CLINICAL ORAL IMPLANTS RESEARCH

Rejane Faria Ribeiro-Rotta
Christina Lindh
Andrea Castro Pereira
Madeleine Rohlin

Ambiguity in bone tissue characteristics as presented in studies on dental implant planning and placement: a systematic review

Authors' affiliations:
Rejane Faria Ribeiro-Rotta, Department of Oral Medicine, School of Dentistry, Federal University of Goiás, Goiás, Brazil
Rejane Faria Ribeiro-Rotta, Department of Oral and Maxillofacial Radiology, Faculty of Odontology, Malmö University, Malmö, Sweden
Christina Lindh, Department of Oral and Maxillofacial Radiology, Faculty of Odontology, Malmö University, Malmö, Sweden
Andrea Castro Pereira, School of Dentistry, Federal University of Goiás, Goiás, Brazil
Madeleine Rohlin, Department of Oral and Maxillofacial Radiology, Faculty of Odontology, Malmö University, Malmö, Sweden

Corresponding author:
Rejane Faria Ribeiro-Rotta
Rua C-235 n. 1323/1501 Nova Suíça
Goiânia-GO 74280-130
Brazil
Tel.:/Fax: +55 62 3209 6067
e-mail: rejanefrr@gmail.com

Key words: bone density, dental implant, systematic literature review

Abstract

Objectives: To survey definitions of bone tissue characteristics and methods of assessing them in studies of dental implant planning and placement.

Material and methodology: Three databases were searched using specified indexing terms. Three reviewers selected from the titles and retrieved abstracts in accordance with inclusion and exclusion criteria. Descriptions of bone tissue characteristics (bone quality, density and quantity) used before or during dental implant placement were searched for and categorized.

Results: The search yielded 488 titles. One hundred and fort-nine publications were selected and read in full text. One hundred and eight were considered relevant. There were many different definitions and classification systems for bone tissue characteristics and examination protocols. Approximately two-third of the included publications reported the Lekholm & Zarb classification system for bone quality and quantity. However, only four studies implemented the Lekholm & Zarb system as originally proposed. A few publications described bone quality in accordance with the Misch or Trisi and Rao classifications systems. Assessment methods were often described only briefly (or not at all in one-fifth of the publications). Only one study presented the diagnostic accuracy of the assessment method, while only two presented observer performance.

Conclusion: The differing definitions and classification systems applied to dental implant planning and placement make it impossible to compare the results of various studies, particularly with respect to whether bone quality or quantity affect treatment outcomes. A consistent classification system for bone tissue characteristics is needed, as well as an appropriate description of bone tissue assessment methods, their diagnostic accuracy and observer performance.

The justification for assessing jawbone tissue in endosseous dental implant treatment is twofold: (1) as a diagnostic tool to assess whether the jawbone tissue is sufficient for implant treatment; (2) as a prognostic tool to predict the probability of success or failure, as the bone tissue characteristics of quality, quantity and density are considered important with regard to treatment outcomes (Friberg et al. 1991). However, it is not evident from the literature what bone quality, bone quantity or bone density represent. It is even difficult to find definitions of these terms in studies whose main objective was to evaluate bone tissue characteristics and treatment outcomes (Engquist et al. 1988; Jaffin & Berman 1991; Jemt 1993; Friberg et al. 1995, 1999; Jemt & Lekholm 1995; Razavi et al. 1995; Truhlar et al. 1997a, 1997b; Trisi & Rao 1999; Bahat 2000; O'Sullivan et al. 2000; Choel et al. 2003; Locante 2004; Herrmann et al. 2005).

A classification system for jaw anatomy (jaw shape and quality) frequently referred to in publications on endosseous dental implant treatment was proposed by Lekholm & Zarb (1985). The system is presented as drawings of the jaws accompanied by text, and assessment methods to classify the bone tissue are recommended. Bone quality is broken down into four groups according to the proportion and structure of compact and trabecular bone tissue, and the quantity of jawbone is broken down into five groups, based on residual jaw shape following tooth extraction. Other classifications of bone tissue have also been used in studies of dental implants (Misch 1990b; Trisi & Rao 1999). Differing classification systems for bone tissue characteristics may lead to confusion and interfere with attempts to compare the results of various studies. Furthermore, the evidence for the efficacy of clinical methods to assess jawbone

Date:
Accepted 7 July 2010

To cite this article:
Ribeiro-Rotta RF, Lindh C, Pereira AC, Rohlin M. Ambiguity in bone tissue characteristics as presented in studies on dental implant planning and placement: a systematic review.
Clin. Oral Impl. Res. **xx**, 2010; 000–000.
doi: 10.1111/j.1600-0501.2010.02041.x

tissue before endosseous dental implant treatment is sparse (Ribeiro-Rotta et al. 2007).

The aim of this review was to survey definitions used for bone tissue characteristics (bone quality, bone quantity and bone density) and the assessment methods utilized to characterize bone tissue in studies on endosseous dental implant planning and placement. The target audience consists of clinicians who treat patients with dental implants, as well as related field professionals.

Methodology for the review of the literature

To ensure a systematic approach, review of the literature was conducted and adapted to Goodman's model (1996), consisting of the following steps: (1) problem specification, (2) formulation of a plan for the literature search, (3) literature search and retrieval of publications and (4) data extraction and interpretation.

Problem specification

For the assessment of jawbone tissue before or during endosseous dental implant placement:

- What definitions of bone tissue characteristics (bone quality, bone quantity and bone density) can be found in original studies?
- What methods were used to assess bone tissue characteristics and how were the methods described?

Formal definitions for the following elements were sought before the literature search:

- Definition = the act or process of stating a precise meaning or significance; formulation of a meaning (The American Heritage Dictionary).
- Quality = degree or grade of excellence (The American Heritage Dictionary).
- Quantity = a specified or indefinite number or amount; the measurable, countable or comparable property or aspect of a thing (The American Heritage dictionary); the aspect in which a thing is measurable in terms of greater, less or equal or of increasing or decreasing magnitude (Merriam-Webster Online Dictionary).
- Bone density = the amount of mineral per square centimeter of BONE. This is the definition used in clinical practice. Actual bone density would be expressed in grams per milliliter. It is most frequently measured by photon absorptiometry or X-ray computed tomography (National Library of Medicine, MeSH browser).

Formulation of a plan for the literature search

Searches were limited to publications with abstracts, published in English, conducted on human tissues and on individuals older than 19. Specific limits were used to search three databases as follows:

- PubMed: Entrez date 01/01/1966/ to 9/2/2005 (first strategy) and 1/1/1966 to 6/7/2009 (second strategy), all adults 19 or older, and publications indexed as ''item with abstracts,'' ''English,'' and ''Human.''
- The Cochrane Library (including Cochrane Database of Systematic Reviews [Cochrane Reviews], Database of Abstracts of Reviews of Effects [Other Reviews] and Cochrane Central Register of Controlled Trials [Clinical Trials]): Date range 1800 to 2009, all records status.
- Web of Science electronic databases: Time span from 1986 to 2009, all citation databases.

To ensure the widest possible search, the indexing terms were used as MeSH terms and free text in the PubMed search, and the truncation symbol (*) was used in the Cochrane Library and Web of Science searches. Publications on primary material and systematic reviews that shed light on problem specifications were included. Case reports, book chapters and narrative reviews were excluded, as well as publications on local bone reaction (healing), the temporomandibular joint, bone grafts and dental implants for orthodontic treatment.

Literature search and retrieval of publications

Three of the authors independently read all retrieved titles and abstracts. When at least one author regarded a publication as having met the inclusion criteria, it was ordered and read in full text. A publication was considered relevant when one or more of the terms of bone quality, bone quantity or bone density was found in the abstract. When no explicit definition of bone tissue or examination protocol was found but was nevertheless referred to, the study in which the reference appeared was retrieved. Relevant publications in the reference lists of the systematic reviews were retrieved. No systematic hand search of the reference lists of other included publications was performed.

Data extraction and interpretation

With a focus on definitions of bone tissue characteristics – bone quality, bone quantity and bone density – material and methods, results and tables of the included publications were read and analyzed using a protocol. The text on assessment methods underpinning the definition of bone tissue was also analyzed. The most commonly used abbreviations, definitions and measurement units for the assessment of bone quality, bone quantity and bone density were listed to enable a better overview (Table 1). The data from the included publications were then listed in tables, along with the main topics related to the problem specifications (assessment methods, classification of jawbone tissue and measurement units) in order to standardize the interpretation of data.

Results

Literature search

The PubMed search yielded 250 titles and abstracts, the Cochrane Library search yielded an additional 148 titles and abstracts, and the Web of Science yielded an additional 90 titles and abstracts. From these titles and abstracts, 149 publications were deemed to meet the inclusion criteria and read in full text. Of these publications, 108 were considered relevant after data extraction and interpretation.

Interpretation of data on bone tissue characteristics presented in the included publications

Overall results

There was a diversity of definitions/classifications of bone tissue characteristics and examination protocols. It was difficult, sometimes impossible, to understand how the bone tissue had been assessed. The diagnostic accuracy of the method used to assess bone tissue was presented in terms of correct diagnoses in only one study (Lindh et al. 1996a), and observer performance of the method was presented in only two studies (Lindh et al. 1996a; Shapurian et al. 2006).

The classification of jawbone tissue proposed by Lekholm & Zarb (1985) was referred to in about two-thirds of the included publications (Tables 2–5). A few publications described bone quality according to Misch (1990b) (Tables 7 and 8) or Trisi & Rao (1999) (Tables 7 and 8). Bone quality was described alone or together with bone density or bone quantity in 22 publications, without referring to Lekholm & Zarb (Tables 6 and 7). Bone density alone was addressed in 18 publications (Table 8). Assessment methods varied and the description of the methods was often brief. About one-fifth of the publications ($n = 19$) contained no account of the assessment methods used (Tables 3–5 and 7).

Publications that referred to Lekholm & Zarb (1985)

Table 2 presents four publications (Johns et al. 1992; Fartash et al. 1996; Bergendal & Engquist 1998; van Steenberghe et al. 2002), that described the classification of jawbone tissue and the assessment methods (radiography and explorative drilling at implant placement) in accordance with the original description by Lekholm &

Table 1. **List of abbreviations and definitions of the clinical methods and measurement units to assess bone quality, bone quantity and bone density related to endosseous dental implant planning and placement**

Abbreviation	Meaning	Definition
BMC	Bone mineral content	The degree of bone mineralization
BMD	Bone mineral density Bone mass density	Bone density – the amount of mineral per square centimeter of bone, expressed in grams per milliliter (National Library of Medicine, MeSH browser)
CT	Computed tomography	Tomography, X-ray CT using X-ray transmission and a computer algorithm to reconstruct the image (National Library of Medicine, MeSH browser)
DXA or DEXA	Dual energy X-ray absorptiometry	An imaging technique that uses two low-dose X-ray beams with different levels of energy to produce a detailed image of body components; used primarily to measure bone mineral density (Dorland's Illustrated Medical Dictionary). Absorptiometry, photon – a non-invasive method for assessing body composition. It is based on the differential absorption of X-rays (or γ rays) by different tissues such as bone, fat and other soft tissues. The source of (X-ray or γ-ray) photon beam is generated either from radioisotopes such as Gadolinium 153, Iodine 125 or Americum 241 which emit γ rays in the appropriate range; or from an X-ray tube, which produces X-rays in the desired range. It is primarily used for quantitating bone mineral content, especially for the diagnosis of osteoporosis, and also in measuring bone mineralization (National Library of Medicine, MeSH browser)
————	Implant stability	Resistance to unscrewing (Friberg 1994)
ISQi	Implant stability quotient at implant placement	The ISQ measured at implant placement (Bischof et al. 2004)
L&Z	Lekholm & Zarb classification	Classification of bone quantity and bone quality in dental implant field established by Lekholm & Zarb and based on preoperative radiographs and explorative drilling at implant site preparation. The residual jaw shape and different rates of bone resorption following tooth extraction are rated in 5 general groups from A to E. Bone quality comprises four groups from 1 to 4, depending on the amount of compact and cancellous bone present (Lekholm & Zarb 1985)
Micro-MRI	Micro or high-resolution magnetic resonance imaging	Non-invasive and radiation-free method considered as a potential imaging tool that could provide clinical evaluation of trabecular bone architecture and quality (Choel et al. 2004)
MRI	Magnetic resonance imaging	Non-invasive method of demonstrating internal anatomy based on the principle that atomic nuclei in a strong magnetic field absorb pulses of radiofrequency energy and emit them as radio waves that can be reconstructed into computerized images. The concept includes proton spin tomographic techniques (National Library of Medicine, MeSH browser)
PTV	Periotest values	Numerical value computed converted from contact time value. Periotest is an electronic device for measuring the damping characteristics of the periodontium and stability of oral implants. It measures the contact time between the rod and the tapped object and the shorter contact time (milliseconds), the more stable periodontium or implant/bone contact (Schulte & Lukas 1993)
QCT	Quantitative computed tomography	Accurate and reproducible CT for quantitative analyses of the bone mineral density, by using a reference phantom (Taguchi et al. 1991)
RFA	Resonance frequency analyses	Method to evaluate implant stability, by using a small beam-like piezo-ceramic transducer. Vibration and response are registered (Hz) (Meredith et al. 1996)
SXA	Single-energy X-ray absorptiometry	A method of assessing bone mineral density using a single energy X-ray beam (Dorland's Illustrated Medical Dictionary)
TBPf	Trabecular bone pattern factor	This factor is based on the idea that the connectedness of cancellous bone structures in a two-dimensional section can be described by the relation of convex to concave structures. Owing to the calculation formula, the trabecular interconnection is higher, the more negative the value (Ulm et al. 1997)
TBV	Trabecular bone volume	Fractional area of the trabeculae expressed as the percentage of mineralized bone tissue within a region of interest (Lindh et al. 1996b, 1997)
TTBV	Total trabecular bone volume	Fractional area of the trabeculae, including the transitional area to cortical bone, expressed as the percentage of mineralized bone tissue within a region of interest (Lindh et al. 1996b, 1997)
————	Cutting torque	A rotatory force applied during low-speed tapping, and according to Johansson & Strid 1994, this technique measures the electric current used during threading. It consists of two parts: true cutting resistance and the friction (surface resistance)
————	Cutting resistance or true cutting resistance	The determination of the torque exerted by the low-speed motor while tapping a drilled hole with a crew tap or a self-tapping implant being forces like friction subtracted. OR Energy needed for cutting out a specific amount of bone material with the screw tap. It is conveniently presented in J/mm^3 (Johansson & Strid 1994)
————	Histomorphometry	The quantitative measurement and characterization of microscopical images using a computer; manual or automated digital image analysis typically involves measurements and comparisons of selected geometric areas, perimeters, length angle of orientation, form factors, center of gravity coordinates, and image enhancement (Stedman's Online Medical Dictionary)
————	Microradiography	Production of a radiographic image of a small or very thin object on fine-grained photographic film under conditions that permit subsequent microscopic examination or enlargement of the radiograph at linear magnifications of up to several hundreds and with a resolution approaching the resolving power of the photographic emulsion (about 1000 lines per millimeter) (National Library of Medicine, MeSH browser)
————	Peak insertion torque	The top or upper limit (positive or negative, maximum or minimum) of the insertion torque (Friberg 1994)
————	Pull-out resistance	The pull-out force required to remove the implant from the jaws (Kido et al. 1997)

Zarb (Fig. 1). Bone quality was categorized into four groups: groups 1–4 in two publications (Johns et al. 1992; Fartash et al. 1996), groups A–D in one (Bergendal & Engquist 1998) and scores I–IV in another (van Steenberghe et al. 2002). No publication described bone tissue as residual jaw shape or contour A–E in accordance with Lekholm & Zarb (Fig. 1). Instead, bone quantity was mentioned and sometimes considered synonymous with the anatomy of bone or degree of resorption (Fartash et al. 1996). One publication (Bergendal & Engquist 1998) presented bone quality and bone quantity as a morphological characterization of jawbone. The description of examination methods was explicit, but the methods varied among the four studies.

Table 3 shows 31 publications that presented jawbone tissue in line with the original classifi-

Table 2. **Publications on planning and placement of dental implants where the description of assessment methods and classification of jawbone tissue proposed by Lekholm and Zarb (1985) (Fig. 1) was described in accordance with the original description**

References	Assessment methods	Classification of jawbone tissue measurement unit	Comments
Johns et al. (1992)	Radiography	Bone quality (bone types 1–4)	John et al.: Panoramic radiography, lateral cephalography
	At implant placement	Bone quantity (bone resorption) bone types A–E	Evaluation at implant placement made independently of radiography. Correlation presented in the table
Fartash et al. (1996)	Radiography	Bone quality 1–4	Fartash et al.: Panoramic survey, lateral cephalogram, axial view and intra-oral films
	At implant placement	Anatomy of jawbone and degree of resorption A–E (bone quantity)	Tactile evaluation during surgery
Bergendal & Engquist (1998)	Radiography	Bone quality A–D	Bergendal & Engquist: Panoramic and lateral cephalography, tomographic examinations in some regions
	At implant placement	Bone quantity 1–5	Visual inspection and tactile perception
van Steenberghe et al. (2002)	Clinical assessment	Bone quality: scores I–IV	van Steenberghe et al.: Panoramic radiography, computed tomography of some regions
	Radiography	Bone quantity (bone resorption): scores A–E	Tactile assessment, eye inspection at implant placement
	At implant placement		

cation by Lekholm & Zarb, but the description of assessment methods was incomplete. Most publications grouped bone quality in grades or scores of 1–4 and bone quantity in grades (scores) of A–E or A–D. Four publications (Becker et al. 1997, 1998, 1999; Herrmann et al. 2007) regarded jaw shape as equivalent to quantity. Radiography and assessment at implant placement were mentioned in five publications (Bass & Triplett 1991; Hutton et al. 1995; Becker et al. 1999; Friberg et al. 2003; Alsaadi et al. 2008), while there was a description of only one assessment method in 19 other publication (Friberg et al. 1992; Jemt 1994; Becker & Becker 1995; Becker et al. 1997, 1998, 2000a, 2000b, 2005; Jagger et al. 2001; Attard & Zarb 2002; Friberg et al. 2002; Calandriello et al. 2003; Rocci et al. 2003; Bergkvist et al. 2004; Ostman et al. 2005, 2006; Ottoni et al. 2005; Montes et al. 2007; Collaert & De Bruyn 2008).

Table 4 presents 26 publications (Truhlar et al. 1994a, 1994b, 1997a, 1997b, 1997c, 2000a, 2000b; Oikarinen et al. 1995; Lindh et al. 1996b; Orenstein et al. 1998; Friberg et al. 1999; Orenstein et al. 2000; O'Sullivan et al. 2000; Spray et al. 2000; Shimpuku et al. 2003; Tawil & Younan 2003; Attard & Zarb 2004; Shin et al. 2004; Zix et al. 2005; Romeo et al. 2006; Shapurian et al. 2006; Achilli et al. 2007; Alsaadi et al. 2007; Huwiler et al. 2007; Siepenkothen 2007; Ganeles et al. 2008) that referred to the classification by Lekholm & Zarb but described bone quality only. Bone quality was classified as quality 1–4 or type I–IV in most publications. In some publications (Spray et al. 2000; Truhlar et al. 2000a, 2000b; Achilli et al. 2007; Alsaadi et al. 2007), bone quality was regarded as synonymous with bone density. Bone quality was related to trabecular bone pattern as assessed by periapical radiography (Lindh et al. 1996b), related to bone density as assessed in Hounsfiled Units (HU) by computed tomography (CT) (Shapurian et al. 2006), related to implant stability as assessed by insertion torque (O'Sullivan et al. 2000) and by RFA values (Huwiler et al. 2007). The description of assessment methods varied.

Seven publications (Friberg et al. 1999; Shahlaie et al. 2003; Aalam & Nowzari 2005; Aalam et al. 2005; Aranyarachkul et al. 2005; Blanes et al. 2007; Lee et al. 2007) that referred to Lekholm & Zarb (Table 5) described jawbone tissue only in terms of bone density, an expression not used by Lekholm & Zarb. Two publications by the same authors (Aalam & Nowzari 2005; Aalam et al. 2005) classified bone tissue into two categories, two publications (Friberg et al. 1999; Blanes et al. 2007) used three categories and the other three publications (Shahlaie et al. 2003; Aranyarachkul et al. 2005; Lee et al. 2007) used four categories.

Publications with other descriptions of jawbone tissue

As shown in Table 6, *bone quality* was combined with either *bone density* (Friberg et al. 1995; Choel et al. 2003, 2004) or *bone quantity* (Saadoun & LeGall 1992; Razavi et al. 1995; Jemt & Hager 2006). Four studies of human cadavers analyzed jawbone tissue in detail. Bone architecture was described by Choel et al. (2004) and Razavi et al. (1995) and the amount of mineral by Friberg et al. (1995) and Choel et al. (2003, 2004). Bone quantity was presented as (1) depth of bone (Saadoun & LeGall 1992), (2) mean bone height (Razavi et al. 1995) and (3) bone resorption index (Jemt & Hager 2006).

Sixteen publications (Manz 1997, 2000; Walker et al. 1997; Gaucher et al. 2001; Khang et al. 2001; Ibanez & Jalbout 2002; Testori et al. 2002; Lettry et al. 2003; Weng et al. 2003; Chou et al. 2004; Kourtis et al. 2004; Morris et al. 2004; Elkhoury et al. 2005; Sullivan et al. 2005; Degidi et al. 2007; Orsini et al. 2007) described jawbone tissue in terms of *bone quality* only (Table 7). The system proposed by Trisi & Rao (1999) with three classes (dense, normal and soft bone) was used in five publications (Gaucher et al. 2001; Khang et al. 2001; Testori et al. 2002; Weng et al. 2003; Sullivan et al. 2005), and the system by Misch (1990b) with four groups (D1–D4) was used in two other publications (Degidi et al. 2007; Orsini et al. 2007). One publication did not refer to any classification system, but bone quality was classified according to a scale of D1–D4 (Kourtis et al. 2004). The assessment methods varied.

Bone density was presented as the sole jawbone tissue characteristic in 18 publications (Lindh et al. 1996a, 1997; Kido et al. 1997; Taguchi et al. 1997; Misch et al. 1999a, 1999b; Homolka et al. 2001, 2002; Beer et al. 2003; Nkenke et al. 2003; Moheng & Feryn 2005; Turkyilmaz et al. 2006, 2007a, 2007b, 2008a, 2008b; Gulsahi et al. 2007; Yang et al. 2008) (Table 8), of which eight were performed on human cadaver jaws. Different classification systems and measurement units were used, such as as the amount of calcium hydroxyapatite expressed in mg/cm^3 (Lindh et al. 1996a, 1997; Kido et al. 1997; Homolka et al. 2001, 2002; Beer et al. 2003; Nkenke et al. 2003), in g/cm^2 (Gulsahi et al. 2007), in percentage of mineralized bone tissue (Lindh et al. 1997), in buccal and oral cortical bone volume trabecular bone volume (Nkenke et al. 2003), in intertrabecular connectivity (Nkenke et al. 2003) or in HU (Taguchi et al. 1997; Moheng & Feryn 2005; Turkyilmaz et al. 2006, 2007a, 2007b, 2008a, 2008b). Most of these publications performed CT (Taguchi et al. 1997; Moheng & Feryn 2005; Turkyilmaz et al. 2006, 2007a, 2007b, 2008a, 2008b), quantitative computed tomography (Lindh et al. 1996a, 1997; Kido et al. 1997; Homolka et al. 2001, 2002; Beer et al. 2003; Nkenke et al. 2003), DEXA (Gulsahi et al. 2007) or weight and volume measurements (Misch et al. 1999b) to assess bone tissue.

Table 3. **Publications on planning and placement of dental implants where the description of assessment methods and classification of jawbone tissue *proposed by* Lekholm and Zarb (1985) (Fig. 1) was referred to**

References	Classification measurement unit	Comments
	Assessment methods: Radiography and evaluation at implant placement	
Bass & Triplett (1991)	Jawbone anatomy: scores 1–4	Bass & Triplett: Panoramic and periapical radiography, lateral cephalography, tomography of some regions. No description of method at implant placement
	Resorption anatomy: scores 1–5	
Hutton et al. (1995)	Bone quality/morphology: quality 1–4	Hutton et al.: Lateral cephalography, panoramic radiography. No description of method at implant placement
Friberg et al. (2003)	Bone quantity/bone resorption: A–E	Friberg et al.: No description of methods
Becker et al. (1999)	Bone quality 1–4	Becker et al.: Periapical radiographs and linear tomograms. No description of method at implant placement
Alsaadi et al. (2008)	Bone quantity (jaw shape) A–E	Alsaadi et al.: No description of radiographic method. Tactile evaluation during drilling. Bone resorption = bone volume
	Assessment method: Only radiography mentioned	
Becker & Becker (1995)	Bone quality: scores 1–4	Becker & Becker: Panoramic and periapical radiography
Friberg et al. (2002)	Bone quantity: scores A–E	Friberg et al.: No description of radiographic method
Becker et al. (1997)	Bone quality type 1–4	Becker et al. (1997): Panoramic radiography supplemented with periapical radiography and linear and computerized tomography
Becker et al. (1998)	Bone quantity (shape) A–D	Becker et al. (1998): Linear tomography
Becker et al. (2005)		Becker et al. (2005): Panoramic and periapical radiography. Linear tomography
Calandriello et al. (2003)	Bone quality: 1–4	Calandriello et al.: No description of radiographic method. Mention low and high bone density
	Bone quantity: A–C	
Ottoni et al. (2005)	Bone quality: types 1–3	Ottoni et al.: Panoramic radiography and tomography
	Bone quantity: A–B	
Jagger et al. (2001)	Bone quality: modified from Lekholm & Zarb classification – 1–3	Jagger et al.: Dental panoramic tomography
	Bone quantity: modified from Lekholm & Zarb classification – 1–3	
Montes et al. (2007)	Bone types II/III and B/C	Montes et al.: Panoramic radiography and periapical radiography
	Assessment method: Only examination during drilling/at the time of surgery or fixture insertion mentioned	
Friberg et al. (1992)	Bone quality: types 1–4	Friberg et al.: Bone quality type 1 = hard bone; type 4 = soft bone
Jemt (1994)		Jemt: Bone quality: 1 (hardest) – 4 (softest), Jawbone anatomy: – E (most severely resorbed). No description of method
Becker et al. (2000b)		Becker et al.: Subjectively scored, no description of method
Attard & Zarb (2002)	Bone quantity/jawbone shapes: A–E	Attard & Zarb: No description of method
Rocci et al. (2003)		Rocci et al.: Bone quantity said to be determined but not presented
Bergkvist et al. (2004)		Bergkvist et al.: No description of method
Östman et al. (2006)		Östman et al.: Bone quality assessed on resistance of bone during drilling at implant placement
Östman et al. (2005)	Bone quality: type 1–4	Östman et al.: No description of method
Becker et al. (2000a)	Bone quantity: A–D	Becker et al.: No description of method
Collaert & De Bruyn (2008)		Collaert & De Bruyn: No description of method
	Assessment method: Not mentioned	
Grunder et al. (1999)	Bone quality: 1–4 and unknown	Grunder et al.: Classification of bone quality and bone quantity stated in Tables
	Bone quantity: A–E and unknown	
Ivanoff et al. (1999)	Bone quality: 1–4	Ivanoff et al.: Classification of bone quality and bone quantity stated in Tables
Maló et al. (2006)	Bone quantity: A–E	Maló et al.: Bone quality considered synonymous with bone density (p 225)
Friberg et al. (2005)		Friberg et al.: Refer to Friberg & Billström (2002)
Herrmann et al. (2005)	Jawbone quality 1–4	Hermann et al. (2005, 2007): Jawbone quality (density) and jaw shape (quantity). Different jaw shape/bone quality combinations were evaluated
Herrmann et al. (2007)	Jaw shape A–E	
Becker et al. (1998)	Bone quality: type 1–4	Becker et al.: Bone quality type 4 considered low bone density
	Bone quantity (jaw/bone shape): A–D	

Jawbone tissue was described as *bone quality* and *bone quantity.* The description of the assessment methods was incomplete in the publications listed.

Discussion

Methodology for the literature search and data interpretation

Only the first step of the search strategy was systematic. The second step of searching the reference lists of included studies, a common approach in systematic reviews of intervention methods, was not performed. We felt that the aim of the study had been achieved with the database searches. However, to ensure the retrieval of many publications, the search strategies comprised three databases – PubMed, Cochrane Library and Web of Science. The search of at least two electronic sources is regarded as improving the methodological quality of a systematic review (Shea et al. 2007). The use of the truncation symbol permits the identification of alternative spellings after the root word, which may vary according to the database used. Studies of human cadavers were included, as data from these studies could be used to validate the assessment methods used for clinical examination of jawbone tissue.

Medical Subject Headings (MeSH) is a controlled vocabulary designed by the National Library of Medicine to search PubMed and other health science databases. This review used it primarily to establish the formal definition of the element problems. Bone density is a MeSH term, but bone quantity and bone quality are not. Four well-known English dictionaries (American Heritage Dictionary; Merriam-Webster Online

Table 4. **Publications on planning and placement of dental implants where the description of assessment methods and classification of jawbone tissue *proposed by* Lekholm and Zarb (1985) was referred to**

References	Classification measurement unit	Comments
	Assessment methods: Radiography and evaluation during drilling/at implant placement	
Truhlar et al. (1994a)	Bone quality (BQ): Quality 1–4	Truhlar et al. (1994a, 1994b): Tactile sensation during implant site preparation;
Truhlar et al. (1994b)		no description of radiographic method
Truhlar et al. (1997a)		Truhlar et al. (1997a): Clinical evaluation during site preparation:
		No description of radiographic method
Truhlar et al. (1997c)		Truhlar et al. (1997c): Tactile sensation of cutting resistance and force
		required during surgery, panoramic, radiography and reformatted CT
Truhlar et al. (2000b)		Truhlar et al. (2000b): Subjective clinical evaluation during site preparation:
		No description of radiographic method. BQ = bone density
Orenstein et al. (2000)		Orenstein et al. (2000): Tactile sensation during preparation of implant site;
		no description of radiographic method
Spray et al. (2000)		Spray et al.: Tactile sensations during implant preparation;
		no description of radiographic method. In fig. 8 BQ = bone density
Orenstein et al. (1998)	Bone density: Q-1, Q-2, Q-3, Q-4	Orenstein et al. (1998): Tactile sensations during the preparation of the implant site;
	and unknown	no description of radiographic method
Attard & Zarb (2004)	BQ (types I–IV)	Attard & Zarb: No description of methods
	Assessment method: Only radiography mentioned	
Lindh et al. (1996b)	BQ: Classes 1–4	Lindh et al. (1996b): Lindh: Human cadaver jaws Periapical radiography.
		Trabecular bone pattern assessed by radiography and related to BQ
Friberg et al. (1999)		Friberg et al.: Tomography and lateral cephalography
Shin et al. (2004)		Shin et al.: Tomography; no explicit measurement unit for BQ
Tawil & Younan (2003)	BQ: types 1–4	Tawil & Younan: Periapical and panoramic radiography, CT of some regions
Zix et al. (2005)		Zix et al.: Panoramic radiography
Shapurian et al. (2006)	Bone type: 1–4, no bone	Shapurian et al.: CT. Bone density assessed in HU and related to BQ
Oikarinen et al. (1995)	Type I–IV bone	Oikarinen et al.: No description of radiographic method
Achilli et al. (2007)	BQ: D1–D4	Acilli et al.: Bone quantity according to Howell classes. BQ = bone density
	Assessment method: Only examination during drilling/at the time of surgery or fixture insertion mentioned	
Truhlar et al. (1997b)	BQ 1–4	Truhlar et al. (1997b): Truhlar: BQ at implant insertion
Romeo et al. (2006)		Romeo et al.: Explorative drilling at implant site
Alsaadi et al. (2007)		Alsaadi et al.: Tactile sensation during drilling and during implant insertion by
		torque force measurement device. BQ for cortical bone and trabecular
		bone classified separately. BQ = trabecular bone density
O'Sullivan et al. (2000)	Bone types 2–4	O'Sullivan et al.: Human cadaver jaws. Tactile impression of BQ at placement and appearance of
		bone at implant site following implant removal. BQ also assessed according to
		Johansson & Strid (1994) and classified by insertions torque (N cm)
Huwiler et al. (2007)	BQ classification: 1–3	Huwiler et al.: No correlation between BQ and micro CT bone characteristics or RFA values
Siepenkothen (2007)	BQ types I–IV	
		Assessment method: Not mentioned
Truhlar et al. (2000a)	BQ-1, 2, 3 and 4	Truhlar et al. (2000a): BQ = bone density
Shimpuku et al. (2003)	BQ type 2/type 3/type 4	Shimpuku et al.:Type 2/3 mentioned in table 4 and type 3/type 4 in table 2
Ganeles et al. (2008)	Types I–IV	Ganeles et al.: Poor-quality (type IV) bone

Characteristics of jawbone tissue described only as *bone quality* and the description of assessment methods was incomplete in the publications listed.
CT, computed tomography.

Dictionary; Dorland's Illustrated Medical Dictionary and Stedman's Online Medical Dictionary) were consulted for the definition of element problems not included in the MeSH.

An *a priori* protocol and tables with main topics related to the problem specifications were used to standardize data extraction and interpretation. The tables facilitated the structuring of the publications into groups according to similarities and dissimilarities among the bone tissue classification systems and assessment methods utilized.

Results

Classification systems are needed in order to provide a framework for the orderly, scientific study of treatment and treatment outcomes. Our review documents deficiencies in the use of classification systems for dental implant planning and placement. The included studies presented a diversity of classification systems and measurement units. Description of bone quantity and quality even varied from one publication to another by the same authors. Furthermore, many studies made it impossible to interpret not only how the bone tissue had been classified but also how the bone tissue had been examined and the results of the examination assessed. Authors should not only provide clear details of the primary and secondary outcomes of the intervention under study, but describe how these outcomes have been measured and whether any particular steps have been taken to increase the reliability of the measurements (Altman et al. 2001; Moher et al. 2001). The reliability of the methods used and the assessment of jawbone tissue were reported in only two publications. This is an inadequate approach to research as inaccuracy of measurements can affect the reported results of any intervention.

The classification system proposed by Lekholm & Zarb (1985) was referred to in most studies. However, only four of 80 retrieved studies that referred to Lekholm & Zarb (1985) actually followed the original description of the classification system and the recommended methods. It seemed as though it had become routine to include the reference by Lekholm & Zarb (1985), apparently without knowledge of the original description of either bone characteristics or the recommended assessment methods. The original publication by Lekholm & Zarb (1985) contains no definitions of bone characteristics. The suggestion that anatomical features of bone tissue be considered before the preparation of implant sites was based on experience. The

Table 5. **Publications on planning and placement of dental implants where the description of assessment methods and classification of jawbone tissue *proposed by* Lekholm and Zarb (1985) (Fig. 1) was referred to**

References	Classification measurement unit	Comments
	Assessment methods: Radiography, during drilling and cutting torque measurements	
Friberg et al. (1999)	Bone density: 1(low density, 2 (medium density), 3 (high density) Newton centimeter (N cm)	Friber et al.: No description of radiographic method. Bone density evaluated by torque measurements during implant insertion in
Lee et al. (2007)	Subjective radiographic bone density: 1–4 of CT and CBCT scans Mean HU from CT and CBCT scans Subjective drilling density: D1–D4 Resistance torque in N cm: three scenarios	Lee et al.: Human cadaver jaws. Radiographic rating according to Lekholm & Zarb and rating during drilling according to Misch (1990a) classification
	Assessment methods: Only radiography mentioned	
Shahlaie et al. (2003)	Subjective bone density class 1–4 Mean HU	Shahlaie et al.: Human cadaver jaws. HU from QCT correlated to subjective assessments of printed images. An overall relationship, but wide ranges of HU within each of four Lekholm & Zarb classes
Aranyarachkul et al. (2005)		Aranayarachkul et al.: Human cadaver jaws. HU from QBCT correlated to subjective assessments of printed images. An overall relationship, but wide ranges of HU within each of four Lekholm & Zarb classes
Aalam & Nowzari (2005)	Bone types 1 and 2 = high-density bone	Aalam & Nowzari; Aalam et al.: Periapical radiography and CT. Bone density classification
Aalam et al. (2005)	Bone types 3 and 4 = low-density bone	modified according to Lekholm & Zarb
	Assessment method: Not mentioned	
Blanes et al. (2007)	Type I: very dense bone Type II: cortical and spongy bone Type III: very spongy bone	Blanes et al.: Type I equal to type-I bone according to Lekholm & Zarb, Type II to types II and III and Type III to type IV according to Lekholm & Zarb

Jawbone tissue was described only as *bone density* or as bone morphology and the description of assessment methods was incomplete in publications listed.
CT, computed tomography; CBCT, cone beam computed tomography; HU, Hounsfield units.

Table 6. Bone quality together with either bone density or bone quantity

References	Assessment method	Classification measurement unit	Comments
		Bone quality and bone density	
Friberg et al. (1995)	Cutting resistance technique	(mJ/mm^3)	Friberg et al.: Human cadaver jaws. Bone quality assessed by cutting resistance and bone density by morphometry Correlation between bone density and cutting resistance of each implant site was $r = 0.9$
	Morphometry from microradiography	Total amount of mineralized bone, of trabecular bone and compact bone (% of bone area)	
Choel et al. (2003)	DEXA	BMC (g) BMD (quotient of BMC and area) (g/cm^2)	Choel et al. (2003, 2004): Slices of human cadaver jaws. BMC and BMD considered as bone quality parameters
Choel et al. (2004)	Magnetic resonance imaging DXA	Trabecular bone architecture: histomorphometric parameter units, angle between trabeculae/tooth axis BMD (g/cm^2)	Human cadaver jaws. DXA presented as method but results of DXA not reported
		Bone quality and bone quantity	
Saadoun & LeGall (1992)	At implant placement (clinical examination) Radiography	Bone Quality – spongiosa (type IV); – cortical bone (type I) Depth of bone (mm)	Saadoun & LeGall: Panoramic and periapical radiography, CT. Own classification of bone quality
Razavi et al. (1995)	Microscopy Caliper measurements	Trabecular distance, cortex thickness, marrow spaces (μm-mm) Mean height of bone (mm)	Razavi et al.: Maxillae of human cadavers
Jemt & Hager (2006)	At surgery	Bone quality: fours grades Bone resorption index (minimal, moderate, advanced, extreme)	Jemt & Hager: No description of method and grades of bone quality

Publications on planning and placement of dental implants where jawbone tissue was described as bone quality together with another bone tissue characteristic.
BMC, bone mineral content; BMD,bone mineral density; CT, computed tomography; DXA/DEXA, dual energy X-ray absorptiometry.

foundation for five groups of jaw shapes or four groups of bone quality was not discussed. Other classification systems have been proposed to categorize bone quality into two groups (Aalam & Nowzari 2005; Aalam et al. 2005), three groups (Friberg et al. 1999; Trisi & Rao 1999; Blanes et al. 2007) or four groups of bone density (Misch et al. 1999a). No such categories were discussed in these publications.

Somewhat surprisingly, the frequently used classification system for jawbone tissue described by Lekholm & Zarb (1985) has not been validated. Furthermore, as concluded on the basis of a systematic review, the evidence concerning accuracy and observer performance of clinical methods used to assess bone tissue characteristics before and during dental implant placement is insufficient (Ribeiro-Rotta et al. 2007). When utilizing systems, such as those proposed by Lekholm & Zarb (1985), Misch (1990b) or Trisi & Rao (1999), knowledge about the efficacy of the assessment method is fundamental. Virtually every visual and tactile piece of information from an examination varies to some degree from patient to patient, while examiners may differ in their ability to detect findings and in their propensity to record them. Even when examiners agree that they are observing

Table 7. **Bone quality**

References	Classification measurement unit	Comments
	Assessment method: Only imaging methods mentioned	
Lettry et al. (2003)	No classification	Lettry et al.: Human cadaver jaws. Measurements of mechanical properties and CT scan numbers of fresh mandibles and correlation between them with a view to provide a non-invasive method for determining bone quality for designers of dental implants. CT number and Young's modulus
Degidi et al. (2007)	Bone quality as indicated by Misch (1990b) D1 = thick cortical and dense cancellous bone D2 = thick cortical and fenestrated cancellous bone D3 = thin cortical and dense cancellous bone D4 = thin cortical and fenestrated cancellous bone	Dgidi et al.: Periapical and panoramic radiography, CT
	Assessment method: Only examination during drilling/at the time of surgery or fixture insertion mentioned	
Khang et al. (2001)	Dense	Khang et al.: Hand-felt perception of the drilling resistance
Testori et al. (2002)	Normal Soft	Testori et al.: Hand-felt perception of the drilling resistance. BQ = bone density. Refer to Trisi & Rao (1999)
Weng et al. (2003)		Weng et al.: Hand-felt perception of drilling resistance
Sullivan et al. (2005)		Sullivan et al.: Hand-felt perception of drilling resistance. BQ = bone density
Orsini et al. (2007)	Low-density bone (type D3–D4)	Orsini et al.: Surgeon's perception of drilling resistance. BQ = bone density
Elkhoury et al. (2005)	Bone quality determined on a bone density scale from 1 to 4	Elkhoury et al.: Subjective grading during implant placement Refer to Brånemark et al. (1985) BQ = bone density
	Assessment method: Not mentioned	
Gaucher et al. (2001)	Dense (type II) bone Normal (type III) bone Soft (type IV) bone	Gaucher et al.: No reference to applied classification
Manz (1997) Manz (2000)	Bone quality type: Bone score 1–4	Manz (1997, 2000): No reference to applied classification
Walker et al. (1997) Chou et al. (2004)	Bone quality (BQ) 1–4	Walker et al.: No reference to applied classification Chou et al.: No reference to applied classification. BQ = bone density
Ibanez & Jalbout (2002)	Bone quality: type I–IV	Ibanez & Jalbout: No reference to applied classification
Kourtis et al. (2004)	Bone quality class D1–D4	Kourtis et al.: No reference to applied classification.
Morris et al. (2004)	Bone quality classification: Quality-1 – Quality-4	Morris et al.: BQ= bone density

Publications on planning and placement of dental implants where jawbone tissue was described only as bone quality.
CT, computed tomography.

the same thing, they may apply different perceptual thresholds. Only two studies of observer performance were used in the index proposed by Lekholm & Zarb (1985), and they were on the radiological part of the index. The reliability of surgeons' perceptions of bone quality during surgery is difficult to investigate. The results of observer performance were contradictory. Shapurian et al. (2006) found the observer agreement of two examiners to be low when assessing bone quality as correlated with HU values ($r = .65$, $P < .001$), concluding that their finding underscored the subjective nature of the Lekholm & Zarb classification system. On the other hand, Lindh et al. (1996a, 1996b) found the Kappa index for observer agreement to be fair when seven observers assessed the trabecular pattern in intra-oral periapical radiographs according to the Lekholm & Zarb classification system. In practice, however, the observers basically used only two of the four classes in their assessment. The applicability of the Lekholm & Zarb classification of bone quality was also supported by the results of two previous studies. Thus, panoramic radiographic appearances of bone quality assessed according to Lekholm and Zarb was found to be correlated with bone mineral density of the body of the mandible as measured by dual energy X-ray absorptiometry (Horner & Devlin 1998). Also the results of a more recent study (Bergkvist et al. 2010) presented a high correlation between the classification performed during surgery and measurements of bone mineral density in CT images of correponding implant sites.

Some studies (Truhlar et al. 1994a, 1994b, 1997a, 1997b, 1997c, 2000a, 2000b; Becker et al. 1998; Testori et al. 2002; Herrmann et al. 2005; Sullivan et al. 2005; Malo et al. 2006; Alsaadi et al. 2007) regarded bone quality as synonymous with bone density without presenting a definition of bone density. The debate about bone quality seems to be more advanced in the literature of osteoporosis (Watts 2002; Recker & Barger-Lux 2004), with a richer notion of bone quality that includes material, mechanical and architectural elements. The combined impact of these factors might equal or exceed that of bone density. In the dental implant field, bone tissue characteristics have also been related to different aspects of bone morphology and biomechanical properties, such as shape (Becker et al. 1997, 1998; Attard & Zarb 2002; Rocci et al. 2003; Bergkvist et al. 2004; Ostman et al. 2006; Herrmann et al. 2007; Alsaadi et al. 2008), degree of mineralization (Friberg et al. 1995; Choel et al. 2003; Gulsahi et al. 2007) and trabecular or cortical microarchitecture (Razavi et al. 1995; Choel et al. 2004). These studies were performed primarily on human cadaver jaws, which facilitated not only detailed analyses of different aspects of jawbone tissue but also the establishment of a reference standard for the assessment method under evaluation.

A number of conclusions can be drawn from our review. First, it has revealed the diversity of classifications of bone tissue characteristics and of methods used to examine and assess jawbone tissue in research concerning dental implants. Second, there is also a lack of consensus with regard to uniform categories and methods among studies when Lekholm & Zarb is referred to. Third, the description of methods used to examine and assess jawbone tissue was frequently scanty and examiner variation when interpreting the findings was not reported. It seems as though there is little understanding of the influence of examiner performance on the outcomes of dental implant interventions. The findings of our review suggest a strong need for future uniformity in the design of implant studies. Similar assessment methods, classification systems and mea-

Table 8. **Bone density**

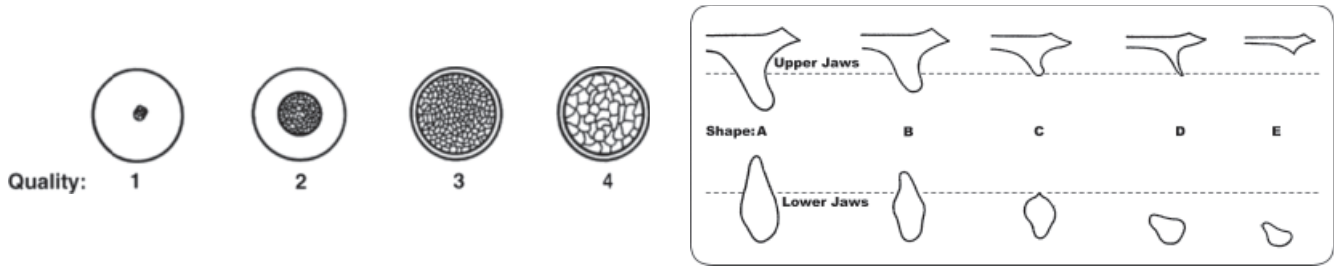
References	Classification measurement unit	Comments
	Assessment method: Computed tomography (CT)	
Turkyilmaz et al. (2007a)	Bone density measured in HU	In the following studies by Turkyilmaz et al. (2006, 2007a, 2007b, 2008a, 2008b) bone density, was measured using software incorporated into CT equipment
Turkyilmaz et al. (2008b)		Turkyilmaz et al. (2008a, 2008b): Bone density = bone quality In following studies: Bone density was correlated with measurements made by insertion torque (N cm) and by resonance frequency (ISQ):
Turkyilmaz et al. (2006)		Turkyilmaz et al. (2006): $r^2 = 0.27$ and 0.22, respectively
Turkyilmaz et al. (2007b)		Turkyilmaz et al. (2007b): $r = 0.58$ and 0.66, respectively
Turkyilmaz et al. (2008a)		Turkyilmaz, 2008a $r = 0.79$–0.87 and 0.82–0-98, respectively
Taguchi et al. (1997)	BMD (HU or CT numbers)	Taguchi et al.: HU correlated to trabecular bone pattern (grades 1–5) visualized in panoramic radiography
Moheng & Feryn (2005)	D1 (low density/quality) D2–D3 D4 (high density/quality)	Moheng & Feryn: Bone density scored using visual inspection and CT-scans: Refer to Misch classification (1990b). Unclear how CT scans was used
	Assessment method: QCT	
Lindh et al. (1996a)	HU converted to BMD values (amount of calcium hydroxyapatite in mg/cm^3 within ROI)	Lindh et al. (1996a): Human cadaver jaws. ROI allocated to trabecular bone tissue
Lindh et al. (1997)		Lindh et al. (1997): Human cadaver jaws. BMD correlated with trabecular bone volume (TBV and TTBV within ROIs expressed as percentage of mineralized bone tissue) obtained from contact radiography
Homolka et al. (2002)		Homolka et al. (2002): Human cadaver jaws. DQCT (dental quantitative CT). BMD correlated with insertion torque ($r^2 = 0.83$)
Homolka et al. (2001)		Homolka et al. (2001): BMD values converted to color maps
Beer et al. (2003)		Beer et al.: Human cadaver jaws. BMD correlated with insertion torque
Kido et al. (1997)	HU converted to BMD (mg/cm^3)	Kido et al.: Human cadaver jaws
Nkenke et al. (2003)	HU converted to BMD (mg/cm^3)	Nkenke et al.: Human cadaver jaws. BMD was correlated with measurements made by insertion torque (N cm), Periotest and by resonance frequency (ISQ). Several parameters were assessed in histomorphometry. Correlations with BMD were not calculated
	Assessment method: DEXA	
Gulsahi et al. (2007)	Bone mineral density (BMD, g/cm^2)	Gulsahi et al.: Jawbone measurements correlated with femoral neck measurements
	Bone mineral content (BMC, g/cm)	
	Assessment method: Weight and volume measurements	
Misch et al. (1999b)	Bone density Specimen wet weight/specimen structure volume (g/cm^3)	Misch et al. (1999b): Human cadaver jaws. Bone density with bone marrow was calculated by dividing specimen structure volume by the specimen wet weight
	Assessment method: Radiography and at surgery	
Misch et al. (1999a)	Bone density groups (bone quality) D1 = most dense bone D2 D3 D4 = least dense bone	Misch et al. (1999a): Panoramic and periapical radiography, lateral cephalography and CT when indicated. The original classification system according to Misch (1988): D1 = almost all dense compact D2 = a combination of dense to porous compact cortical bone on the outside and "coarse" trabecular bone on the inside D3 = porous, thinner cortical bone and "fine" trabecular bone D4 = "fine" trabecular bone that has very light density and little or no cortical crestal bone
	Assessment method: During surgery/at implant placement	
Yang et al. (2008)	Dense Normal Soft	Yang et al.: Surgeon's hand-felt resistance of bone drilling. Refer to Trisi & Rao (1999); Khang et al. (2001)

Publications on planning and placement of dental implants where jawbone tissue was described only as bone density.
BMD, bone mineral density; BV/TV, trabecular bone volume per tissue volume; CBV/TV, cortical bone volume per tissue volume; CT, computed tomography; HU, Hounsfield units; QCT, quantitative computed tomography; ROI, region of interest; TBPf, trabecular bone pattern factor; TBV, trabecular bone volume; TTBV, total trabecular bone volume.

surement units are essential prerequisites for comparing the results of different studies and for improving our understanding of treatment outcomes in relation to different bone characteristics. If there is no distinct and generally accepted definition of bone tissue characteristics, comparisons of results cannot be trusted. Moreover, recording of methods to select and generate samples should be reported (Altman et al. 2001; Moher et al. 2001) in order to ensure representativeness. It should be possible to develop more homogeneous categories in which to place those that are of importance to the treatment outcome.

The first step should be the use of more uniform classification and assessment methods. We propose the classification system presented by Lekholm & Zarb for several reasons: (1) it is well-known; (2) it describes jawbone tissue from both qualitative and quantitative aspects; and (3) results indicate a good correlation with bone mineral content (Bergkvist et al. 2010). The second step is to validate the classification, analyze diagnostic accuracy and describe observer performance of the method utilized to assess bone tissue. As emphasized in our previous study, a reference method must be identified by which a test method can be validated. To accomplish this, studies on human cadavers are essential.

Whatever classification system is applied and referred to, it should be strictly followed in order



Bone quality: A classification of the jaws with regard to jawbone quality recognized four groups - 1 to 4. The assessment methods recommended were the same as suggested for residual jaw shape or contour together with explorative drilling at implant site.

Residual jaw shape or contour: The proposed classification included five general groups - A to E. Clinical assessment (palpation and probing through the mucosa) and radiography (periapical, panoramic and lateral cephalostatic radiography, and sometimes tomography and occlusal radiography) were recommended

Fig. 1. Original description according to Lekholm & Zarb (1985) with kind permission from Quintessence Publishing Co. Inc.

to enable comparisons and meta-analyses of the results of different studies. Not only bone tissue categories but also the patient sample, the examination methods used and the means of assessing treatment outcomes should be described, particularly in clinical trials for the purpose of analyzing the possible influence of bone tissue characteristics on implant treatment outcomes. Given that bone characteristics vary within the same jaw (Lindh et al. 2004), we propose that each implant site be assessed and characterized in such clinical trials.

References

Aalam, A.A. & Nowzari, H. (2005) Clinical evaluation of dental implants with surfaces roughened by anodic oxidation, dual acid-etched implants, and machined implants. *The International Journal of Oral & Maxillofacial Implants* **20**: 793–798.

Aalam, A.A., Nowzari, H. & Krivitsky, A. (2005) Functional restoration of implants on the day of surgical placement in the fully edentulous mandible: a case series. *Clinical Implant Dentistry & Related Research* **7**: 10–16.

Achilli, A., Tura, F. & Euwe, E. (2007) Immediate/early function with tapered implants supporting maxillary and mandibular posterior fixed partial dentures: preliminary results of a prospective multicenter study. *The Journal of Prosthetic Dentistry* **97**: S52–S58.

Alsaadi, G., Quirynen, M., Michiels, K., Jacobs, R. & van Steenberghe, D. (2007) A biomechanical assessment of the relation between the oral implant stability at insertion and subjective bone quality assessment. *Journal of Clinical Periodontology* **34**: 359–366.

Alsaadi, G., Quirynen, M., Michiles, K., Teughels, W., Komarek, A. & van Steenberghe, D. (2008) Impact of local and systemic factors on the incidence of failures up to abutment connection with modified surface oral implants. *Journal of Clinical Periodontology* **35**: 51–57.

Altman, D.G., Schulz, K.F., Moher, D., Egger, M., Davidoff, F., Elbourne, D., Gøtzsche, P.C. & Lang, T. (2001) The revised CONSORT statement for reporting randomized trials: explanation and elaboration. *Annals of Internal Medicine* **134**: 663–694.

Aranyarachkul, P., Caruso, J., Gantes, B., Schulz, E., Riggs, M., Dus, I., Yamada, J.M. & Crigger, M. (2005) Bone density assessments of dental implant sites: 2. Quantitative cone-beam computerized tomography. *The International Journal of Oral & Maxillofacial Implants* **20**: 416–424.

Attard, N.J. & Zarb, G.A. (2002) A study of dental implants in medically treated hypothyroid patients. *Clinical Implant Dentistry & Related Research* **4**: 220–231.

Attard, N.J. & Zarb, G.A. (2004) Long-term treatment outcomes in edentulous patients with implant overdentures: the toronto study. *The International Journal of Prosthodontics* **17**: 425–433.

Bahat, O. (2000) Branemark system implants in the posterior maxilla: clinical study of 660 implants followed for 5 to 12 years. *The International Journal of Oral & Maxillofacial Implants* **15**: 646–653.

Bass, S.L. & Triplett, R.G. (1991) The effects of preoperative resorption and jaw anatomy on implant success. A report of 303 cases. *Clinical Oral Implants Research* **2**: 193–198.

Becker, B.E., Becker, W., Ricci, A. & Geurs, N. (1998) A prospective clinical trial of endosseous screw-shaped implants placed at the time of tooth extraction without augmentation. *Journal of Periodontology* **69**: 920–926.

Becker, W. & Becker, B.E. (1995) Replacement of maxillary and mandibular molars with single endosseous implant restorations: a retrospective study. *The Journal of Prosthetic Dentistry* **74**: 51–55.

Becker, W., Becker, B.E., Alsuwyed, A. & Al-Mubarak, S. (1999) Long-term evaluation of 282 implants in maxillary and mandibular molar positions: a prospective study. *Journal of Periodontology* **70**: 896–901.

Becker, W., Becker, B.E., Israelson, H., Lucchini, J.P., Handelsman, M., Ammons, W., Rosenberg, E., Rose, L., Tucker, L.M. & Lekholm, U. (1997) One-step surgical placement of Branemark implants: a prospective multicenter clinical study. *The International Journal of Oral & Maxillofacial Implants* **12**: 454–462.

Becker, W., Becker, B.E., Ricci, A., Bahat, O., Rosenberg, E., Rose, L.F., Handelsman, M. & Israelson, H. (2000a) A prospective multicenter clinical trial comparing one- and two-stage titanium screw-shaped fixtures with one-stage plasma-sprayed solid-screw fixtures. *Clinical Implant Dentistry & Related Research* **2**: 159–165.

Becker, W., Goldstein, M., Becker, B.E. & Sennerby, L. (2005) Minimally invasive flapless implant surgery: a prospective multicenter study. *Clinical Implant Dentistry & Related Research* **7** (Suppl. 1): S21–S27.

Becker, W., Hujoel, P.P., Becker, B.E. & Willingham, H. (2000b) Osteoporosis and implant failure: an exploratory case-control study. *Journal of Periodontology* **71**: 625–631.

Beer, A., Gahleitner, A., Holm, A., Tschabitscher, M. & Homolka, P. (2003) Correlation of insertion torques with bone mineral density from dental quantitative CT in the mandible. *Clinical Oral Implants Research* **14**: 616–620.

Bergendal, T. & Engquist, B. (1998) Implant-supported overdentures: a longitudinal prospective study. *The International Journal of Oral & Maxillofacial Implants* **13**: 253–262.

Bergkvist, G., Koh, K.J., Sahlholm, S., Klintstrom, E. & Lindh, C. (2010) Bone density at implant sites and its relationship to assessment of bone quality and treatment outcome. *The International Journal of Oral & Maxillofacial Implants* **25**: 321–328.

Bergkvist, G., Sahlholm, S., Nilner, K. & Lindh, C. (2004) Implant-supported fixed prostheses in the edentulous maxilla. A 2-year clinical and radiological follow-up of treatment with non-submerged ITI implants. *Clinical Oral Implants Research* **15**: 351–359.

Bischof, M., Nedir, R., Szmukler-Moncler, S., Bernard, J.P. & Samson, J. (2004) Implant stability measurement of delayed and immediately loaded implants during healing. *Clinical Oral Implants Research* **15**: 529–539.

Blanes, R.J., Bernard, J.P., Blanes, Z.M. & Belser, U.C. (2007) A 10-year prospective study of ITI dental implants placed in the posterior region. I: clinical and radiographic results. *Clinical Oral Implants Research* **18**: 699–706.

Brånemark, P.I., Zarb, G.A., Albrektsson, T. (eds.) (1985) Tissue-integrated prostheses: osseointegration in clinical dentistry. 1st editon, Chicago: Quintessence Publishing Co. 356pp.

Calandriello, R., Tomatis, M. & Rangert, B. (2003) Immediate functional loading of Branemark system implants with enhanced initial stability: a prospective 1- to 2-year clinical and radiographic study. *Clinical Implant Dentistry & Related Research* **5** (Suppl. 1): 10–20.

Choel, L., Duboeuf, F., Bourgeois, D., Briguet, A. & Lissac, M. (2003) Trabecular alveolar bone in the human mandible: a dual-energy x-ray absorptiometry study. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **95**: 364–370.

Choel, L., Last, D., Duboeuf, F., Seurin, M.J., Lissac, M., Briguet, A. & Guillot, G. (2004) Trabecular alveolar bone microarchitecture in the human mandible using high resolution magnetic resonance imaging. *Dentomaxillofacial Radiology* **33**: 177–182.

Chou, C.T., Morris, H.F., Ochi, S., Walker, L. & DesRosiers, D. (2004) AICRG, part II: Crestal bone loss associated with the ankylos implant: loading to 36 months. *The Journal of Oral Implantology* **30**: 134–143.

Collaert, B. & De Bruyn, H. (2008) Immediate functional loading of TiOblast dental implants in full-arch edentulous maxillae: a 3-year prospective study. *Clinical Oral Implants Research* **19**: 1254–1260.

Degidi, M., Piattelli, A., Iezzi, G. & Carinci, F. (2007) Do longer implants improve clinical outcome in immediate loading? *The International Journal of Oral and Maxillofacial Surgery* **36**: 1172–1176.

Dorland's Illustrated Medical Dictionary, 31st edition, Philadelphia, W. B. Saunders, p. 2088, 2007

Elkhoury, J.S., McGlumphy, E.A., Tatakis, D.N. & Beck, F.M. (2005) Clinical parameters associated with success and failure of single-tooth titanium plasma-sprayed cylindric implants under stricter criteria: a 5-year retrospective study. *The International Journal of Oral & Maxillofacial Implants* **20**: 687–694.

Engquist, B., Bergendal, T., Kallus, T. & Linden, U. (1988) A retrospective multicenter evaluation of osseointegrated implants supporting overdentures. *The International Journal of Oral & Maxillofacial Implants* **3**: 129–134.

Fartash, B., Tangerud, T., Silness, J. & Arvidson, K. (1996) Rehabilitation of mandibular edentulism by single crystal sapphire implants and overdentures: 3–12 year results in 86 patients. A dual center international study. *Clinical Oral Implants Research* **7**: 220–229.

Friberg, B. (1994) Bone quality evaluation during implant placement.Thesis, University of Gothenburg, Gothenburg, 41pp.

Friberg, B. Billström, C. (2002) Preliminary results of a prosperative multicenter clinical study on TiUnite implants. *Applied Osseointegration Research* **3**: 29–31.

Friberg, B., Dahlin, C., Widmark, G., Ostman, P.O. & Billstrom, C. (2005) One-year results of a prospective multicenter study on Branemark System implants with a TiUnite surface. *Clinical Implant Dentistry & Related Research* **7** (Suppl. 1): S70–S75.

Friberg, B., Ekestubbe, A. & Sennerby, L. (2002) Clinical outcome of Branemark System implants of various diameters: a retrospective study. *The International Journal of Oral & Maxillofacial Implants* **17**: 671–677.

Friberg, B., Grondahl, K. & Lekholm, U. (1992) A new self-tapping Branemark implant: clinical and radiographic evaluation. *The International Journal of Oral & Maxillofacial Implants* **7**: 80–85.

Friberg, B., Jemt, T. & Lekholm, U. (1991) Early failures in 4,641 consecutively placed Branemark dental implants: a study from stage 1 surgery to the connection of completed prostheses. *The International Journal of Oral & Maxillofacial Implants* **6**: 142–146.

Friberg, B., Jisander, S., Widmark, G., Lundgren, A., Ivanoff, C.J., Sennerby, L. & Thoren, C. (2003) One-year prospective three-center study comparing the outcome of a "Soft bone implant" (prototype Mk IV) and the standard Branemark implant. *Clinical Implant Dentistry & Related Research* **5**: 71–77.

Friberg, B., Sennerby, L., Grondahl, K., Bergstrom, C., Back, T. & Lekholm, U. (1999) On cutting torque measurements during implant placement: a 3-year clinical prospective study. *Clinical Implant Dentistry & Related Research* **1**: 75–83.

Friberg, B., Sennerby, L., Roos, J. & Lekholm, U. (1995) Identification of bone quality in conjunction with insertion of titanium implants. A pilot study in jaw autopsy specimens. *Clinical Oral Implants Research* **6**: 213–219.

Ganeles, J., Zollner, A., Jackowski, J., ten Bruggenkate, C., Beagle, J. & Guerra, F. (2008) Immediate and early loading of Straumann implants with a chemically modified surface (SLActive) in the posterior mandible and maxilla: 1-year results from a prospective multicenter study. *Clinical Oral Implants Research* **19**: 1119–1128.

Gaucher, H., Bentley, K., Roy, S., Head, T., Blomfield, J., Blondeau, F., Nicholson, L., Chehade, A., Tardif, N. & Emery, R. (2001) A multi-centre study of Osseotite implants supporting mandibular restorations: a 3-year report. *Journal of the Canadian Dental Association* **67**: 528–533.

Goodman, C. (1996) Literature searching and evidence interpretation for assessing health care practices. The Swedish Council on Technology Assessment in Health Care, Stockholm.

Grunder, U., Polizzi, G., Goene, R., Hatano, N., Henry, P., Jackson, W.J., Kawamura, K., Kohler, S., Renouard, F., Rosenberg, R., Triplett, G., Werbitt, M. & Lithner, B. (1999) A 3-year prospective multicenter follow-up report on the immediate and delayed-immediate placement of implants. *The International Journal of Oral & Maxillofacial Implants* **14**: 210–216.

Gulsahi, A., Paksoy, C.S., Yazicioglu, N., Arpak, N., Kucuk, N.O. & Terzioglu, H. (2007) Assessment of bone density differences between conventional and bone-condensing techniques using dual energy x-ray absorptiometry and radiography. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **104**: 692–698.

Herrmann, I., Kultje, C., Holm, S. & Lekholm, U. (2007) A study on variances in multivariate analyses of oral implant outcome. *Clinical Implant Dentistry & Related Research* **9**: 6–14.

Herrmann, I., Lekholm, U., Holm, S. & Kultje, C. (2005) Evaluation of patient and implant characteristics as potential prognostic factors for oral implant failures. *The International Journal of Oral & Maxillofacial Implants* **20**: 220–230.

Homolka, P., Beer, A., Birkfellner, W., Gahleitner, A., Nowotny, R. & Bergmann, H. (2001) Local calibrated bone mineral density in the mandible presented using a color coding scheme. *Medical Engineering & Physics* **23**: 673–677.

Homolka, P., Beer, A., Birkfellner, W., Nowotny, R., Gahleitner, A., Tschabitscher, M. & Bergmann, H. (2002) Bone mineral density measurement with dental quantitative CT prior to dental implant placement in cadaver mandibles: pilot study. *Radiology* **224**: 247–252.

Horner, K. & Devlin, H. (1998) The relationships between two indices of mandibular bone quality and bone mineral density measured by dual energy x-ray absorptiometry. *Dentomaxillofacial Radiology* **27**: 17–21.

Hutton, J.E., Heath, M.R., Chai, J.Y., Harnett, J., Jemt, T., Johns, R.B., McKenna, S., McNamara, D.C., van Steenberghe, D. Taylor, R., Watson, R.M., Herrmann, I. (1995) Factors related to success and failure rates at 3-year follow-up in a multicenter study of overdentures supported by Branemark implants. *The International Journal of Oral & Maxillofacial Implants* **10**: 33–42.

Huwiler, M.A., Pjetursson, B.E., Bosshardt, D.D., Salvi, G.E. & Lang, N.P. (2007) Resonance frequency analysis in relation to jawbone characteristics and during early healing of implant installation. *Clinical Oral Implants Research* **18**: 275–280.

Ibanez, J.C. & Jalbout, Z.N. (2002) Immediate loading of Osseotite implants: two-year results. *Implant Dentistry* **11**: 128–136.

Ivanoff, C.J., Grondahl, K., Sennerby, L., Bergstrom, C. & Lekholm, U. (1999) Influence of variations in implant diameters: a 3- to 5-year retrospective clinical report. *The International Journal of Oral & Maxillofacial Implants* **14**: 173–180.

Jaffin, R.A. & Berman, C.L. (1991) The excessive loss of Branemark fixtures in type IV bone: a 5-year analysis. *Journal of Periodontology* **62**: 2–4.

Jagger, R.G., Shaikh, S. & Jagger, D.C. (2001) Clinical effectiveness of mandibular implant-retained overdentures. *Prima Dental Care* **8**: 19–24.

Jemt, T. (1993) Implant treatment in resorbed edentulous upper jaws. A three-year follow-up on 70 patients. *Clinical Oral Implants Research* **4**: 187–194.

Jemt, T. (1994) Fixed implant-supported prostheses in the edentulous maxilla. A five-year follow-up report. *Clinical Oral Implants Research* **5**: 142–147.

Jemt, T. & Hager, P. (2006) Early complete failures of fixed implant-supported prostheses in the edentulous maxilla: a 3-year analysis of 17 consecutive cluster failure patients. *Clinical Implant Dentistry & Related Research* **8**: 77–86.

Jemt, T. & Lekholm, U. (1995) Implant treatment in edentulous maxillae: a 5-year follow-up report on patients with different degrees of jaw resorption. *The International Journal of Oral & Maxillofacial Implants* **10**: 303–311.

Johansson, P. & Strid, K.G. (1994) Assessment of bone quality from cutting resistance during implant surgery. *The International Journal of Oral & Maxillofacial Implants* **9**: 279–288.

Johns, R.B., Jemt, T., Heath, M.R., Hutton, J.E., McKenna, S., McNamara, D.C., van Steenberghe, D., Taylor, R., Watson, R.M. & Herrmann, I. (1992) A multicenter study of overdentures supported by Branemark implants. *The International Journal of Oral & Maxillofacial Implants* **7**: 513–522.

Khang, W., Feldman, S., Hawley, C.E. & Gunsolley, J. (2001) A multi-center study comparing dual acid-etched

and machined-surfaced implants in various bone qualities. *Journal of Periodontology* **72**: 1384–1390.

Kido, H., Schulz, E.E., Kumar, A., Lozada, J. & Saha, S. (1997) Implant diameter and bone density: effect on initial stability and pull-out resistance. *The Journal of Oral Implantology* **23**: 163–169.

Kourtis, S.G., Sotiriadou, S., Voliotis, S. & Challas, A. (2004) Private practice results of dental implants. Part I: survival and evaluation of risk factors – part II: Surgical and prosthetic complications. *Implant Dentistry* **13**: 373–385.

Lee, S., Gantes, B., Riggs, M. & Crigger, M. (2007) Bone density assessments of dental implant sites: 3. Bone quality evaluation during osteotomy and implant placement. *The International Journal of Oral & Maxillofacial Implants* **22**: 208–212.

Lekholm, U. & Zarb, G.A. (1985) Patient selection and preparation. In: Brånemark, P.-I., Zarb, G.A. & Albrektsson, T., eds. *Tissue Integrated Prostheses: Osseointegration in Clinical Dentistry*, 199–209. Chicago, IL: Quintessence.

Lettry, S., Seedhom, B.B., Berry, E. & Cuppone, M. (2003) Quality assessment of the cortical bone of the human mandible. *Bone* **32**: 35–44.

Lindh, C., Nilsson, M., Klinge, B. & Petersson, A. (1996a) Quantitative computed tomography of trabecular bone in the mandible. *Dentomaxillofacial Radiology* **25**: 146–150.

Lindh, C., Obrant, K. & Petersson, A. (2004) Maxillary bone mineral density and its relationship to the bone mineral density of the lumbar spine and hip. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics* **98**: 102–109.

Lindh, C., Petersson, A., Klinge, B. & Nilsson, M. (1997) Trabecular bone volume and bone mineral density in the mandible. *Dentomaxillofacial Radiology* **26**: 101–106.

Lindh, C., Petersson, A. & Rohlin, M. (1996b) Assessment of the trabecular pattern before endosseous implant treatment: diagnostic outcome of periapical radiography in the mandible. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **82**: 335–343.

Locante, W.M. (2004) Single-tooth replacements in the esthetic zone with an immediate function implant: a preliminary report. *The Journal of Oral Implantology* **30**: 369–375.

Malo, P., Nobre Mde, A., Petersson, U. & Wigren, S. (2006) A pilot study of complete edentulous rehabilitation with immediate function using a new implant design: case series. *Clinical Implant Dentistry & Related Research* **8**: 223–232.

Manz, M.C. (1997) Radiographic assessment of periimplant vertical bone loss: DICRG interim report no. 9. *The International Journal of Oral and Maxillofacial Surgery* **55**: 62–71.

Manz, M.C. (2000) Factors associated with radiographic vertical bone loss around implants placed in a clinical study. *Annals of Periodontology* **5**: 137–151.

Meredith, N., Alleyne, D. & Cawley, P. (1996) Quantitative determination of the stability of the implant-tissue interface using resonance frequency analysis. *Clinical Oral Implants Research* **7**: 261–267.

Merriam-Webster Online Dictionary. Available at http://www.m-w.com/cgi-bin/dictionary?book=Dictionary&va=quantity (accessed April 6, 2006).

Misch, C.E. (1988) Bone character: second vital implant criteria. *Dentistry Today* **7**: 39–40.

Misch, C.E. (1990a) Division of available bone in implant dentistry. International. *The International Journal of Oral Implantology* **7**: 9–17.

Misch, C.E. (1990b) Density of bone: effect on treatment plans, surgical approach, healing, and progressive bone loading. *The International Journal of Oral Implantology* **6**: 23–31.

Misch, C.E., Dietsh-Misch, F., Hoar, J., Beck, G., Hazen, R. & Misch, C.M. (1999a) A bone quality-based implant system: first year of prosthetic loading. *The Journal of Oral Implantology* **25**: 185–197.

Misch, C.E., Qu, Z. & Bidez, M.W. (1999b) Mechanical properties of trabecular bone in the human mandible: implications for dental implant treatment planning and surgical placement. *The International Journal of Oral and Maxillofacial Surgery* **57**: 700–706; discussion 706–708.

Moheng, P. & Feryn, J.M. (2005) Clinical and biologic factors related to oral implant failure: a 2-year follow-up study. *Implant Dentistry* **14**: 281–288.

Moher, D., Schulz, K.F. & Altman, D. (2001) The CONSORT statement: revised recommendations for improving the quality of reports of parallel-group randomized trials. *Annals of Internal Medicine* **134**: 657–662.

Montes, C.C., Pereira, F.A., Thome, G., Alves, E.D., Acedo, R.V., de Souza, J.R., Melo, A.C. & Trevilatto, P.C. (2007) Failing factors associated with osseointegrated dental implant loss. *Implant Dentistry* **16**: 404–412.

Morris, H.F., Ochi, S., Crum, P., Orenstein, I.H. & Winkler, S. (2004) AICRG, part I: a 6-year multicentered, multidisciplinary clinical study of a new and innovative implant design. *The Journal of Oral Implantology* **30**: 125–133.

National Library of Medicine and National Institutes of Health. Mesh browser. Available at http://www.ncbi.nlm.nih.gov/mesh/ (accessed April 11, 2010)

Nkenke, E., Hahn, M., Weinzierl, K., Radespiel-Troger, M., Neukam, F.W. & Engelke, K. (2003) Implant stability and histomorphometry: a correlation study in human cadavers using stepped cylinder implants. *Clinical Oral Implants Research* **14**: 601–609.

Oikarinen, K., Raustia, A.M. & Hartikainen, M. (1995) Prosthetic possibilities using endosseal implants as anchorages – an epidemiological study in 65-year-old subjects. *Journal of Oral Rehabilitation* **22**: 403–407.

Orenstein, I.H., Tarnow, D.P., Morris, H.F. & Ochi, S. (1998) Factors affecting implant mobility at placement and integration of mobile implants at uncovering. *Journal of Periodontology* **69**: 1404–1412.

Orenstein, I.H., Tarnow, D.P., Morris, H.F. & Ochi, S. (2000) Three-year post-placement survival of implants mobile at placement. *Annals of Periodontology* **5**: *32–41.*

Orsini, G., Piattelli, M., Scarano, A., Petrone, G., Kenealy, J., Piattelli, A. & Caputi, S. (2007) Randomized, controlled histologic and histomorphometric evaluation of implants with nanometer-scale calcium phosphate added to the dual acid-etched surface in the human posterior maxilla. *Journal of Periodontology* **78**: 209–218.

Ostman, P.O., Hellman, M. & Sennerby, L. (2005) Direct implant loading in the edentulous maxilla using a bone density-adapted surgical protocol and primary implant stability criteria for inclusion. *Clinical Implant Dentistry & Related Research* **7** (Suppl. 1): S60–S69.

Ostman, P.O., Hellman, M., Wendelhag, I. & Sennerby, L. (2006) Resonance frequency analysis measurements of implants at placement surgery. *The International Journal of Prosthodontics* **19**: 77–83; discussion 84.

O'Sullivan, D., Sennerby, L. & Meredith, N. (2000) Measurements comparing the initial stability of five designs of dental implants: a human cadaver study. *Clinical Implant Dentistry & Related Research* **2**: 85–92.

Ottoni, J.M., Oliveira, Z.F., Mansini, R. & Cabral, A.M. (2005) Correlation between placement torque and survival of single-tooth implants. *The International Journal of Oral & Maxillofacial Implants* **20**: 769–776.

Razavi, R., Zena, R.B., Khan, Z. & Gould, A.R. (1995) Anatomic site evaluation of edentulous maxillae for dental implant placement. *Journal of Prosthodontics* **4**: 90–94.

Recker, R.R. & Barger-Lux, M.J. (2004) The elusive concept of bone quality. *Current Osteoporosis Reports* **2**: 97–100.

Ribeiro-Rotta, R.F., Lindh, C. & Rohlin, M. (2007) Efficacy of clinical methods to assess jawbone tissue prior to and during endosseous dental implant placement: a systematic literature review. *The International Journal of Oral & Maxillofacial Implants* **22**: 289–300.

Rocci, A., Martignoni, M. & Gottlow, J. (2003) Immediate loading of Branemark system TiUnite and machined-surface implants in the posterior mandible: a randomized open-ended clinical trial. *Clinical Implant Dentistry & Related Research* **5** (Suppl. 1): 57–63.

Romeo, E., Lops, D., Amorfini, L., Chiapasco, M., Ghisolfi, M. & Vogel, G. (2006) Clinical and radiographic evaluation of small-diameter (3.3-mm) implants followed for 1–7 years: a longitudinal study. *Clinical Oral Implants Research* **17**: 139–148.

Saadoun, A.P. & LeGall, M.L. (1992) Clinical results and guidelines on Steri-Oss endosseous implants. *The International Journal of Periodontics & Restorative Dentistry* **12**: 486–495.

Schulte, W. & Lukas, D. (1993) Periotest to monitor osseointegration and to check the occlusion in oral implantology. *The Journal of Oral Implantology* **19**: 23–32.

Shahlaie, M., Gantes, B., Schulz, E., Riggs, M. & Crigger, M. (2003) Bone density assessments of dental implant sites: 1. Quantitative computed tomography. *The International Journal of Oral & Maxillofacial Implants* **18**: 224–231.

Shapurian, T., Damoulis, P.D., Reiser, G.M., Griffin, T.J. & Rand, W.M. (2006) Quantitative evaluation of bone density using the Hounsfield index. *The International Journal of Oral & Maxillofacial Implants* **21**: 290–297.

Shea, B.J., Grimshaw, J.M., Wells, G.A., Boers, M., Andersson, N., Hamel, C., Porter, A.C., Tugwell, P., Moher, D. & Bouter, L.M. (2007) Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. *BMC Medical Research Methodology* **7**: 10. Available at http://www.biomedcentral.com/1471-2288/7/10.

Shimpuku, H., Nosaka, Y., Kawamura, T., Tachi, Y., Shinohara, M. & Ohura, K. (2003) Genetic polymorphisms of the interleukin-1 gene and early mar-

ginal bone loss around endosseous dental implants. *Clinical Oral Implants Research* **14**: 423–429.

Shin, S.W., Bryant, S.R. & Zarb, G.A. (2004) A retrospective study on the treatment outcome of wide-bodied implants. *The International Journal of Prosthodontics* **17**: 52–58.

Siepenkothen, T. (2007) Clinical performance and radiographic evaluation of a novel single-piece implant in a private practice over a mean of seventeen months. *The Journal of Prosthetic Dentistry* **97**: S69–S78.

Spray, J.R., Black, C.G., Morris, H.F. & Ochi, S. (2000) The influence of bone thickness on facial marginal bone response: stage 1 placement through stage 2 uncovering. *Annals of Periodontology* **5**: 119–128.

Steadman's Medical Dictionary, 26th edition, Baltimore,Williams & Wilkins, 1995.

Sullivan, D., Vincenzi, G. & Feldman, S. (2005) Early loading of Osseotite implants 2 months after placement in the maxilla and mandible: a 5-year report. *The International Journal of Oral & Maxillofacial Implants* **20**: 905–912.

Taguchi, A., Tanimoto, K., Akagawa, Y., Suei, Y., Wada, T. & Rohlin, M. (1997) Trabecular bone pattern of the mandible. Comparison of panoramic radiography with computed tomography. *Dentomaxillofacial Radiology* **26**: 85–89.

Taguchi, A., Tanimoto, K., Ogawa, M., Sunayashiki, T. & Wada, T. (1991) Effect of size of region of interest on precision of bone mineral measurements of the mandible by quantitative computed tomography. *Dentomaxillofacial Radiology* **20**: 25–29.

Tawil, G. & Younan, R. (2003) Clinical evaluation of short, machined-surface implants followed for 12 to 92 months. *The International Journal of Oral & Maxillofacial Implants* **18**: 894–901.

Testori, T., Del Fabbro, M., Feldman, S., Vincenzi, G., Sullivan, D., Rossi, R. Jr, Anitua, E., Bianchi, F., Francetti, L. & Weinstein, R.L. (2002) A multicenter prospective evaluation of 2-months loaded Osseotite implants placed in the posterior jaws: 3-year follow-up results. *Clinical Oral Implants Research* **13**: 154–161.

The American Heritage Dictionary of the English Language, 3rd edition, Boston, Houghton, 1992.

Trisi, P. & Rao, W. (1999) Bone classification: clinical-histomorphometric comparison. *Clinical Oral Implants Research* **10**: 1–7.

Truhlar, R.S., Farish, S.E., Scheitler, L.E., Morris, H.F. & Ochi, S. (1997a) Bone quality and implant design-related outcomes through stage II surgical uncovering of spectra-system root form implants. *The International Journal of Oral and Maxillofacial Surgery* **55**: 46–54.

Truhlar, R.S., Lauciello, F., Morris, H.F. & Ochi, S. (1997b) The influence of bone quality on periotest values of endosseous dental implants at stage II surgery. *The International Journal of Oral and Maxillofacial Surgery* **55**: 55–61.

Truhlar, R.S., Morris, H.F. & Ochi, S. (2000a) Stability of the bone-implant complex. Results of longitudinal testing to 60 months with the periotest device on endosseous dental implants. *Annals of Periodontology* **5**: 42–55.

Truhlar, R.S., Morris, H.F. & Ochi, S. (2000b) Implant surface coating and bone quality-related survival outcomes through 36 months post-placement of root-form endosseous dental implants. *Annals of Periodontology* **5**: 109–108.

Truhlar, R.S., Morris, H.F., Ochi, S. & Winkler, S. (1994a) Assessment of implant mobility at second-stage surgery with the periotest: DICRG interim report no. 3. Dental implant clinical research group. *Implant Dentistry* **3**: 153–156.

Truhlar, R.S., Morris, H.F., Ochi, S. & Winkler, S. (1994b) Second-stage failures related to bone quality in patients receiving endosseous dental implants: DICRG interim report no. 7. Dental implant clinical research group. *Implant Dentistry* **3**: 252–255.

Truhlar, R.S., Orenstein, I.H., Morris, H.F. & Ochi, S. (1997c) Distribution of bone quality in patients receiving endosseous dental implants. *The International Journal of Oral and Maxillofacial Surgery* **55**: 38–45.

Turkyilmaz, I., Aksoy, U. & McGlumphy, E.A. (2008a) Two alternative surgical techniques for enhancing primary implant stability in the posterior maxilla: a clinical study including bone density, insertion torque, and resonance frequency analysis data. *Clinical Implant Dentistry & Related Research* **10**: 231–237.

Turkyilmaz, I., Ozan, O., Yilmaz, B. & Ersoy, A.E. (2008b) Determination of bone quality of 372 implant recipient sites using Hounsfield unit from computerized tomography: a clinical study. *Clinical Implant Dentistry & Related Research* **10**: 238–244.

Turkyilmaz, I., Tozum, T.F. & Tumer, C. (2007a) Bone density assessments of oral implant sites using computerized tomography. *Journal of Oral Rehabilitation* **34**: 267–272.

Turkyilmaz, I., Tozum, T.F., Tumer, C. & Ozbek, E.N. (2006) Assessment of correlation between computerized tomography values of the bone, and maximum torque and resonance frequency values at dental implant placement. *Journal of Oral Rehabilitation* **33**: 881–888.

Turkyilmaz, I., Tumer, C., Ozbek, E.N. & Tozum, T.F. (2007b) Relations between the bone density values from computerized tomography, and implant stability parameters: a clinical study of 230 regular platform implants. *Journal of Clinical Periodontology* **34**: 716–722.

Ulm, C.W., Kneissel, M., Hahn, M., Solar, P., Matejka, M. & Donath, K. (1997) Characteristics of the cancellous bone of edentulous mandibles. *Clinical Oral Implants Research* **8**: 125–130.

van Steenberghe, D., Jacobs, R., Desnyder, M., Maffei, G. & Quirynen, M. (2002) The relative impact of local and endogenous patient-related factors on implant failure up to the abutment stage. *Clinical Oral Implants Research* **13**: 617–622.

Walker, L., Morris, H.F. & Ochi, S. (1997) Periotest values of dental implants in the first 2 years after second-stage surgery: DICRG interim report no. 8. Dental implant clinical research group. *Implant Dentistry* **6**: 207–212.

Watts, N.B. (2002) Bone quality: getting closer to a definition. *Journal of Bone Mineral Research* **17**: 1148–1150.

Weng, D., Jacobson, Z., Tarnow, D., Hurzeler, M.B., Faehn, O., Sanavi, F., Barkvoll, P. & Stach, R.M. (2003) A prospective multicenter clinical trial of 3I machined-surface implants: results after 6 years of follow-up. *The International Journal of Oral & Maxillofacial Implants* **18**: 417–423.

Yang, S.M., Shin, S.Y. & Kye, S.B. (2008) Relationship between implant stability measured by resonance frequency analysis (RFA) and bone loss during early healing period. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **105**: e12–e19.

Zix, J., Kessler-Liechti, G. & Mericske-Stern, R. (2005) Stability measurements of 1-stage implants in the maxilla by means of resonance frequency analysis: a pilot study. *The International Journal of Oral & Maxillofacial Implants* **20**: 747–752.