©

Det här verket är upphovrättskyddat enligt *Lagen (1960:729) om upphovsrätt till litterära och konstnärliga verk*. Det har digitaliserats med stöd av Kap. 1, 16 § första stycket p 1, för forskningsändamål, och får inte spridas vidare till allmänheten utan upphovsrättsinehavarens medgivande.

Alla tryckta texter är OCR-tolkade till maskinläsbar text. Det betyder att du kan söka och kopiera texten från dokumentet. Vissa äldre dokument med dåligt tryck kan vara svåra att OCR-tolka korrekt vilket medför att den OCR-tolkade texten kan innehålla fel och därför bör man visuellt jämföra med verkets bilder för att avgöra vad som är riktigt.

This work is protected by Swedish Copyright Law (*Lagen (1960:729) om upphovsrätt till litterära och konstnärliga verk)*. It has been digitized with support of Kap. 1, 16 § första stycket p 1, for scientific purpose, and may no be dissiminated to the public without consent of the copyright holder.

All printed texts have been OCR-processed and converted to machine readable text. This means that you can search and copy text from the document. Some early printed books are hard to OCR-process correctly and the text may contain errors, so one should always visually compare it with the images to determine what is correct.

GÖTEBORGS UNIVERSITET

ODONTOLOGISKA FAKULTETEN

GÖTEBORGS UNIVERSITET

BONE QUALITY EVALUATION DURING IMPLANT PLACEMENT

BERTIL FRIBERG

D.D.S.

[redacted]

Academic dissertation for the degree of

Master of Dental Science

No 9

BONE QUALITY EVALUATION DURING IMPLANT PLACEMENT

BERTIL FRIBERG

D.D.S.

ODONTOLOGISKA FAKULTETEN · GÖTEBORGS UNIVERSITET

The Brånemark Clinic, Public Dental Health Care,

Department of Handicap Research, and

Department of Oral and Maxillofacial Surgery

University of Göteborg

1994

BONE QUALITY EVALUATIONS
DURING IMPLANT PLACEMENT

LICENTIATAVHANDLING

som med tillstånd av Odontologiska fakulteten vid Göteborgs Universitet för avläggande av licentiatexamen i odontologisk vetenskap kommer att offentligen diskuteras vid examinationsseminarium i demonstrationssal 1, Odontologiska kliniken, Göteborg, Torsdagen den 15 december, 1994, klockan 13.00.

av

BERTIL FRIBERG

Leg. tandläkare

Avhandlingen baseras på följande delarbeten:

I. Friberg, B., Jemt, T. & Lekholm, U. (1991) Early failures in 4641 consecutively placed Brånemark dental implants. A study from stage I surgery to the connection of completed prostheses. Int J Oral Maxillofac Implants: 6:142-146.

II. Friberg, B., Sennerby, L., Roos, J., Johansson, P., Strid, CG. & Lekholm, U. (1994) Evaluation of bone density using cutting resistance measurements and microradiography. An in vitro study in pig ribs. Clinical Oral Implants Research (accepted for publication).

III. Friberg, B., Sennerby, L., Roos, J. & Lekholm, U. (1994) Identification of bone quality in conjunction with insertion of titanium implants. A pilot study in jaw autopsy specimens. Clinical Oral Implants Research (accepted for publication).

This thesis was supported by grants from:

The Greta and Einar Asker Foundation,

The Wilhelm and Martina Lundgrens Research Foundation,

The Faculty of Odontology, University of Göteborg.

CONTENTS

INTRODUCTION

Osseointegrated oral implants, as originally defined for the Brånemark system (Brånemark et al 1977), are today extensively used around the world also via other implant systems, such as e.g. IMZ, ITI, and Astra (Babbush et al 1989, Buser et al 1991, Arvidson et al 1992). Regarding the Brånemark technique, a series of reports have been published focusing on its successful long-term results (van Steenberghe et al 1987, Albrektsson et al 1988, Zarb & Schmitt 1989, Adell et al 1990, Henry et al 1993, Nevins & Langer 1993, Jemt & Pettersson 1993, Ekfeldt et al 1994). Despite a meritorious treatment outcome, one must still expect to encounter complications and failures, when wielding the procedure (Lekholm et al 1985, Worthington 1987, van Steenberghe 1991, Zarb & Schmitt 1990, van Steenberghe 1991, Jemt 1991). Along with extreme jaw bone resorption, soft bone quality have been the parameters most frequently judged as the causes of implant (fixture) losses (Engquist et al 1988, Jaffin & Berman 1991, Triplett et al 1991, Sennerby 1991, Jemt 1993, Jemt & Lekholm 1995). Consequently, a proper evaluation of the bone characteristics is needed, both pre- and peroperatively, in order to find patients at risk for implant failures. By doing so, it might be possible to adapt both the surgical technique as well as the length of the healing period to the current bone situation, thereby minimizing the number of complications.

At present, however, a description of jaw bone characteristics will predominantly focus upon size and shape of different anatomical structures. Furthermore, jaw bone quality may not be expressed without a certain amount of subjectivity, and the opinion will mainly be based on quantitative measures. Studies have thereby been carried out to describe the edentate jaws, with regard to anatomy and age-related changes of both outer and inner bone dimensions in presumptive implant regions. Cawood and Howell (1988) e.g., when classifying the edentulous jaw shape, found the macroscopic bone resorption of the alveolar process to follow a predictable pattern. A significant change in shape was shown in both the vertical and horizontal axes of maxillae and mandibles. Through mapping of inner bone structures of mandibles, von Wowern (1977 a + b) was able to show a decrease in buccal cortical bone mass and trabecular bone density from incisor to premolar to molar regions. While the cortical porosity increased with age, no such change was, however, revealed within the trabecular bone (von Wowern 1978). Even though these reports tend to characterize the jaw bone, very little is really said about the bone quality per se. Far more information is instead available regarding the human axial and peripheral skeleton, knowledge which can be obtained from the osteoporosis literature (Cummings 1985, Compston 1990, Melton 1990).

Definitions of the term bone quality

With regard to the implication of bone quality, a clear definition has still not been presented. Stulberg et al (1989) for example, found the expression to be an imprecise term. They stressed that the mechanical performance of the bone depended on the bone mass and on the ability of the bone to adapt to specific loads. In the long term, they considered that the remodelling capability of the bone could be of equal or greater importance. Thus, the authors preferred the term bone strength, when describing the mechanical characteristics of the bone.

In a review article, Martin (1991) related the strength and stiffness of the bone to its shape and size, and to the mechanical properties of the structures within the hard tissues. The latter was assumed to depend on the composition and organization of the bone. The composition was discussed in terms of porosities or voids, filled with soft tissue, and the state of bone mineralization. With regard to organization, the trabecular and cortical bone architecture, the collagen fibre orientation, and microdamage, were said to be influencial factors.

Einhorn (in Wallach et al 1992) described the bone quality via parameters, measuring the mechanical properties of the bone under load, such as elastic modulus, stiffness, strength, and strain. Stiffness was thereby referred to as the capability of bone to accept mechanical load, and strength as the maximum stress, which the bone could take immediately prior to fracture. The strain, defined as the deformation of bone under load in tension, could either be an elastic, reversible deformation or, when overloaded, be a plastic and irreversible one, up to the point of fracture.

According to Hayes (in Wallach et al 1992), the bone quality was sometimes related to various aspects of bone morphology, such as microdamage, trabecular dimensions and contiguity, as well as to the state of mineralization. He also claimed that few data supported a relationship between these quality characteristics and the mechanical properties of the bone.

From a clinical standpoint of implant treatment, a more practical definition may be suggested, where the bone quality is rated according to the hardness, experienced during drilling. Such a subjective opinion of bone density may, in turn, be dependent on the state of mineralization, the coarseness and contiguity of the trabecular bone, and the width of the cortical layers, and thus, it is very much correlated to the experience of the performing surgeon.

Techniques available for measurements of jaw bone quality

A radiographic examination of the jaw bone, in the treatment planning for implants, may comprise standard intraoral radiographs, an orthopantomogram, a lateral cephalostatic view, and at times, tomographic images (Brånemark et al 1985). The tomographs, which can be obtained either with a conventional technique (Eckerdal & Kvint 1986, Gröndahl et al 1991, Tammisalo et al 1992), or with a computed technique (Andersson & Svartz 1988, Quirynen et al 1990), are mainly required when investigating the maxilla and the posterior mandible. With regard to the absorbed dose and energy imparted, these have been found to be low for both spiral and hypocycloidal tomography (Ekestubbe et al 1992). However, Clark et al (1992) found the absorbed radiation dose to be considerably higher with the computed tomography (CT) than with the conventional one. All the radiographs together, including tomographs, may yield extensive data of anatomical characteristics, such as e.g. the structures of the nasal cavity, the incisive canal, the sinuses, the mandibular canal, the mental foramina, etc. Along with these landmarks, the images offer a possibility to decribe the jaws with regard to volume and composition of compact and cancellous bone, as well as in terms of pathology. By applying the proposed **classification of jaw bone quality** (Lekholm & Zarb 1985) to the radiographic images, it may be possible to rate the quality from 1 to 4, depending on the amount of cortical and trabecular bone present. Together with explorative drilling of fixture sites, a more complete but still subjective picture of the bone quality can be obtained. However, only a rough mean value will be presented for each examined jaw. To overcome this, Jensen (1989) suggested a classification of individual bone sites, relating to a number of jaw bone characteristics. A density index, based upon the quality classification by Lekholm and Zarb (1985), has also been presented (Misch 1990), however both latter indices have not been in common use.

Comments: When planning for oral implants the subsequent treatment will, to a high extent, be based on the radiographic examination. In this sense, tomography may add information, which will render a more complete view of the preoperative status. CT may reveal more information via paraxial reformattings of the alveolar crest, compared to conventional tomography. However, apart from the absorbed radiation dose, additional disadvantages of CT have been described by Clark et al (1992), such as the limited availability and accessibility of the CT units, and the cost per examination. With regard to the quality classification by Lekholm and Zarb (1985), the radiographs used and rated, provide for quantitative information only, since they describe the cortical width and the density of the trabecular bone present. The method is associated with drawbacks, due to that only one value is given for the entire jaw. Moreover, it is based upon the personal experience and the subjective opinion of the surgeon.

With the use of **Houncefield units (HU) in quantitative computed tomography (QCT)** (Andersson & Kurol 1987, Berman 1989), a density value can be assigned each picture element (pixel) of the computer calculated jaw image. A value of - 1000 HU corresponded to air, 0 HU to water, and + 1000 HU was regarded to be dense cortical bone. The obtained numbered units of the bone might serve as an indicator of the resistance to be anticipated during drilling. With QCT, density measurements of cortical and trabecular bone can be performed separately (Taguchi et al 1991, Klemetti et al 1993 a). This may, in turn, be an important piece of information in the treatment planning phase, since most implants will be inserted in, and come in contact with, both cortical and cancellous bone. Some studies have been performed on mandibles to quantify the bone mineral density of osteoporosis patients (Klemetti 1993 a+b+c), but the main indication for QCT has been for measurements of the axial skeleton (Alhava 1991, Greenfield 1992, Jonson 1994).

Comments: Many CT scanners can produce the bone density in Houncefield units. Regarding the jaw regions, few reports describe its use together with implant placement (Andersson & Kurol 1987, Berman 1989). The method may be associated with drawbacks, such as a high absorbed radiation dose, as well as a high cost per examination. The technique is also circumstantial and time consuming in the effort to find representative jaw regions, when planning for implants. When screening patient groups for reference values, the scanners must use the same calibration standard (phantom), otherwise the obtained figures of bone mineral content may not be comparable (Jonson 1994).

Techniques, to estimate bone density of mainly axial or appendicular skeleton, using **ionizing beams** from either isotopes or X-ray tubes (Dual-energy Photon Absorptiometry, DPA, and Dual-energy X-ray Absorptiometry, DXA), relate only to the mineral content and do not give expression to the bone quality present (Alhava 1991). Osteopenia e.g., is a condition characterized by low bone density, the latter being frequently seen also in osteoporosis (Melton 1990). One main difference between the two conditions could be that the osteoporotic patient has experienced fractures, or may be at risk for such conditions, which is not the situation for the patient with osteopenia. The aforementioned ionizing beam methods may, however, not present a differential diagnosis of the two conditions, since a quality factor is not measured with the techniques (Alhava 1991).

With DPA and DXA, utilizing two energy levels, most parts of the skeleton may be evaluated with regard to bone mineral content (Greenfield 1992, Jonson 1994). Von Wowern (1988) used DPA to examine the in vivo relationship of bone mineral content (BMC) of mandibles, forearms, and lumbar spine. A significant correlation of BMC was found between forearms and lumbar spine, but no corresponding relationship with these regions and the mandible could be seen. The conclusion was that BMC changes of mandibles could only be evaluated by investigations of the mandible itself. In relation to treatment with osseointegrated ITI-implants supporting overdentures (von Wowern et al 1990), BMC was measured with DPA in different mandibular regions, 3 weeks and 2 years postoperatively. The authors concluded that the implant treatment caused a load-related bone formation, which could minimize or even counteract, the physiologic age-related BMC loss seen in osteoporosis. An attempt to measure mandibular bone mineral density (BMD) ex vivo and in vivo by DXA was performed by Corten et al (1993). Even though it was mentioned that the method needed improvement of its reproducibility, they stated it would be possible to define an average mandibular BMD in categories of normal reference populations and in patients.

Comments: The DPA- and DXA- techniques have had a limited use in jaw bone diagnostics so far. With DPA, the source of ionizing beams (isotopes) must be exchanged annually to a high cost, why most scanners are being replaced by DXA. The radiation dose is reported low for both techniques (von Wowern 1985, Corten 1993). Even though, the bone mineral density is a quantitative measure (Alhava 1991), it is regarded to have a relationship with compressive strength and elastic modulus of bone (Martin 1991), both being looked upon as quality parameters (Einhorn, in Wallach et al 1992).

The noninvasive method of measuring **ultrasound attenuation and velocity** in heel bone and forearm has been claimed possible to use for bone quality determination (Greenfield 1992, Antich et al 1993, Jonson 1994). With the investigated bone placed in between a transmitting and a receiving transducer, the attenuation of ultrasound is registered by a computer (Greenfield 1992). According to Jonson (1994) the ultrasound velocity is influenced by the orientation of the trabeculae, and is also dependent on modulus of elasticity and bone density (Buckingham 1992, Antich 1993).

Comments: So far, no information is available regarding the use of ultrasound for evaluation of the jaw bone characteristics. Sonographic measurements of the alveolar bone topography and width have been performed with mixed results (Palou et al 1987, Traxler et al 1992). In other parts of the human peripheral skeleton, ultrasound measurements are said to be of value for bone quality determination (Greenfield 1992, Antich 1993, Jonson 1994), and to predict the risk of fractures in osteoporosis.

Jaw **bone biopsies** may be used for morphology evaluation. However, due to the invasive character of the procedure, it does not seem practical to obtain a bone sample from every patient preoperatively. Furthermore, it has been reported that biopsies from mandibles are not representative, when using microradiographed ground sections for bone mass analyses (von Wowern 1977 a+b). The trabecular bone may show a great intraindividual variation in bone mass and coarseness, and thus, a single biopsy may not be used, when general information of the jaw region is wanted. A similar variation was seen for the buccal alveolar cortex. The results are in accordance with the findings of de Vernejoul et al (1981), who removed biopsies from 4 regions of the iliac crest in 16 females, and showed an intraindividual variation of 15%.

Comments: To improve the available information of a presumptive implant site, a bone biopsy may be taken, although it will require an extra surgical intervention and time for evaluation. Furthermore, to have a representative sample, it must be obtained close to the region of interest. The main indication for bone biopsies, thus, may be to evaluate the presence of bone disease, such as osteomalacia (Jonson 1994).

General remarks on techniques identifying bone quality

In the absence of a clear definition of bone quality, it may be difficult to fully value the methods available for bone quality investigation. Nevertheless, the aforementioned techniques mainly express the bone characteristics in quantity measures, either by rating the bone structures obtained from radiographs, or by analysing the bone mineral content. Although, a bone biopsy may reveal the histomorphology, it seems to be of no practical use in routine implant treatment. Consequently, there seem still to be a need for a simple and reliable method, which can peroperatively be used for an objective evaluation of the bone hardness present in individual implant sites, as an addition to the conventional radiographic examinations.

A possible future technique to identify bone quality

The method to measure **true cutting resistance** during low speed threading (Johansson and Strid 1994) has proven to be a possible technique for evaluation of bone quality. The technique is performed in such a way that the electric current consumed during low speed threading is registered by a computer, connected to the motor unit, thereby determining the total measured torque used. Via computer calculation procedures, it is thereafter possible to subtract the friction part of the torque, as well as the contribution of bone shiver packing in deeper holes. The true cutting resistance, corresponding to the remaining part of the torque and measured in mJ/mm^3, has been said to express the bone quality in terms of "energy required to cut away a unit volume of bone". In the study by Johansson and Strid (1994), test slabs of bovine bone were radiographed in areas where holes had been tapped and measured. Subsequently, the radiographs were assessed, using an aluminum-reference to identify the density. A good agreement was found between values of the true cutting resistance and of the aluminum-referred density obtained from the radiographs.

The most encouraging results of this technique may open for future clinical possibilities to obtain an objective measure, expressing the bone quality in terms of bone hardness.

AIMS OF THE INVESTIGATION

Three studies have been included in this research project, and the separate aims of these were as follow:

- to study the frequency of early implant failures of the Brånemark implant technique; and to relate this outcome to various patient characteristics and implant lengths and positions.

- to test the reliability of the true cutting resistance method (Johansson and Strid 1994) in simulated clinical situations, using two investigators, different hand pressure, and deviating tapping directions; and to perform bone area measurements for evaluation of homogeneity of bone samples; and to correlate bone density values with the true cutting resistance measurements.

- to investigate the applicability of the true cutting resistance method in different jaw regions of post mortem human mandibles and maxillae; and to correlate bone area and bone density measurements of microradiographs with the true cutting resistance values from the same jaw sites.

OVERVIEW OF MATERIALS AND METHODS

Study I: Early implant failures

A total of 889 consecutive patients, representing both complete and partial edentulism and treated with a standard Brånemark technique during a three-year period, were included in the study. Treated patients, comprising 4641 fixtures in 943 jaws, were followed from fixture insertion to the connection of prosthetic constructions. Jaw and sex distributions showed a preponderance of mandibles (564/943) and females (510/889), and the patient mean age was 57.5 years.

The preoperative examination and surgical treatment followed the standard protocol (Adell et al 1981). Fixture length and position, as well as jaw bone quantity and quality (according to Lekholm and Zarb 1985), were recorded at implant placement, together with other important information on the surgical procedure.

In cases where fixtures failed to osseointegrate, patient files were retrospectively examined with regard to remarks on patient and implant data, errors and complications during surgery, initial implant stability, bone defects at implant sites due to severe resorption or insufficient bone regeneration after tooth extraction, postoperative wound infection, and/or insufficient healing.

Study II: Reliability test

For evaluation of the true cutting resistance technique (Johansson & Strid 1994), seventeen pig ribs of acceptable homogeneity were used as test samples. The study was executed by two investigators to evaluate the influence on registered torque values, when tapping with different hand pressure and with deviating tapping direction. In each pig rib bone, three preparations were made, and the low speed threading was performed in three different ways; i.e. with a standard technique, with an extra weight of 0.5 kg, and with 5 degrees deviation from the vertical plane. During these procedures the total torque was registered by a computer. Thereafter, one implant was inserted in each rib, i.e. into the site being threaded the standard way. Specimens, including the fixture and the surrounding bone tissues, were then taken and fixed. After dehydration, the samples were embedded and sectioned for subsequent microradiography, and analysed with regard to bone density and bone morphometry, as described below.

The analysis of the microradiographs was carried out with the use of a microscope, equipped with a computer connected video camera. The light transmittance of each image was captured by the video camera and the video signal was converted into a 256 level gray scale in a matrix of 768 x 512 pixels, and monitored on a computer screen. A mean density profile was obtained from each specimen by an analysing computer programme, expressing the bone distribution along two 0.35 mm wide corridors, situated on each side of the implant. Density profiles and torque profiles were compared, and the distances from the start of the graphs, corresponding to the reference point of the implant, to the maximum and minimum density/torque peaks were calculated.

With the same computer programme, the amount of total bone, trabecular bone, and cortical bone, respectively, were quantified in two 0.7 mm wide corridors and expressed as % bone area of the corridors, in order to elucidate any possible homogeneity of the test samples.

Study III: Applicability test

To further evaluate the applicability of the technique of Johansson & Strid (1994), 31 implant sites were prepared with subsequent cutting resistance measurements during low speed threading in 10 post mortem human jaws (6 maxillae and 4 mandibles). Mean cutting resistance values for the total upper and lower jaw samples, as well as for various jaw regions, were calculated. After fixture insertion, specimens including the implant and surrounding bone tissues, were prepared and microradiographed as in Study II.

Density calculations and bone area measurements were executed according to the same principles as in Study II, and correlations between torque and density profiles, together with correlations between mean torque values and total bone area values, were accomplished.

Statistics

No statistical analyses were performed in Study I, since it was designed to be reported as a descriptive paper.

The reproducibility of the morphometric analysis (Study II) was tested by repeating the measurements once in six specimens with three weeks interval.

Mean values, standard deviations, and confidence intervals of the 0.95

probability level were calculated in relation to the histomorphometric measurements. The Student's t distribution was thereby used.

Differences between tapping procedures and between the investigators (Study II) were statistically tried with paired Student's t-test and a nonparametric test. Similar tests were used for comparison of mean true cutting resistance figures, as well as of total bone area values of mandibles and maxillae (Study III).

Spearman's Correlation Rank Test was used for correlation analyses in both Study II and III.

RESULTS AND DISCUSSION

Study I: Factors related with implant failures

Out of the 4641 inserted implants, 69 fixtures (1.5%), in 57 jaws (6.0%), were found mobile before the connection of the prosthetic constructions. No typical pattern of the outcome, with regard to patient characteristics, such as age or gender, was seen. Of registered failures, most losses were observed in edentulous maxillae (46/69), and short 7 mm implants predominated (37/46). Fixtures placed in terminal positions of the upper jaw, i.e. mainly in premolar regions, failed to a higher degree (4.9%) than in other locations. The corresponding figures for implants in central positions, i.e. closest to the midline, and intermediate ones, i.e. in the canine strut region, were 3.0% and 0.9%, respectively.

With regard to edentulous mandibles, 15 fixture losses were registered, of which 6 were 7 mm long implants. No specific location for failures was found in the lower jaw.

Of the remaining 8 fixture losses, 5 were present in partially edentulous maxillae and 3 (one 7 mm) in corresponding mandibles. No obvious pattern concerning size and position of failing implants was seen in patients with partial edentulism.

When referring to jaw bone shape, the groups D and E with severe to extreme resorption (Lekholm & Zarb 1985), showed the highest failure rates for both jaws, 17.4% (23/132) in maxillae and 7.0% (6/85) in mandibles.

By rating jaw bone quality (Lekholm & Zarb 1985), it was revealed that a majority of the maxillary implant losses were seen in connection with soft bone, as 40% of the treated jaws judged as quality 4, were involved. In mandibles, the failures occurred more often (13%) in very hard bone, judged as quality 1.

The total failure rate of 1.5% (69/4641) was regarded most encouraging, since the outcome was derived from a material including a large number of maxillary implants (1729/4641). The result corresponded well with, and even exceeded, what has been found in previous studies (Adell et al 1981, van Steenberghe et al 1987, Cox & Zarb 1987, Engquist et al 1988, Adell et al 1990). Irrespective of the good result, most failures were still observed in edentulous maxillae and among the 7 mm implants, which coincide well with other reports (Lekholm 1992, Jemt 1993, Nevins & Langer 1993).

The different outcome of various locations in maxillae, with the low failure figure for intermediately placed implants, may be explained by a better bone support normally achieved in the canine strut region. In edentulous mandibles, on the other hand, no such pattern could be seen, probably due to a more uniform bone situation in between the mental foramina, resulting in that inserted implants can be of equal size and supported by two well-defined cortical layers.

The fixture losses in patients with partial edentulism were too few to be used for conclusions, as only 1.7% (8/470) of the implants failed to osseointegrate. However, similar good results have later also been shown by Jemt & Lekholm (1993).

It was not surprising to find the majority of the jaws with failing fixtures to be severely resorbed (Groups D and E), since the short 7 mm implant represented the highest figures for losses in both maxillae and mandibles. Furthermore, the results of failures, related to the jaw shape, were in accordance with other studies (Engquist et al 1988, Triplett et al 1991, Jemt 1993).

With regard to bone quality, the high incidence of failures in soft bone of maxillae, observed in the current study, has also been verified by Jaffin and Berman (1991), who lost 44% of the maxillary fixtures inserted in quality 4 bone during a 5-year period. Regarding the higher rate of mobile implants in hard and dense mandibular bone, on the other hand, that might be explained by the increased risk of overheating the bone during high speed preparation of implant sites. The latter may also have contributed to the somewhat higher failure rate reported by Triplett et al (1991), for extremely resorbed mandibles.

It was concluded from Study I that small bone volumes and/or soft bone qualities were the parameters most frequently related with failing implants. Consequently, it must be important to acquire good knowledge regarding these parameters both pre- and peroperatively.

Study II: Cutting resistance reliability

When comparing the mean true cutting resistance values of the three low speed threading modalities tested in the pig ribs, no significant differences were revealed ($p > 0.05$). A similar finding was also seen when comparing the cutting resistance values of the two investigators ($p > 0.05$). It can therefore be stated that, in this study, it was not possible to find any influential effect of the surgeons, neither when applying high or low hand pressure, i.e. with or without an extra load upon the drilling unit, nor when diverging from the original preparation direction, i.e. by threading with 5 degrees deviation from the vertical plane. In the clinical situation such findings may be interpreted in the way that the registered torque values had been the same, if the low speed threading procedure had been executed by two independent clinicians performing differently.

The videodensitometric technique, using 0.7 mm wide corridors along each side of the implant for bone area measurements, was found to have a good precision (± 1.12%). By calculating the mean values of total, compact, and trabecular bone, respectively, together with the standard deviations and confidence intervals of the 0.95 probability level, a certain homogeneity of the samples was indicated. Thereby, the pig ribs were considered to be of use for the cutting resistance measurements.

Regarding the measurements of the mean distances from the start of the torque registration to the first and second maximum as well as to the minimum torque peaks of the pig ribs, a good agreement was seen with the corresponding distances to the maximum and minimum density peaks of the microradiographs ($p < 0.05$). Furthermore, the calculation of the mean values, standard deviations, and confidence intervals of the 0.95 probability level, for the aforementioned distances emphasized the homogeneity of the samples. The agreement between torque and density peaks is in accordance with what was reported by Johansson & Strid (1994), who used bovine bone slabs for radiographic examination with subsequent implant site preparation. In the areas of the tapped holes, they used the radiographs to assess the aluminum referred density. By inspecting the diagram obtained, a relationship was seen between the true cutting resistance and the bone density, though not statistically tried. Higher true cutting resistance figures coincided with higher bone density values, i.e. more energy was required to cut dense bone. Increased bone density, however, does not necessarily imply improved bone quality (Mosekilde et al 1987). A high daily fluoride intake can increase the bone density, but may not always be accompanied by an increase in bone strength.

It was concluded from Study II that the true cutting resistance technique proved to be reliable, and the values correlated well with the density measurements of bone surrounding the implants. Indications for a further applicability test on post mortem human jaw bone were therefore at hand.

Study III: Cutting resistance applicability

The mean true cutting resistance values were significantly higher for post mortem human mandibles compared to the corresponding maxillary ones ($p < 0.001$). There were also tendencies of a decrease in cutting resistance towards posterior (i.e. premolar) regions bimaxillary.

The morphometrical measurements of the total bone area, in the corridors along the implants, revealed a higher mean value for mandibles compared to maxillae ($p < 0.001$). The compact/cancellous bone ratio was also significantly higher for mandibles ($p < 0.05$), whereas a tendency towards decreasing bone volumes in posterior (i.e. premolar) regions was seen for both jaws. This may partly explain the outcome seen in Study I, where more implants were lost in maxillae, especially in premolar regions. The findings of von Wowern (1977 a+b), who showed that the trabecular bone was more dense and delicately woven, in mandibular incisor regions compared to premolar and molar ones, and who also showed that the bone mass of the buccal alveolar cortex decreased in posterior direction, further support this assumption.

Values of mean total bone area and mean true cutting resistance showed a statistically significant correlation ($p < 0.001$). Hence, the larger volume of bone the more torque required, which was also stated by Johansson & Strid (1994). An expression for bone quality, derived from the cutting resistance calculations of the bone, was by them said to be the energy consumed for cutting one full turn of a thread divided by the volume of bone substance thus removed.

When evaluating the distances to the peaks of maximum bone density and true cutting resistance, a statistically significant correlation ($p < 0.001$) was found. Consequently, the true cutting resistance technique was applicable when identifying bone density variations of post mortem human jaws, with their specific brittle bone character. If the same holds true also in patients has not yet been elucidated, but clinical trials have been initiated including an adaptation of the procedure, so it may be used together with the Mark II selftapping fixture.

In conclusion, when comparing the cutting resistance technique with the previously mentioned preoperative examination methods used for bone quality identification, it can be concluded that the cutting resistance procedure may serve as a good complement, being both simple and reliable, when peroperatively evaluating jaw bone hardness as an expression for the bone quality.

CONCLUDING REMARKS

Study I

- higher implant failure rates were seen in terminal positions of the maxillae, i.e. most frequently in premolar regions, in connection with small bone volumes and soft bone qualities.

- no such failure locations could be observed regarding the mandible.

- the short 7 mm fixture failed to a higher extent in both jaws than other implant lengths.

- fixture failures did not correlate with age and sex of the patient.

Study II

- the true cutting resistance technique was found to be a reliable method, insensitive to differences in hand pressure and tapping direction, as well as to different investigators, when tested in acceptably homogeneous rib samples.

- a significant correlation was seen between values of true cutting resistance and bone density measurements of pig ribs.

Study III

- higher cutting resistance values, as well as total bone area figures, were seen in mandibles compared to maxillae, with a tendency of decreasing values towards posterior (i.e. premolar) regions.

- a significant correlation was seen between values of true cutting resistance and bone density measurements, as well as with true cutting resistance and total bone area calculations.

- the applicability of the method was judged favourable for future clinical investigation.

CLINICAL IMPLICATIONS

The results of this investigation imply a need for recommendations how to clinically handle special bone situations.

During fixture placement, the primary goal is to achieve initial implant stability, which may be difficult to obtain when small bone volumes of spongy qualities are at hand. One possible way to overcome such problems when occurring in maxillae is to engage the cortical bone of the floor of the nasal cavity and sinuses, which together with the marginal cortex will render a bicortical anchorage (Ivanoff et al 1990). A further option could be to choose wider implants, of the 5 mm diameter (Langer et al 1993), which might be possible when sufficient bucco-palatal dimensions are at hand. A standard high speed drill set, including the countersink but without the low speed screw tap, is thereby used. In cases of narrow alveolar ridges, on the other hand, a twist drill of less diameter (2.85 mm) is recommended prior to the insertion of the 3.75 mm diameter implant. To improve bone volumes, local onlay and/or inlay grafting, have also been proposed (Breine & Brånemark 1980, Jensen et al 1991, Hirsch & Ericsson 1991, Schliephake et al 1994), so far with short-term results only. To make full use of available bone in more anterior positions, i.e. the canine strut region, it can be suggested that the intermediate and the terminal implants should be inserted with converging apices, thereby providing for a longer posterior fixture. This may reduce the higher failure rate, which was observed for short terminal fixtures.

In mandibles with very dense and hard bone, emphasis must be given to the need for an intermittent drilling technique and for excessive cooling with saline. Also the use of a wider twist drill (3.15 mm) is recommended, especially when preparing deeper bone sites, since the packing of bone shivers around the implant may act as an additional torque during insertion (Johansson & Strid 1994). In locations with soft mandibular bone, the basal compact layer should whenever possible be engaged for stabilization of the implant also in that jaw. In posterior regions, however, where the mandibular nerve canal will prevent the implants to reach a second cortex and where a thin marginal cortical layer may be at hand, a minimum of countersinking is recommended. If the buccolingual dimension may allow for a wider fixture (e.g. 5 mm diameter, Langer et al 1993), also the buccal and lingual cortices can be utilized for obtaining primary stability. In the absence of a sufficient vertical bone height above the canal, a transposition procedure of the inferior alveolar nerve, with subsequent implant insertion, has been suggested (Rosenquist 1992, Friberg et al 1992).

When handling situations with soft bone qualities, the unloaded healing period could also be prolonged. This is a statement partly based on a study by Johansson and Albrektsson (1987), who in rabbit bone found the required fixture removal torque, to increase during a 12 month period with a corresponding increase in bone to implant contact when analyzed histomorphometrically. A similar increase in fixture removal torque was found, during a 6 month period by Sennerby et al (1992), with the insertion of implants into the cancellous femoral bone of rabbit knee joints. Also in that study it was shown that the bone to implant contact increased during healing. Both the aforementioned studies show the importance of the time factor for osseointegration of implants, at least up to 6 months, though determined in rabbit bone. Whether the timetable is applicable to the human bone is not fully understood, and perhaps an even longer unloaded healing period is needed in patients sometimes. Based on the two reports and on acquired clinical experience of the Brånemark group, a healing period of up to 12 months in maxillae and of up to 6 months in mandibles might be recommended in compromised bone quality situations. The cutting resistance technique could thereby be a valuable additional tool for the unexperienced surgeon to obtain peroperative information, which may help to estimate a proper healing period. The implant site with the most soft bone quality, represented by the lowest torque value registered, may then determine the intermediate time needed to achieve osseointegration with sufficient capacity to carry load.

During follow-up of implant patients, with clinical and radiographic examinations at certain intervals, the implants placed in extreme bone shape/quality situations should require extra attention.

REFERENCES

Adell R, Lekholm U, Rockler B, Brånemark P-I 1981. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surgery; 10: 387-416.

Adell R, Eriksson B, Lekholm U, Brånemark P-I, Jemt T 1990. A long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants; 5: 347-359.

Albrektsson T et al 1988. Osseointegrated oral implants. A Swedish multicenter study of 8139 consecutively inserted Nobelpharma implants. J Periodontology; 59: 287-296.

Alhava EM 1991. Bone Density Measurements. Calcif Tissue Int; 49: 21-23.

Andersson L, Kurol M 1987. CT scan prior to installation of osseointegrated implants in the maxilla. Int J Oral Maxillofac Surg; 16: 50-55.

Andersson JE, Svartz K 1988. CT-scanning in the preoperative planning of osseointegrated implants in the maxilla. Int J Oral Maxillofac Surg; 17: 33-35.

Antich PP, Pak CYC, Gonzales J, Anderson J, Sakhaee K, Rubin C 1993. Measurement of intrinsic bone quality in vivo by reflection ultrasound: Correlation of impaired quality with slow-release sodium fluoride and calcium citrate. Journal of Bone and Mineral Research; 8: 301-311.

Arvidson K, Bystedt H, Frykholm A, von Konow L, Lothigius E 1992. A 3-year clinical study of Astra dental implants in the treatment of edentulous mandibles. Int J Oral Maxillofac Implants; 7: 321-329.

Babbush CA, Kirsch A, Mentag PJ, Hill B 1989. Intramobile cylinder (IMZ) two-stage osteointegrated implant system with the intramobile element (IME): Part I. Its rationale and procedure for use. Int J Oral Maxillofac Implants; 2: 203-216.

Berman CL 1989. Complications, prevention, recognition, treatment. Dental Clinics of North America; 33: 635-663.

Breine U, Brånemark P-I 1980. Reconstruction of alv eolar jaw bone. Scand J Plast Reconstr Surg; 14: 23-48.

Brånemark P-I, Hansson B-O, Adell R, Breine U, Lindström J, Hallin O, Öhman A 1977. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plastic Reconstr Surg 16 (Suppl).

Brånemark P-I, Zarb GA, Albrektsson T 1985. Tissue-integrated prostheses: Osseointegration in clinical dentistry, Chicago, Quintessence Publishing Co.

Buckingham SHW, Jeffcott LB, Anderson GA, McCartney RN 1992. In vivo measurement of bone quality in the horse: estimates of precision for ultrasound velocity measurement and single photon absorptiometry. Med & Biol, Eng & Comput; 30: 41-45.

Buser D, Weber HP, Brägger U, Balsiger C 1991. Tissue integration of one-stage ITI implants: 3-year results of a longitudinal study with hollow-cylinder and hollow-screw implants. Int J Oral Maxillofac Implants; 6: 405-412.

Cawood JI, Howell RA 1988. A classification of the edentulous jaws. Int J Oral Maxillofac Surg; 17: 232-236.

Clark DE, Danforth RA, Barnes/Monte RW, Burtch L 1990. Radiation absorbed from dental implant radiography: A comparison of linear tomography, CT scan, and panoramic and intraoral techniques. Journal Oral Implantology; 16: 156-164.

Compston JE 1990. Review osteoporosis. Clinical endocrinology; 33: 653-682.

Corten FGA, van T Hof MA, Buijs WCAM, Hoppen brouwers P, Kalk W, Corstens FHM 1993. Measurement of mandibular bone density ex vivo and in vivo by Dual-Energy X-ray Absorptiometry. Archs Oral Biol; 38: 215-219.

Cox JF, Zarb GA 1987. The longitudinal clinical efficacy of osseointegrated dental implants: A 3-year report. Int J Oral Maxillofac Implants; 2: 91-100.

Cummings SR 1985. Are patients with hip fractures more osteoporotic? Review of evidence. The Americal Journal of Medicine; 78: 487-494.

de Vernejoul MC, Kuntz D, Miravet L, Goutallier D, Ryckewaert A 1981. Bone histomorphometric reproducibility in normal patients. Calcif Tissue Int; 33: 369-374.

Eckerdal O, Kvint S 1986. Presurgical planning for osseointegrated implants in the maxilla. Int J Oral Maxillofac Surg; 15: 722-726.

Ekestubbe A, Thilander A, Gröndahl HG 1992. Absorbed doses and energy imparted from tomography for dental implant installation. Spiral tomography using the Scanora ® technique compared with hypocycloidal tomography. Dentomaxillofac Radiol; 29: 65-69.

Ekfeldt A, Carlsson GE, Börjesson G 1994. Clinical evaluation of single-tooth restorations supported by osseointegrated implants: A retrospective study. Int J Oral Maxillofac Implants; 9: 179-183.

Engquist B, Bergendahl T, Kallus T, Lindén U 1988. A retrospective multicenter evaluation of osseointegrated implant supporting overdentures. Int J Oral Maxillofac Implants; 3: 129-134.

Friberg B, Ivanoff CJ, Lekholm U 1992. Inferior alveolar nerve transposition in combination with Brånemark implant treatment. Int J Periodontics Rest Dent; 12: 441-449.

Greenfield MA 1992. Current status of physical measurements of the skeleton. Med Phys; 19: 1349-1357.

Gröndahl K, Ekestubbe A, Gröndahl HG, Johnsson T 1991. Reliability of hypocycloidal tomography for the evaluation of the distance from the alveolar crest to the mandibular canal. Dentomaxillofac Radiol; 19: 200-204.

Henry PJ, Tolman DE, Bolender C 1993. The applicability of osseointegrated implants in the treatment of partially edentulous patients: Three-year results of a prospective multicenter study. Quintessence Int; 24: 123-129.

Hirsch JM, Ericsson I 1991. Maxillary sinus augmentation using mandibular bone grafts and simultaneous installation of implants. Clin Oral Impl Res; 2: 91-96.

Ivanoff CJ 1990, 25th Anniversary Brånemark Implant System

Jaffin RA, Berman CL 1991. The excessive loss of Brånemark fixtures in type IV bone: A 5-year analysis. J Periodontology; 62: 2-4.

Jemt T 1991. Failures and complications in 391 consecutively inserted fixed prostheses supported by Brånemark implants in edentulous jaws: A study of treatment from the time of prosthesis placement to the first annual check-up. Int J Oral Maxillofac Implants; 6: 270-276.

Jemt T 1993. Implant treatment in resorbed edentulous upper jaws. A three-year follow-up study on 70 patients. Clin Oral Impl Res; 4: 187-194.

Jemt T, Lekholm U 1993. Oral implant treatment in posterior partially edentulous jaws: A 5-year follow-up report. Int J Oral Maxillofac Implants; 8: 635-640.

Jemt T, Pettersson P 1993. A 3-year follow-up study on single implant treatment. J Dent; 21: 203-208.

Jensen O 1989. Site classification for the osseointegrated implant. J Prosthet Dent 1: 228-234.

Jensen J, Sindet-Pedersen S 1991. Autogenous mandibular bone grafts and osseointegrated implants for reconstruction of the severely atrophied maxilla: A preliminary report. J Oral Maxillofac Surg; 49: 1277-1287.

Johansson C, Albrektsson T 1987. Integration of screw implants in the rabbit: A 1-year follow-up of removal torque in titanium implants. Int J Oral Maxillofac Implants; 2: 69-75.

Johansson P, Stid KG 1994. Assessment of bone quality from cutting resistance during implant surgery. Int J Oral Maxillofac Implants; 9: 279-288.

Jonson R 1994. Metoder för benmineralbestämning in vivo. Rapport för statens beredning för utvärdering av medicinsk metodik (SBU). Rapport KFANÄL; 2: 1-31.

Klemetti E, Vaimo P, Lassila V, Alhava E 1993 a. Trabecular bone mineral density of mandible and alveolar height in postmenopausal women. Scand J Dent Res; 101: 166-170.

Klemetti E, Vainio P 1993 b. Effect of bone mineral density in skeleton and mandible on extraction of teeth and clinical alveolar height. J Prosthet Dent; 70: 21-25.

Klemetti E, Vainio P, Lassila V, Alhava E 1993 c. Cortical bone mineral density in the mandible and osteoporosis status in postmenopausal women. Scand J Dent Res; 101: 219-223.

Langer B, Langer L, Herrmann I, Jörneus L 1993. The wide fixture: A solution for the special bone situations and a rescue for the compromised implant. Part I. Int J Oral Maxillofac Implants; 8: 400-408.

Lekholm U, Zarb GA 1985. Patient selection and preparation. In: Brånemark P-I, Zarb GA & Albrektsson T, eds. Tissue-integrated prostheses: Osseointegration in clinical dentistry. Chicago: Quintessence Publishing Co, pp 199-209.

Lekholm U, Adell R, Brånemark P-I 1985. Complications. In: Brånemark P-I, Zarb GA, Albrektsson T, eds. Tissue-integrated prostheses: Osseointegration in clinical dentistry, Chicago, Quintessence Publishing Co, pp 233-240.

Lekholm U 1992. The Brånemark implant technique: A standardized procedure under continuous development. In: Laney WR, Tolman DE (eds). Tissue-Integration in Oral, Orthopaedic and Maxillofacial Reconstruction, Chicago, Quintessence, pp 194-199.

Lekholm U, Jemt T 1995. Implant treatment in edentulous maxillae. A 5-year follow-up report on patients with different degrees of jaw resorption. Int J Oral Maxillofac Implants. Accepted for publication.

Martin RB 1991. Determinants of the mechanical properties of bones. J Biomechanics; 24: 79-88.

Melton LJ 1990. Epidemiology of osteoporosis: Predicting who is a risk. Annals New York Academy of Sciences; 295-306.

Misch CE 1990. Density of bone: Effect on treatment plans, surgical approach, healing and progressive bone loading. Int J Oral Implant; 6: 23-31.

Mosekilde L, Kragstrup J, Richards A 1987. Compressive strength, ash weight, and volume of vertebral trabecular bone in experimental fluorosis in pigs. Calcif Tissue Int; 40: 318-322.

Nevins M, Langer B 1993. The successful application of osseointegrated implants to the posterior jaw: A long-term retrospecitive study. Int J Oral Maxillofac Implants; 8: 428-432.

Palou ME, McQuade MJ, Rossmann JA 1987. The use of ultrasound for the determination of periodontal bone morphology. J Periodontol; 58: 262-265.

Quirynen M, Lemoral Y, Dekeyser C, Peene P, van Steenberghe D, Bonte J, Baert A 1990. The CT-scan standard reconstruction technique for reliable jaw bone volume determination. Int J Oral Maxillofac Implants; 5: 384-389.

Rosenquist B 1992. Fixture placement posterior to the mental foramen with transposition of the inferior alveolar nerve. Int J Oral Maxillofac Implants; 7: 45-50.

Schliephake H, Neukam FW, Scheller H, Bothe KJ 1994. Local ridge augmentation using bone grafts and osseointegrated implants in the rehabilitation of partial edentulism: Preliminary results. Int J Oral Maxillofac Implants; 9: 557-564.

Sennerby L 1991. On the bone tissue response to titanium implants. Thesis. Department of Handicap Research, University of Göteborg, Sweden.

Sennerby L, Thomsen P, Ericsson LE 1992. A morphometric and biomechanic comparison of titanium implants inserted in rabbit cortical and cancellous bone. Int J Oral Maxillofac Implants; 7: 62-71.

Stulberg BN, Bauer T, Watson T, Richmond B 1989. Bone quality roentgenographic versus histologic assessment of hip bone structure. Clin Orthopaedics and Related Research; 240: 200-205.

Taguchi A, Tanimoto K, Ogawa M, Sunayashiki T, Wada T 1991. Effects of size of region of interest on precision of bone mineral measurements of the mandible by quantitative computed tomography. Dentomaxillofac Radiol; 20: 25-29.

Tammisalo E, Hallikainen D, Kanerva H, Tammisalo T 1992. Comprehensive oral X-ray diagnosis: Scanora ® multimodal radiography. A preliminary description. Dentomaxillofac Radiol; 21: 9-15.

Traxler M, Ulm C, Solar P, Lill W 1992. Sonographic measurement versus mapping for determination of residual ridge width. J Prosthet Dent; 67: 358-361.

Triplett RG, Mason ME, Alfonso WF, Mcanear JT 1991. Endosseous cylinder implants in severely atrophic mandibles. Int J Oral Maxillofac Implants; 6: 264-269.

van Steenberghe D, Quirynen M, Calberson L, Demanet M 1987. A prospecitve evaluation of the fate of 697 consecutive intraoral fixtures ad modum Brånemark in the rehabilitation of edentulism. J Head & Neck Pathol; 6: 53-58.

van Steenberghe D et al 1990. The applicability of osseointegrated oral implants in the reliabilitation of partial edentulism. A prospective multicenter study on 558 fixtures. Int J Oral Maxillofac Implants; 5: 272-281.

van Steenberghe D 1991. Oral Implants. Current opinion in dentistry; 1: 138-145.

von Wowern N 1977 a. Variations in bone mass withing the cortices of the mandible. Scand J Dent Res; 85: 444-455.

von Wowern N 1977 b. Variations in structure within the trabecular bone of the mandible. Scand J Dent Res; 85: 613-622.

von Wowern N, Stoltze K 1978. Sex and age differences in bone morphology of mandibles. Scand J Dent Res; 86: 478-485.

von Wowern N 1985. In vivo measurement of bone mineral content of mandibles by dual photon absorptiometry. Scan J Dent Res; 93: 162-168.

von Wowern N, Lyager Storm T, Olgaard K 1988. Bone mineral content by photon absorptiometry of the mandible compared with that of the forearm and the lumbar spine. Calcif Tissue Int; 42: 157-161.

von Wowern N, Harder F, Hjörting-Hansen E, Gotfredsen K 1990. ITI implants with overdentures: a prevention of bone loss in edentulous mandibles? Int J Oral Maxillofac Implants; 5: 135-139.

Wallach S 1992. Editorial. The bone "quality" problem. Calcif Tissue Int; 51: 169-172.

Worthington P, Bolender CL, Taylor TD 1987. The Swedish system of osseointegrated implants: Problems and complications encountered during a 4-year trial period. Int J Oral Maxillofac Implants; 2: 77-84.

Zarb GA, Schmitt A 1989. The longitudinal clinical effectiveness of osseointegrated dental implants. The Toronto study, Part I: Surgical results. J Prosthet Dent; 63: 451-457.

Zarb GA, Schmitt A 1990. The longitudinal clinical effectiveness of osseointegrated dental implants. The Toronto study Part III: Problems and complications encountered. J Prosthes Dent; 64: 185-194.

GÖTEBORGS UNIVERSITET