the jaw regions was also recorded. The radiographs were divided between two oral radiologists, one of them analysed 104 patients (patients with complete or partial prosthetic constructions) and the other analysed the remaining patients. Some patients (n=38), representing 2 274 implant surfaces, were analyzed by both radiologists. The 38 patients were randomly chosen among the 184 patients exhibited progressive bone loss according to the results presented by Fransson et al. (2005). For these patients the mean value of each implant surface from the two radiologists was used.

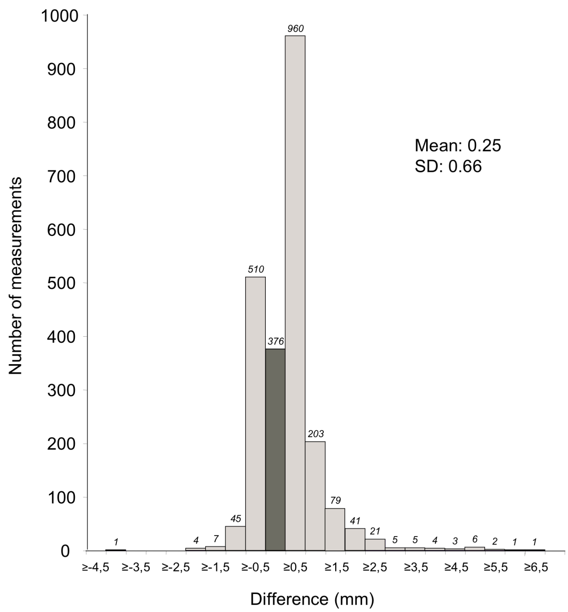


Fig. 5. Difference between the two oral radiologists when measuring 2 274 implants surfaces.

Most radiographs were of a high quality with only 0.13% unreadable. The radiographic error based on the recordings of the bone level assessments by the 2 radiologists was as a mean 0.25 mm (SD 0.66, r=0.82) (Fig. 5).

Statistical methods

Mann-Whitney U-test was used for comparison of difference of bone loss between two groups, Kruskal-Wallis test was used for more than two unordered groups, and Spearman correlation coefficient for analyzing relations between bone loss and other continuous variables. All tests were two-tailed and conducted at 5% significance level. In order to select independent predictors of bone loss a stepwise multiple regression was used. Multiple linear regression with all variables included in the model was used for adjustment of other variables.

Results

Altogether 61 implants in 43 (6.7%) patients had been removed, most of them from the upper jaw. The mean distance between fixture-abutment junction (FAJ) and marginal bone level was 3.0 mm (SD 1.6, range 0.0-7.5) as measured in radiographs at the latest previous examination. Radiographic evidence of loss of osseointegration was found in 8 patients, in each at one implant.

Table 3. Bone level (in mm) at different time periods based on a mean value per implant (n)

year	n	mean	sd	median	range
0	3245	1.1	0.8	1.1	0-8.1
1	2926	1.6	0.8	1.6	0-7.4
2	498	2.1	1.0	2.0	0-7.5
3	1657	2.0	0.8	1.9	0-6.3
4	462	2.1	1.0	2.0	0-7.0
5	2121	1.9	0.9	1.8	0-7.4
6	535	2.1	1.0	2.0	0-7.3
7	288	2.2	1.1	2.0	0-7.2
8	224	2.2	1.3	2.0	0-7.7
9	283	2.3	1.2	2.1	0-8.4
10	1612	2.1	1.0	2.0	0-10.6
11	354	2.2	1.2	2.0	0-8.5
12	216	2.4	1.1	2.1	0-6.1
13	135	2.8	1.2	2.6	0.2-7.3
14	122	2.3	1.2	2.1	0.2-6.0
15	278	2.1	1.1	2.0	0-6.2
16	133	2.2	1.3	2.0	0-7.2
17	33	2.9	1.9	2.9	0-9.7
18	42	2.4	2.6	1.9	0-14.4
19	13	2.3	1.4	2.1	0.8-5.9
20	56	2.5	1.2	2.2	1.0-8.0

Table 4. Bone level (in mm) at different time periods on a patient level (n)

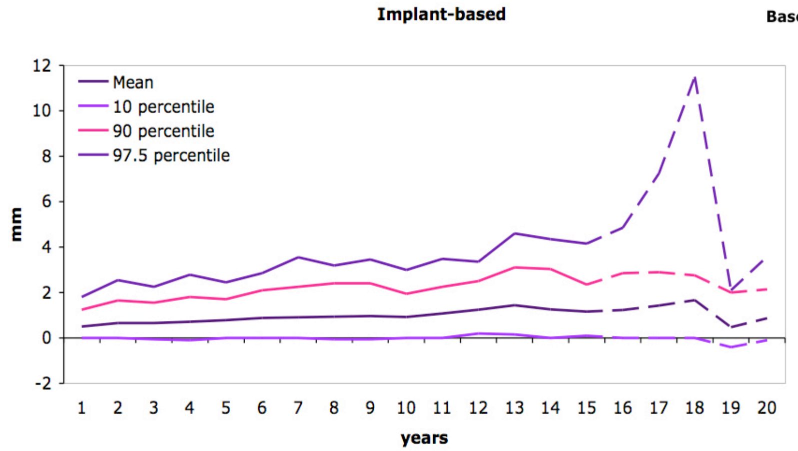
year	n	mean	sd	median	range
0	602	1.1	0.7	1.1	0-3.9
1	559	1.6	0.6	1.6	0.1-4.1
2	101	2.0	0.7	2.0	0.1-3.7
3	337	1.9	0.7	1.9	0.2-4.3
4	88	2.1	0.8	2.0	0.6-4.2
5	445	1.9	0.7	1.8	0.2-4.5
6	113	2.2	0.7	2.1	0.3-4.1
7	64	2.2	0.9	2.1	0.7-4.8
8	47	2.3	1.0	2.1	0.5-5.1
9	60	2.4	0.9	2.3	1.0-4.9
10	311	2.1	0.8	2.0	0.2-4.7
11	72	2.2	1.0	2.0	0.5-6.1
12	43	2.4	1.0	2.1	0.4-4.7
13	27	2.8	0.9	2.8	1.0-4.9
14	25	2.4	0.9	2.4	1.0-4.4
15	53	2.1	0.9	2.0	0.5-4.8
16	25	2.3	0.9	2.3	0.4-4.6
17	6	3.0	1.7	2.9	0.3-5.6
18	8	2.3	1.8	1.9	0.2-6.4
19	3	2.1	0.8	1.7	1.5-3.0
20	10	2.6	0.9	2.3	1.5-4.8

At prosthesis installation the mean distance between FAJ and the marginal bone level on the implant level was 1.4 mm (SD 0.9) in the upper jaw and 0.9 mm (SD 0.7) in the lower jaw regardless of prosthetic construction. The distance between FAJ and the marginal bone level increased over time, except for minor variations, both on the implant and the patient level (Tables 3 and 4). Although low average values, there were implants with considerably larger distances. Table 5 shows the frequency distribution for the marginal bone level based on mean values per implant at different time intervals.

Table 5. Bone level (in mm) for individual implants; a frequency distribution at different time periods

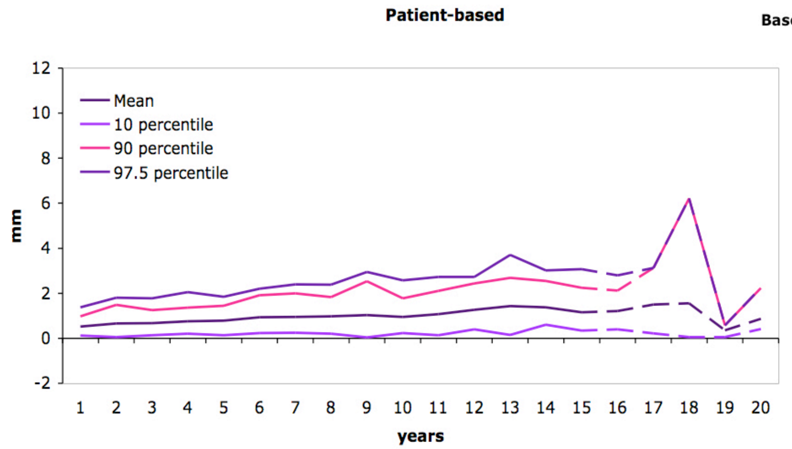
	Bridge installation		**Year 1**		**Year 3**		**Year 5**		**Year 10**		**Year 15**		**Year 16-20**	
	No of implants	%	No of implants	%	No of implants	%	No of implants	%	No of implants	%	No of implants	%	No of implants	%
< 1	1486	(45.8)	576	(19.7)	165	(10.0)	280	(13.2)	172	(10.7)	40	(14.4)	27	(10.4)
1.0-1.9	1276	(39.3)	1442	(49.3)	745	(45.0)	959	(45.2)	667	(41.4)	103	(37.1)	76	(29.2)
2.0-2.9	395	(12.2)	742	(25.4)	560	(33.8)	653	(30.8)	529	(32.8)	87	(31.3)	96	(36.9)
3.0-3.9	65	(2.0)	133	(4.5)	146	(8.8)	178	(8.4)	156	(9.7)	24	(8.6)	35	(13.5)
4.0-4.9	16	(0.5)	26	(0.9)	34	(2.1)	44	(2.1)	64	(4.0)	17	(6.1)	8	(3.1)
5.0-5.9	5	(0.2)	6	(0.2)	6	(0.4)	3	(0.1)	11	(0.7)	5	(1.8)	10	(3.8)
> 6	2	(0.1)	1	(0.0)	1	(0.1)	4	(0.2)	13	(0.8)	2	(0.7)	8	(3.1)
n	**3245**		**2926**		**1657**		**2121**		**1612**		**278**		**260**	

The overall mean bone loss from prosthesis insertion to the 1-year follow-up was on patient level (n=523) 0.5 mm (SD 0.4) and on implant level (n=2 756) 0.5 mm (SD 0.6). The accumulated mean bone loss continued over the years to increase on both implant and patient level (Fig.s 6 and 7). Tables 6 and 7 show the frequency distribution of the bone loss for some of the different time intervals.



Baseline to	n=
1 yr	2756
2 yrs	463
3 yrs	1542
4 yrs	426
5 yrs	2009
6 yrs	467
7 yrs	249
8 yrs	200
9 yrs	263
10 yrs	1521
11 yrs	334
12 yrs	194
13 yrs	123
14 yrs	110
15 yrs	252
16 yrs	128
17 yrs	33
18 yrs	42
19 yrs	13
20 yrs	50

Fig. 6. Distribution of implant-based annual bone loss up to 20 years after prosthesis insertion.



Baseline to	n=
1 yr	523
2 yrs	94
3 yrs	314
4 yrs	80
5 yrs	421
6 yrs	99
7 yrs	55
8 yrs	43
9 yrs	57
10 yrs	296
11 yrs	69
12 yrs	40
13 yrs	25
14 yrs	23
15 yrs	49
16 yrs	24
17 yrs	6
18 yrs	8
19 yrs	3
20 yrs	9

Fig. 7. Distribution of patient-based annual bone loss up to 20 years after prosthesis insertion.

Significant correlation between age at surgery and bone loss was found at years 1, 3, 5, and 10, strongest at year 5. The older the patient the more bone loss. When adjusted for jaw and type of bridgework a significant correlation was found at years 1, 3 and 5 with the strongest correlation at year 5. Regarding gender a larger bone loss was found for females, but when adjusted for jaw and type of bridgework no significant difference was found. Further, on the patient level significantly larger bone loss was found for the lower jaw than for the upper jaw at years 1, 5 and 10. A significant overall difference in bone loss was found between complete, partial and single restorations with more bone loss for complete restorations. Finally, an overall test regarding calendar year of surgery showed larger bone loss for surgery performed during 1985-1989 compared to 1980-1984, 1990-1994, and 1995 and later. From multiple stepwise regression jaw had most impact on bone loss at year 1, and age at years 3, 5 and 10, when only one variable was entered into each model. After adjustment for all variables, jaw had a significant impact on bone loss at year 1, age for both years 5 and 10, and gender at year 15.

Table 6. Implant-based bone loss (in mm), as a mean of distal and mesial implant surfaces, and its frequency distribution at different time periods using bridge installation as baseline

	Baseline to 1 year		**Baseline to 3 years**		**Baseline to 5 years**		**Baseline to 10 years**		**Baseline to 15 years**		**Baseline to 16-20 years**	
n= **Mean (sd)** **10pctl, 90pctl**	2756 0.51 (0.55) (0.00, 1.25)		1542 0.66 (0.69) (-0.05, 1.55)		2009 0.79 (0.75) (0.00, 1.70)		1521 0.93 (0.91) (0.00, 1.95)		252 1.16 (1.02) (0.10, 2.35)		249 1.24 (1.63) (0.10, 2.70)	
	n	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**
< 1	2253	(81.7)	1098	(71.2)	1293	(64.4)	873	(57.4)	124	(49.2)	127	(51.0)
1.0-1.9	465	(16.9)	384	(24.9)	602	(30.0)	498	(32.7)	88	(34.9)	72	(28.9)
2.0-2.9	35	(1.3)	50	(3.2)	90	(4.5)	109	(7.2)	24	(9.5)	31	(12.4)
3.0-3.9	3	(0.1)	9	(0.6)	17	(0.8)	28	(1.8)	8	(3.2)	7	(2.8)
≥ 4	0	(0.0)	1	(0.1)	7	(0.3)	13	(0.9)	8	(3.2)	12	(4.8)

Table 7. Patient-based bone loss (in mm), as a mean of distal and mesial implant surfaces, and its frequency distribution at different time periods using prosthesis insertion as baseline

	Baseline to 1 year		**Baseline to 3 years**		**Baseline to 5 years**		**Baseline to 10 years**		**Baseline to 15 years**		**Baseline to 16-20 years**	
n= **Mean (sd)** **10pctl, 90pctl**	523 0.52 (0.36) (0.12, 0.98)		314 0.67 (0.46) (0.14, 1.25)		421 0.78 (0.55) (0.13, 1.45)		296 0.95 (0.66) (0.23, 1.78)		49 1.15 (0.77) (0.34, 2.25)		44 1.26 (1.07) (0.41, 2.51)	
	n	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**	**n**	**(%)**
< 1	474	(90.6)	244	(77.7)	298	(70.8)	171	(57.8)	23	(46.9)	22	(50,0)
1.0-1.9	48	(9.2)	67	(21.3)	114	(27.1)	112	(37.7)	21	(42.9)	14	(31.8)
2.0-2.9	1	(0.2)	3	(1.0)	8	(1.9)	10	(3.4)	3	(6.1)	6	(13.6)
3.0-3.9	0	(0.0)	0	(0.0)	0	(0.0)	2	(0.7)	1	(2.0)	1	(2.3)
≥ 4	0	(0.0)	0	(0.0)	1	(0.2)	1	(0.3)	1	(2.0)	1	(2.3)

When identifying individual implant surfaces (mesial or distal) with bone loss ≥3 mm compared to the bone level at prosthesis insertion, regardless of follow-up time, 183

(5.3%) implant surfaces in 107 (16.7%) patients were found. None was found in connection with single tooth restorations. Using the bone level at year 1 as baseline, 78 implant surfaces (2.7%) in 50 patients (8.9%) with a bone loss of ≥3 mm regardless of follow-up time were found.

Conclusions

The results indicate a complexity of bone level changes where most of the differences in bone reaction, although statistical significant, are small from a clinically point of view. Around 5.3% of the implants, however, a more advanced bone loss was found when using a loss of ≥3 mm as a threshold value and the prosthesis insertion as baseline.

Study IV

Radiographic analyses of "advanced" marginal bone loss around Brånemark® dental implants.

Material and methods

Material and methods are the same as in *Study III*.

Statistical methods

For comparison of dichotomous variables between two groups Fisher´s exact test was used. For comparison of the amount of bone loss that had taken place 1 year before first bone loss ≥2 mm was observed with that taken place during the subsequent year, Wilcoxon signed rank test was used. If a measurement was missing 1 year before or after, a linear interpolation was used based on earlier and later measurement values. Univariate and multiple logistic regressions using the method of generalized estimation equations (GEE) were used to select independent predictors for bone loss ≥2 mm. A compound symmetry covariance pattern was used to model the dependency within the patient. All significance tests were two-tailed and conducted at the 5% significance level.

A strategy where not all implants of the same patient are examined with radiography was developed. In order to calculate the conditional probability that any of the other implants has a bone loss ≥2 mm given the bone loss of a randomly chosen implant and number of implants per patient the following analysis was done. The bone loss of the different implants of the same patient was considered as a vector having a multivariate normal distribution. For each number of implants (n=2,…,8) the corresponding matrix of covariance was estimated. The numbers of the main diagonal of the matrix were equal and all numbers outside the diagonal were equal. The conditional distribution of a random vector given that one of its element equals a number x, is again a vector, which has a multivariate normal distribution. The matrix of covariance of the last mentioned vector was determined from the first matrix. By solving a system of non-linear equations we found constants, which determined linear combinations of independent variables having the same multivariate distribution as the conditional one. Numerical integration yielded the results presented in Figure 8.

Results

When selecting patients (n=256) with a radiographic examination at prosthesis insertion and follow-ups both after 1 year and 10 years, and identifying the implant surface with the largest bone loss the difference in mean bone loss for year 0-1 versus mean bone loss years 1-10 was 0.0015 mm (median -0.10 mm). Hence, the progression rate was lower after the first year in function.

There was on the patient level (n=211) a significant difference in bone loss before and after the first occurrence of a bone loss ≥2 mm with a higher bone loss before the first occurrence. The mean difference was -0.94 mm (SD 0.86).

When predicting a bone loss of ≥2 mm on implant level, from prosthesis installation up to 5 years, 6-10 years, and 11-15 years, respectively, in the entire group of patients, minor bone loss from abutment connection to prosthesis insertion and implant position in the jaw region were found to be predictors at all 3 intervals. Implants with larger bone loss during this short and early time period showed minor bone loss after prosthesis insertion. Implants placed in a middle position versus in an end position, regardless of jaw-type, showed larger bone loss. At 5 years jaw-type was identified as a predictor with more bone loss for the upper jaw, and finally, at 6-10 years age was identified as a predictor with more bone loss the older the patient. Gender, type of prosthetic construction and calendar year of surgery were not correlated to a bone loss ≥2 mm.

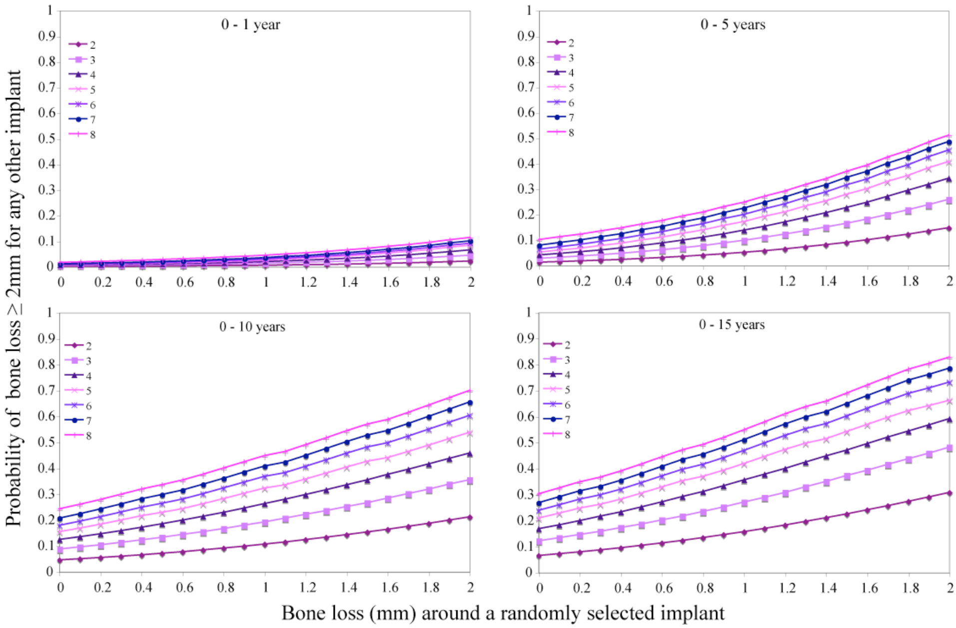


Fig. 8. Predicted probability (%) that any of the other implants per patient has a bone loss ≥2 mm given the bone loss of the investigated implant after 4 different time intervals using prosthesis insertion as baseline.

Figure 8 shows the conditional probability (%) of bone loss ≥2 mm for not radiographically examined implants at 4 different time intervals; 1, 5, 10 and 15 years after prosthesis insertion, given different degree of bone loss of a randomly chosen and examined implant and number of implants per patient. The probability for a bone loss ≥2 mm at any of the unexamined implants will, *e.g.* be 20% after 5 years if the patient has 6 implants and the examined implant suffered from a mean bone loss of 1 mm compared to prosthesis insertion.

When identifying individual implant surfaces (mesial or distal) with a bone loss ≥3 mm (range 3-14.5 mm) compared to the bone level at prosthesis insertion, regardless of follow-up time, 183 (5.3%) implant surfaces in 107 (16.7%) patients were found. The majority of them (79%) were found in edentulous patients (59 in upper and 85 in lower jaws), while remaining 39 implants were found in partially dentate patients (21 in upper and 19 in lower jaws). Of the 183 surfaces a bone loss of 3.0-3.9 mm was found at 112 surfaces, another 37 surfaces had lost 4.0-4.9 mm, 22 had lost 5.0-5.9 mm, 7 between 6.0-6.9 mm, 2 between 7.0-7.9 mm, 1 had lost 8.6 mm and 2 surfaces showed a bone loss >10 mm.

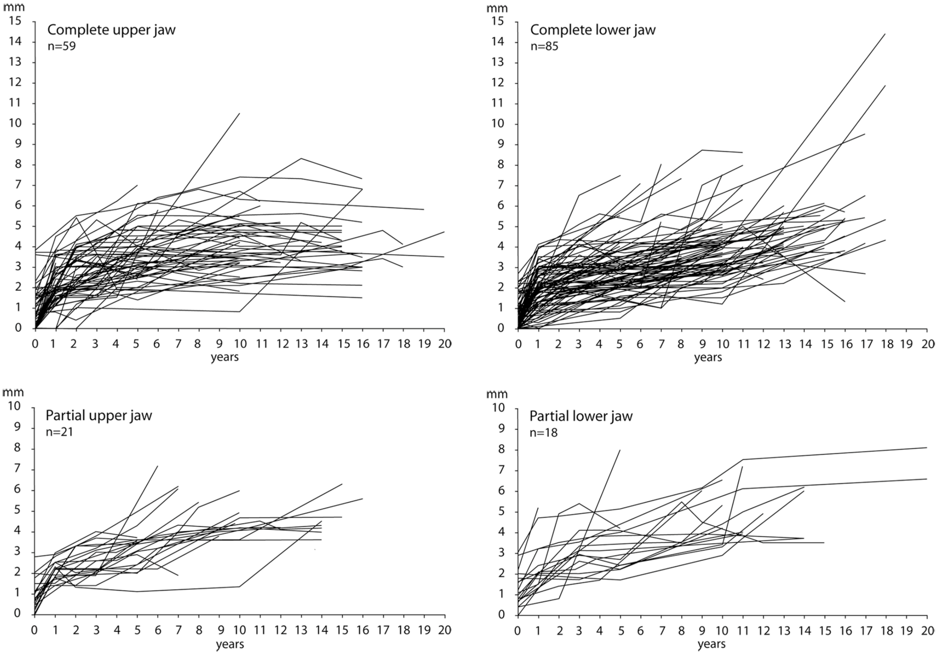


Fig. 9. Progression of bone loss per jaw and type of prosthetic construction for each of the 183 surfaces with advanced bone loss ≥3mm as a threshold.

Of the 183 implant surfaces 33% had their maximal loss 1-15 years before the last radiographic examination, while remaining implants showed a continuous loss with its maximal loss at the last observation (range 5-20 years). Of the 107 patients, 63 patients had 1 implant each, 25 patients 2, 10 patients 3, 5 patients 4, and 4 patients 5 implants with this degree of bone loss. Figure 9 shows the progression of bone loss per jaw and type of prosthetic construction for each of the 183 implants. Seventeen of the 107 patients (15.9%) had lost one implant or more (n=24) to be compared to 26 patients (5.0%) of the other 533 patients, which were found to be significantly different. Among the 183 implants with a bone loss ≥3 mm 6 implants were lost.

Conclusions

The results indicate that implant therapy is still a reliable and safe procedure with a high success rate from marginal bone support point of view even when identifying implant surfaces with the larger bone loss. Also in this subgroup the highest progress rate was found during the first year in function. A cluster effect was found with more advanced bone loss in few patients. Implants position was found to be important with larger bone loss for implants placed in the middle of the construction. Further, age and jaw-type were identified as predictors. Dependency within the patient was found. The number of intra-oral radiographs per examination and, more important, radiographic examinations can be reduced without jeopardizing good clinical management, a statement valid even for Brånemark implants with advanced bone loss.

Discussion

Radiography is one of the most important methods to assess success or failure of osseointegrated implants. Post-operative radiographs to monitor the reactions around implants are usually taken at intervals from the day of delivery of the prosthesis and continuing as long as felt necessary from a clinical point of view (Gröndahl & Lekholm 1997). For some implant systems there might be a need for radiography already at the second stage surgery to control the seating of the abutments. Intra-oral radiography is to be preferred for implants placed in the alveolar bone because irradiation geometry and exposure factors that are individualised for each implant can, as a rule, be used (Gröndahl et al. 1996). Intra-oral radiographs are also superior to extra-oral techniques because of their better geometric resolution and lower amount of radiographic noise, anatomical noise as well as quantum noise. In some patients, however, as well as when implants have been placed in other anatomical regions than the tooth-bearing parts of the jawbone, extra-oral techniques have to be used.

Radiography has the advantage of being non-invasive but has the disadvantage that it is based on the use of ionising radiation and on two-dimensional data of three-dimensional scenes. Its results are also highly dependent on irradiation geometry and exposure conditions. Nevertheless, radiography is the only non-invasive method that can provide *in vivo* information about the bone height and its changes over time, status of the bone-implant interface zone, the remodelling of the bone as a function of loading, and the condition of the components of the implant pillar. These are some of the important parameters to evaluate when monitoring the success of the implant treatment. The information contained in a radiograph is in most cases evaluated by one observer who interprets the image pattern. The diagnosis is therefore the results of an interaction between image content, observer perception and nosological knowledge of the observer. Hence, it is not observer-independent, *i.e.* it is not objective (Goldman et al. 1972, Haugejorden 1974, Molven 1974, Duinkerke et al. 1975, Gröndahl 1979, Gröndahl et al. 1987, Åkesson et al. 1992, Gürgan et al. 1994). As a result intra- as well as inter-observer variations will occur.

In *Study I* when testing the diagnostic accuracy and precision in the radiographic diagnosis of clinical instability, 62 implants lacking clinical stability and 158 clinical stable implants were identified and interpreted by 8 observers. Hence, the prevalence of unstable implants (28.2%) was not in concordance with published data. Loss of implants before loading has been reported in a range of 0.8-7.5% and late loss in 2.1-11.3% (Berglund et al. 2002). The observers were not given information on the probability of presence of implant failures. The A_z-value under the ROC curve, used as the technique to evaluate the diagnostic accuracy, is not dependent on the prevalence of the disease, while the spread and location of the points are. The positive predictive value, however, depends on the prevalence of the disease, in this case unstable implants. At the true-positive and false-positive rates obtained, when the observers felt definitely confident that a peri-fixtural radiolucency was present, the positive predictive value of the test amounted to 17%, although high A_z-values (as a mean 0.844 at the first reading and

0.856 at the second) were achieved. Thus, a decision to detach the prosthetic construction, even when the observer was definitely sure about the presence of a peri-implant radiolucency, would imply that clinically stable implant would be found in over 80%. An increase in the true-positive rate can be brought about by using less strict criteria for considering a perifixtural radiolucency to be present. The positive predictive value of radiographic identification of unstable Brånemark implants was evaluated in a clinical study based on approximately 2 000 patients by Gröndahl & Lekholm (1997). They found a high positive predictive value (83%), and only 5% were clinically found to be failing without having been radiographically detected. Further, they found that in 11% of the jaws (9 out of a total 79 patients with detached prosthetic constructions) the fixed prosthetic constructions were unnecessarily detached because of an inaccurate radiographic diagnosis. They concluded that radiography, when performed with high image quality, is a valuable method to be used in follow-up examinations of implant patients. In addition, it was recommended that for an un-experienced clinician it could be recommended that radiographic examinations should be conducted on an annual basis during the first 3 years of implant function.

The multiple regression analysis used in *Study I* failed to identify a particular factor that significantly influenced the diagnostic performance, probably due to the high quality of the radiographs used in the study. Another factor of importance for the high diagnostic accuracy and precision might be the long experience of the observers evaluating the radiographs. The inter-observer variability was found to be larger than the intra-observer variability.

In *Study II* the influence of image quality and jaw-type on the observer variation was determined when assessing the implant bone level in radiographs obtained at prosthesis insertion and follow-ups after both 1 and 3 years. In the material 82% of the radiographs had optimal vertical projection geometry, *i.e.* threads were clearly visible on both sides and only 4% showed diffuse threads on both sides. Differences between the observers were found with one being an outlier. The difference between observers was more obvious when calculating the bone loss over time, as the variation among the observers increased the larger the bone loss. The bone loss for the 3-year follow-up period varied among the observers from 0.18 to 0.74 mm. More than 50% of the total variation depended on the variation within the observers. These results are important when evaluating different implant studies. For obvious reasons there are many factors that will differ between different studies; the image quality, the observers, the amount of bone loss, which often is connected to the length of the follow-up time. It is noteworthy to mention that the diagnostic accuracy and precision might depend on whether the interpreter is biased or not (Goldman et al. 1972).

In the majority of long-term follow-up studies the standard turned Brånemark implant system using the classical, well-defined two-stage surgical protocol has been used. *Studies III* and *IV* are based on that implant-system and the results are therefore only valid for this system. Nobel Biocare has moved from their original turned-surface *ad modum* Brånemark to a current rougher one with an oxidized surface, called TiUnite. In a 1-year follow-up study on the TiUnite implant system (Nobel Biocare Holding AG, Zurich, Switzerland) Friberg et al. (2005) found the survival rate of the implants (98.6% for the maxillae and 100% for the mandible) and the mean marginal bone loss (1.4 mm) to be concordant with studies from studies on Brånemark turned implants. However, in long-term perspectives other patterns of bone loss at implants with other types of surfaces have been indicated (Brocard et al. 2000, Baelum & Ellegaard 2004).

Studies III and *IV* are retrospective studies with the disadvantages that come with that type of studies but it is difficult to make a comprehensive prospective study with a large group of patients to be followed for a long period of time. One disadvantage with retrospective studies is that the patients will have different follow-up times as some patients may have been treated years ago, while others have been treated just recently (Babbush & Shimura 1993). In the present studies all patients had been followed for at least 5 years after prosthesis insertion, although implant surgery could have been performed up to 20 years before the latest follow-up. When comparing different implant systems, treatment modalities or, side effects as marginal bone loss, it has been recommended that one should use a controlled, randomised and prospective multi-center study design (Iacono & Cochran 2007). With few exceptions the patients in our studies were treated at The Brånemark Clinic, Göteborg, Sweden by oral surgeons and prosthodontists with long experience of implant treatment using a well-defined two-stage surgical protocol (Adell et al. 1985) and the constructions were manufactured in either gold alloy or titanium (Zarb & Janson 1985, Jemt et al. 1999). All these factors suggest a fairly homogeneous type of patient management instead of the variations that one can expect had many clinics and clinicians been involved.

Two oral radiologists interpreted all radiographs in *Studies III* and *IV*, which can be seen as a drawback based on the results from *Study II*. The large number of patients (640 patients representing 3 462 implants followed for a long period of time resulted in 30 466 implants surfaces to be measured) demanded active interest that might not have been possible to achieve if the number of observers should have been increased. The mean difference between the 2 observers, when reading radiographs from the same 38 patients with 229 implants, was 0.25 mm (SD 0.66, r=0.82). Hence, our measurement error was larger than earlier studies (Adell et al. 1990, Jemt et al. 1990, Thilander et al. 1994) reporting a mean error of 0.1-0.3 mm with a standard deviation of 0.2-0.4 mm. One reason could be that the patients chosen for determining the inter-observer variation were selected among the patients exhibiting progressive bone loss according to the criteria suggested by Fransson et al. (2005). As shown in *Study II* the inter-observer variation will be higher the larger the bone loss. Ahlqvist and co-workers (1990) found that measurement precision increased with time of loading. They also calculated that the detection threshold for marginal bone loss exceeded 0.5 mm.

During the year 1999, 1 716 patients were admitted for clinical examination at The Brånemark Clinic. Based on available information from recorded codes on payment for annual check-ups it was possible to identify 1 346 patients (78.4%). It can only be speculated on why the remaining 370 patients were not charged according to established protocols at the clinic. Roos-Jansåker and co-workers (2006b) showed that patients not showing up for a check-up at the specialist clinic after 9-14 years had more bone loss after 5 years than the patient group willing to take part in the research project. Some of our patients may have been in need of additional implant treatment in other jaw regions and, therefore, not charged for the follow-up examination. Other patients may not have been charged because of a fast and uncomplicated examination, while for others the reason can be that major clinical adjustments were necessary and the charging for the examination itself was missed or included in later payments.

To allow for comparisons between different studies it is vital that the same reference point is used for bone level measurements or described in a manner making comparisons possible. When no reference point is mentioned, the results become difficult to compare with those from other studies (Lekholm et al. 1999, Roos-Jansåker et al. 2006b). Over the years two different reference points have been used for the Brånemark implant. In *Study II* the edge between the vertical and conical part of the implant head was used as the reference point, whereas in *Studies III* and *IV* the fixture–abutment junction (FAJ) was used. In order to compare the results on bone level changes in *Study II* with the result in *Studies III* and *IV* one has to add another 0.8 mm to the bone level in *Study II*. In our studies, as in most studies on the Brånemark System, the bone level at the time of prosthesis insertion was chosen as baseline for the bone loss assessments. Other baseline data have been used in the literature, such as those at the time for abutment connection (Snauwaert et al. 2000) or the 1-year examination (Fransson et al. 2005, Roos-Jansåker et al. 2006b), which add more difficulties when comparing different studies.

The mean distance between FAJ and the bone level at prosthesis insertion was in the entire group of patients 1.1 mm (SD 0.7) and on the implant level 1.1 mm (SD 0.8). Thus, a bone loss from implant placement up to loading of the implants can indirectly be noticed. The mean distance increased in general over time both on the implant and the patient level. Although, low average values, there were implants with considerably larger distances. The number of implants with a bone level at ≥3 mm relative FAJ increased from 3% at prosthesis insertion to 15% after 10 years, and to 17% after 15 years. Roos-Jansåker and co-workers (2006b) found that at 20% of the implants, the bone level was located at or apical to the third thread (≥3.1 mm) after 9-14 years. They used the surface with the most pronounced bone loss (mesial or distal) when calculating their data, while a mean value per implant was used in our study. Consequently, there might be only minor differences between our studies concerning the location of the bone level after approximately 10-15 years.

The bone loss, in the entire group of patients, was 0.5 mm (SD 0.4) on the patient level during the first year in service and on the implant level 0.5 mm (SD 0.6), which is less than what have been regarded as acceptable (Albrektsson et al. 1986, Duyck & Naert 1998). The accumulated mean bone loss increased over the years on both implant and patient level, but at a low progression rate. A bone loss <1 mm was found at 82% of the implants after 1 year. The corresponding values were after 3 years 71%, 5 years 64%, 10 years 57%, and after 15 years 49%. Hence, after 15 years in function the bone loss after prosthesis insertion was <1mm at about 50% of the implants followed.

Over the years, many authors have tried to define criteria for success and different thresholds for acceptable bone loss have been suggested. Albrektsson and co-workers (1986) incorporated a time factor into their criterion in acceptable levels of bone loss; <2.4 mm and <3.4 mm after 5 and 10 years of follow-up, respectively, while Wennström & Palmer (1999) claimed that a bone loss <2 mm during the first 5 years should be required for an implant system to be considered successful. Applying the criteria proposed by Wennström & Palmer in the present studies 5.2% of the implants supporting a complete lower jaw restoration showed an unacceptable bone loss (≥2 mm). The corresponding value for complete upper jaw implants was 8.3%, and for the entire group of implants the corresponding value was 5.6%. Using the patient-based bone loss instead, a loss of ≥2 mm was found in 2.1% of the patients. Roos-Jansåker et al. (2006b) regarded a bone loss of 1.8 mm as an unacceptable bone loss, but used the 1-year data as baseline. They found an advanced bone loss at 8% of the implants after 9-14 years in service. In the present studies the frequency of implants with a bone loss of ≥2 mm from prosthesis insertion was 10% in 4% of the patients after 10 years in function. The frequency would have been lower with a time interval from year 1 to year 10, excluding the bone loss during the first year of follow-up. Consequently, there cannot be major differences between the two studies regarding success rates. Fransson and co-workers (2005) found, among the same patients as in *Studies III* and *IV*, that 12% of the implants in 28% of the patients exhibited progressive bone loss, that is, the bone level at the 1-year follow-up was located at <3 threads but at ≥3 threads at the 5 to 20 years of follow-up. Hence, a lower threshold of ≥0.1 mm was used in their study, making it hard to compare with the study by Roos-Janåker et al. (2006b) and our studies. When comparing results from different studies one has to be aware of, not only that different baseline data and different threshold values for *e.g.* advanced bone loss have been used, but also that the observers interpreting the radiographs are different. The results from *Study II* clearly demonstrate the influence of the observer on the results achieved. Furthermore, the radiographic material will vary between different studies. Sewerin (1990) showed that the accuracy of bone level measurements was compromised even at very small deviations (5 degrees) from strict parallelism between the implant and the detector.

All suggested criteria for success accept some yearly marginal bone loss. In this context the age of the patient at implant surgery, hence the remaining lifetime of the patient, and the length of the implant, have to be taken into account. There must be a different situation if a 75-year old patient having 18 mm-implants will show a bone loss of 5 mm at the 15-year check-up compared to a 40-year old patient having 10 mm-implants showing the same amount of bone loss at the 15-year check-up. Wennström and co-workers (1990) presented a model for decision-making regarding needs for periodontal treatment at teeth based on the amount of remaining periodontal bone support. A maintained alveolar bone height of one third of the root length at the age of 75 years was regarded to be a reasonable goal. Maybe the survival rate of dental implants should be evaluated using such a model instead of focusing on the bone level or loss around implants without taking the age of the patient and/or length of implant into account. For obvious reasons the root lengths cannot be compared with the various lengths of implants, since the latter show a much larger variation.

When studying the implant surfaces with the largest bone loss within each patient during a 10-year period, the largest bone loss took place during the first year in function. During this year 2.3% of the surfaces demonstrated a bone loss ≥3 mm, while the corresponding value for the next coming 9 years was 7.0%. This finding is concordant with most studies on turned Brånemark implants when including all implants within the patient.

When identifying individual implant surfaces with a bone loss of ≥3 mm from the time of prosthesis inserting, regardless of follow-of time, 183 implants (5.3%) in 107 patients (16.7%) were found. A majority of them (79%) were found in totally edentulous patients, and a majority (61%) demonstrated a bone loss of 3.0-3.9 mm. Among the 107 patients, 70 (38%) of the 183 implants were found in 19 patients, 18% of all patients. Hence, there seems to be also a cluster effect regarding marginal bone loss as for implant failures due to loss of osseointegration (Weyant & Burt 1993, Hutton et al. 1995, Herrmann et al. 1999, Jemt & Häger 2006). The marginal bone loss around implants seems to follow the pattern seen for advanced bone loss around teeth, *i.e.* a minor population suffers from more advanced bone loss. Periodontitis has been classified into aggressive and chronic subtypes (Armitage 1999), maybe a similar classification can be applied on bone loss associated to implants. Of the 183 implants 33% had their maximal loss 1-15 years before the last radiographic examination indicating that the bone loss was not continuous. The same result was also found when studying implants supporting a complete prosthetic construction that had a bone loss of ≥2 mm regardless of follow-up time. Patients with a bone loss of ≥2 mm had a significantly larger bone loss the year before this was noted than the year after. A significantly higher frequency of implant loss was found among the 107 patients with the most advanced bone loss than in the entire group of patients indicating a relation between implant loss and marginal bone loss. Such a relationship was also noted by Hultin and co-workers (2000). They found significantly larger bone loss around remaining implants in patients who had lost implants than for those with no implant losses.

In the entire group of patients a statistically significant correlation between age at surgery and bone loss was found with more bone loss the older the patient. Salonen and co-workers (1993) suggested that advanced age is a contributing factor to implant failure, and also Brocard and co-workers (2000) found lower success rates for implants placed in older patients. In contrast, Bryant & Zarb (2003) found better results for elderly compared to younger individuals and Kuperschmidt et al. (2007) found no correlation between bone loss and age.

In our study we found a significantly larger bone loss was found for jaw-type with more bone loss for the lower jaw at years 1, 5 and 10. A significant overall difference in bone loss was found at year 5 between the different prosthetic constructions with more bone loss for the complete constructions compared to partial constructions and single tooth replacements, a finding in concordance with the review study by Berglundh and co-workers (2002). For calendar year of surgery the overall test showed a larger bone loss for surgery performed during 1985-1989. From a multiple stepwise regression, after adjustment for all other variables, jaw-type had a significant impact on the bone loss at year 1, age at both years 5 and 10, and gender at year 15. Females had significantly larger bone loss than males at year 15. Kim et al. (2008) reported significantly more bone loss for males with implants up 10 years in function. The position of the implant within the prosthetic construction was found to be important for the lower jaw, but not for the upper jaw, with less bone loss observed for implants placed in an end position. This is in accordance with results found by Carlsson et al. (2000), Ekelund et al (2003) and Kim et al. (2008). Smoking has been identified as a risk factor in other studies, and it has also been shown that patients with a history of periodontitis are more likely to develop more bone loss around implants than periodontally healthy patients. As the present studies were solely based on radiographic bone level assessments the influence of other clinical parameters or patient history were not included.

Placement of the implant within the prosthetic construction, regardless of jaw-type, was found to be an independent predictor of a bone loss of ≥2 mm with minor bone loss around implants placed in an end position. Jaw-type was also found to be an independent predictor of a bone loss of ≥2 mm with larger bone loss in the upper jaw. Further, age was found to be a predictor of a bone loss of ≥2 mm, while factors like gender, type of prosthetic construction, and calendar year of surgery were not.

In an effort to reduce the radiation burden to the patients the probabilities of a bone loss of ≥2 mm over different periods of time, given different degrees of bone loss at one randomly selected implant, were calculated. Based on the results it seems safe to exclude radiography during the first 5 years of follow-up. With longer follow-up times, the probability of a bone loss of ≥2 mm around any other implant in patients having 4 implants or more will increase to 50% or more given a bone loss of ≥2 mm around the examined implant. Hence, implants placed in the same patient cannot be regarded as independent, not only with respect to loss of osseointegration (Herrmann 2007), but also with respect to marginal bone loss. Consequently, the “one-implant-per-patient technique” introduced by Mau (1993) can be used as a simple method to decrease the radiation burden, which is in accordance to the recommendations by the International Commission on Radiological Protection (1991).

In a consensus statement by Lang et al. (2004) it was recommended for the systematic and continuous monitoring of the peri-implant tissue that the following parameters should be used to assess the presence and severity of disease; assessment of plaque accumulation, probing, width of keratinized mucosa, analysis of sulcus fluid, monitoring of suppuration, and if indicated, radiographic evaluation. According to Lang and co-workers, it is appropriate to perform radiography at prosthesis insertion to establish a baseline bone level, while the following radiographic examinations should be based on individual needs and not on predetermined protocols. A cumulative interceptive supportive therapy protocol was suggested with recommendations for radiographs to be taken only on patients having pocket depths >5 mm in combination with bleeding on probing. Our recommendation is that intra-oral radiographs should be taken when it is likely to benefit the patient. We agree with Lang and co-workers that a radiographic examination should be performed at prosthesis insertion to assess baseline data. Intervals between follow-up examinations ought to be determined on the incidence of various pathological changes associated with oral implant treatment and its consequences. Patient-related negative factors regarding bone loss, such as smoking, poor hygiene, history of periodontitis, implants system used, and implant position in the prosthetic restoration should also be taken into account when deciding when radiographs should be taken.

In order to improve the accuracy and precision of radiography, a number of techniques have been developed during the years. These techniques mainly deal with the radiograph in a digital format. Digital radiographs can be electronically generated by means of photo-stimulable phosphor plate techniques, solid-state sensors or digital scanning of film images. Many mathematical algorithms have been proposed for the analysis of digital radiographs. The most successful methods are bone density measurement using bone equivalent standards (Kribbs et al. 1983), digital subtraction (Gröndahl 1987) and fractal analysis (Geraets & van der Stelt 2000). A recently new technique, Tuned Aperture Computed Tomography (TACT) implies promising possibilities to obtain radiographic data in ways hitherto non-existent (Webber et al. 1997). In a study by Nair & Bezik (2006) TACT was compared to conventional digital intra-oral radiography in the detection of induced buccal/lingual alveolar bone defects. They concluded that TACT appears to be the imaging modality of choice for detection of small osseous changes in crestal bone in mid-buccal/lingual sites. Since the introduction of cone beam computed tomography (CBCT) in the late 1990s its usefulness in various discipline of dentistry has been described (Nakagawa et al. 2002, Tsiklakis et al. 2004, Lofthag-Hansen et al. 2007, Suomalainen et al. 2007) because of its relatively low radiation dose (Schultze et al. 2004, Tsiklakis et al. 2005, Ludlow et al. 2006, Lofthag-Hansen et al. 2008) and high image quality. However, Vandenberghe and colleagues (2007) could not find any significant difference between conventional intra-oral radiography and the CBCT technique (i-CAT, Imaging Sciences International, Hatfield, PA, USA) when studying marginal bone loss at teeth in an experimental study. To our knowledge there are no studies using TACT or CBCT in follow-up studies on dental implants. There are, however, reasons to believe that the new techniques will be useful, most likely in research studies when evaluating bone level changes, in particular on buccal and lingual sides of dental implants. The radiation dose is higher than for the conventional intra-oral technique and the equipment is more expensive than for the intra-oral technique.

Conclusions

From the results of these studies the following conclusions were drawn:

- The diagnostic accuracy associated with radiographic evaluation of clinical implant instability in Brånemark implants was found to be high, an accuracy on a level with that of many other radiographic procedures. No specific factor/s with an influence on the diagnostic accuracy could be identified among several investigated.

- Both intra- and inter-observer variations were small. Thus, a high precision was associated with the radiographic examination both as regards radiographic signs indicating clinical implant instability and marginal bone level assessments. Nevertheless, post-operative implant evaluations can benefit from the use of several, independent observers.

- The number of radiographs in which individual implants were displayed had an influence on intra-observer variation and radiographic density and degree of bone loss had an effect on the total observer variation of bone level assessments.

- The marginal bone support at Brånemark implants was with few exceptions stable over the years when following a large group of patients treated at a Swedish specialist clinic. The number of implants with a mean bone level of ≥3 mm increased from 2.8% at prosthesis installation to 17.2% after 15 years.

- Progression rate for implants with advanced bone loss (≥2 mm) was largest during the first year, thereafter slow. Thus, the findings are in accordance with most studies on turned Brånemark implants when including all implants within the patients.

- Several factors were found to have an influence on the marginal bone loss in general at Brånemark implants. The bone loss increased with increasing age at surgery. Larger bone loss was registered for lower jaw compared to the upper jaw and for totally edentulous jaws compared to partially dentate jaws. The position of the implant within the prosthetic construction was found to be important with more bone loss for implants in a middle position compared to an end position.

- A cluster effect was found with more advanced bone loss in few patients. Age, jaw-type and implant placement were identified as predictors for a bone loss of ≥2 mm. Dependency within the patient regarding degree of bone loss was found.

- Radiography, preferably with an intra-oral technique, should be performed at delivery of prosthetic construction to achieve baseline data. Thereafter, it seems safe to exclude radiographic follow-ups during the first 5 years unless patient-related negative factors regarding bone loss exist.

- Regardless of when the radiographic examination is performed high image quality is needed.

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