Quantitative Evaluation of Bone Density Using the Hounsfield Index

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Purpose: *The primary aims of this retrospective study were to: (1) evaluate bone quality in different segments of the edentulous jaw and correlate it with demographic data and (2) establish a quantitative and objective assessment of bone quality based on the Hounsfield scale.* ***Materials and Methods:*** *One hundred one randomly selected computerized tomographic (CT) scans were used for the analysis. Edentulous segments ranging from 10 to 30 mm were selected for evaluation, and the findings were analyzed and correlated to demographics. Implant recipient sites were evaluated visually for bone classification by 2 independent examiners. The same sites were subsequently evaluated digitally using the Hounsfield scale, and the results were correlated with the visual classification.* ***Results:*** *The 4 quadrants of the mouth displayed Hounsfield unit (HU) values ranging from −240 HU to 1,159 HU. The highest unit/mean density value (559 ± 208 HU) was found in the anterior mandible, followed by 517 ± 177 HU for the anterior maxilla, 333 ± 199 HU for the posterior maxilla, and 321 ± 132 HU for the posterior mandible. There was no association between the Hounsfield value and density and age or gender. When subjective bone quality was correlated to Hounsfield index findings, only the relationship between HU and type 4 bone was found to be significant.* ***Conclusions:*** *Knowledge of the Hounsfield value as a quantitative measurement of bone density can be helpful as a diagnostic tool. It can provide the implant surgeon with an objective assessment of bone density, which could result in modification of surgical techniques or extended healing time, especially in situations where poor bone quality is suspected.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:290–297

Key words: *bone density, bone quality, dental implants, Hounsfield index*

In the last decade endosseous dental implants have become a popular first choice in the rehabilitation of the edentulous patient. Although long-term implant survival surpasses 85% to 90%, several systemic factors can predispose patients for higher rates of implant loss, including osteopenia, uncontrolled diabetes, alcohol abuse, and smoking.[1]

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Osteopenia is a generic term indicating a reduction in bone mass because of imbalance between bone resorption and formation. This results in bone mineral content loss and structural change in bone, which can lead to osteoporosis.[2] Structural modifications related to osteoporosis mainly affect cancellous bone, but cortical bone can be compromised as well, because of endosteal resorption and medullary expansion.

Although there is evidence to support a correlation between systemic and oral bone density, a causal nature to that association has not been firmly established.[3–9] Overall, the quality of the bone in osteoporotic jaws seems to have little importance if neither fracture nor residual ridge resorption takes place. However, once a tooth is lost, the impact of osteoporotic disease could be a major determinant in the success of dental implant therapy.[10] Furthermore, implant success seems to be influenced by bone quality.[11–15] *Bone quality* is a collective term referring to the mechanical properties, architecture, degree of mineralization of the bone matrix, and chemistry and structure of the bone mineral crystals, as well as the remodeling properties of bone.

Lekholm and Zarb[16] classified bone density into 4 types based on the amount of cortical versus cancellous bone in a given area of the alveolar process observed on a pantograph film. The term *quality* was introduced to refer to these density types. Misch[17] further characterized the 4 bone density classes based on the tactile sense of the clinician placing the implant.

Bone quality and quantity are typically estimated from radiographs or at the time of implant site preparation. It is assumed that implants placed in poor quality bone have a greater incidence of loss; however, a distinction between the 4 types of bone has not been clearly established. In most studies[15,18,19] classification of bone type was based on the subjective evaluation of the surgeon, and different operators were usually not calibrated during clinical or radiographic examination.

In 1972 Godfrey Hounsfield presented a novel imaging technique referred to as computerized axial transverse (CAT) scanning.[20] Computed tomography (CT) is currently the only diagnostically justifiable imaging technique that allows at least rough conclusions about the structure and density of the jawbones.[21] It is an excellent tool for assessing the relative distribution of compact and cancellous bone. Bone density can be evaluated using Hounsfield units (HU), which are directly related to tissue attenuation coefficients. The Hounsfield scale is based on density values for air, water, and dense bone, which are assigned arbitrarily values of −1,000, 0, and +1,000, respectively.

Using these parameters to establish a relative scale, a range of values was provided[22] for different types of bone, including very dense cortical bone (> 600 HU), dense cortical-spongy bone (between 400 and 600 HU), and cortical-spongy bone of low density (< 200 HU). The Hounsfield scale has been used to evaluate bone densities for implant placement,[23,24] and the results were considered site specific, objective, and quantitative.

The effect of osteopenia on long-term success of dental implants has not been unequivocally established. Therefore, establishment of objective criteria for evaluation of jawbone density might prove useful in improving predictability of implant therapy in patients who have been diagnosed with or are at risk of osteoporosis. The goals of this study were to *(1)* evaluate bone quality in different segments of edentulous maxilla/mandible based on the Hounsfield index and correlate the results with demographic data, *(2)* assess operator accuracy and reproducibility of bone quality determination based on Lekholm-Zarb classification, and *(3)* create a quantitative and objective scale of bone quality based on the Hounsfield index.

MATERIALS AND METHODS

For this retrospective study, which was approved by the Tufts–New England Medical Center institutional review board, Boston, MA, 101 CT scan images were randomly selected from a pool of 4,000 CT scans of patients who had undergone implant placement between 1997 and 2001 in a private practice. The CTs for this study were provided by Boston Imaging (Brookline, MA). A GE Hi-Speed helical scanner with a slice thickness of 1 mm was used (GE Healthcare Technologies, Waukesha, WI). The scanner was calibrated daily before the first patient according to the manufacturer's guidelines.

To utilize the Simplant/Master software (Materialise, Ann Arbor, MI) there should be no gantry tilt when the scan is performed. Ideally, the gantry (ie, the x-ray tube) is perpendicular to the field of examination (0 degree tilt) as it rotates around the body. For the patient's comfort, the gantry can be tilted and accounted for without causing any distortions to the image. Only CT scans where the gantry was set at 0 were used in this study. Each CT scan was copied on a CD-ROM and subsequently downloaded to a personal computer, creating a central database.

Traditionally, the segment of alveolar process mesial to the first premolar is considered anterior, whereas the one distal to and including the first premolar is considered posterior.[25] To evaluate bone quality in different segments of edentulous maxillae and mandibles using the Hounsfield index, 4 areas were defined in each hemimandible in each CT scan: maxillary zone 1, maxillary zone 2, mandibular zone 1, and mandibular zone 2. The most anterior wall of the maxillary sinus was used in the maxilla as an anatomic landmark separating zone 1 from zone 2. The mesial wall of the mental foramen was used for this purpose in the mandible.

Existing edentulous spaces that ranged from 10 to 30 mm in length were evaluated serially every 5 mm for bone density. On each selected transaxial image, 3 regions of interest with an area of 3.0 to 3.5 mm^2 in the path of optimum implant placement were considered (Fig 1a). Using the Simplant software, the mean Hounsfield value for each point was calculated. The average of these readings represented the density of that site. Potential correlation between alveolar bone density assessed using CT scans and alveolar process location, gender, age, and history of hormone replacement therapy (HRT) was explored.

To compare subjective bone quality determination with bone density evaluation using the Hounsfield index, 2 expert clinicians blindly evaluated implant sites randomly selected from every patient's CT scan. Three hundred nineteen sections

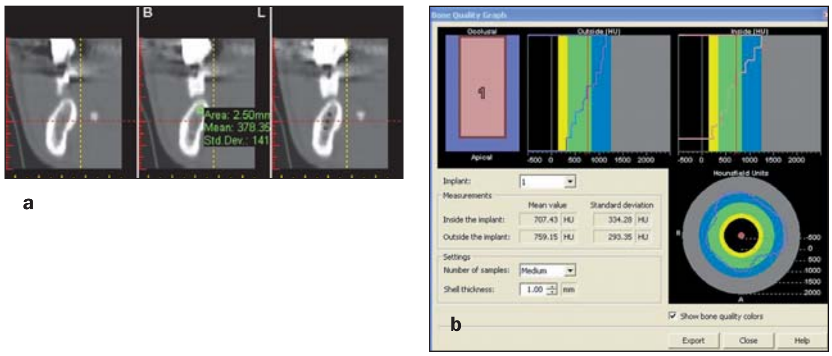

Fig 1 *(a)* Transaxial cut depicting 3 areas of interest in the path of optimum implant placement. Three areas of interest were selected from each scan to evaluate the bone density. The mean of these 3 values was used to correlate the Hounsfield index with the demographic data. *(b)* The bone quality measurement feature of the Simplant/Master was utilized to evaluate bone density 0.25 and 1.00 mm circumferentially around the length of a simulated implant.

were provided for analysis. For each site, 3 sections were selected for evaluation—the future implant site as well as the 2 flanking sections. Each clinician performed each evaluation on 2 separate occasions. Sections were evaluated in random order. Agreement within and between the examiners was assessed.

Software-based analysis of bone density was performed by a separate operator who had no knowledge of the bone type assigned by the 2 examiners. The selected sections were then assigned a number on the Hounsfield scale with the Simplant/Master software. For this analysis, the software required that the size and type of implant be specified (Fig 1b). This simulated implant placement is necessary so that bone quality in the immediate proximity of the future implant can be evaluated. This evaluation is of great interest, since it can affect the primary stability and maintenance of the osseointegrated interface. For all measurements, an implant size and type based on clinical data gathered from the patient record was selected from the menu. The implant was positioned in the optimum angulation as determined by the operator performing the analysis. Density of the bone around the implant was determined 0.25 mm and 1 mm circumferentially from the implant perimeter, and a mean value (± SD) was recorded. Since these readings can be affected by the contrast and brightness settings on the CT machine,[23] appropriate calibration is important. From the 319 sections initially selected, only those for which the 2 examiners were 100% in agreement were used for correlation with Hounsfield values.

Data Analysis

Data were collected in Microsoft Excel and imported to SPSS v 12 (SPSS, Chicago, IL) for description and analysis. Scatter plots and histograms of data were examined visually for indications of outliers and skew. Since visual examination showed no need to test for outliers or non-normality, no tests were run on the data at this stage, given the lack of sensitivity and power of the available tests. After this graphical examination, all variables were described using standard statistics. Because the scoring scale was ordinal, between- and within-examiner comparisons were evaluated with correlations and paired *t* tests. The relationships between Hounsfield values and demographic data were described and tested using *t* tests for dichotomous variables. Differences between the maxilla and mandible as well as between zones were tested using 2-way analysis of variance (ANOVA), and linear correlation was used to compare age and Hounsfield values. *P* values less than .05 were considered significant.

RESULTS

The total sample consisted of 101 patients (65 women and 36 men) with an age range of 18 to 89 years at the time of implant placement. For patients without implant treatment, age at the time of CT-scan exposure was recorded. Within this population, only 6 smokers (4 women and 2 men) and 3 patients with type II diabetes were present, so no provision for separate analysis of these patients was made. Thirty-three subjects from the female population were postmenopausal, of whom 17 were taking HRT. None of the patients in the sample had been clinically diagnosed with osteoporosis.

For 40 patients (24 women, 16 men) data reflecting teeth present for maxilla and mandible were available. In females, there were approximately 10.5 missing teeth per subject, compared to 9.6 in men. For both genders, the majority of the missing teeth were in the maxilla (194 of 251 or 77.3% for women and 92 of 154 or 59.7% for men). Tooth loss was also evaluated in relation to menopause and HRT in the female population (data were available for 23 of 24 subjects). Women in menopause had on average more missing teeth per person (15.8 versus 10.5); however, this difference might reflect the difference in the average age of the 2 groups (67.9 years for women in the menopause/postmenopause group versus 46.1 years in the premenopause group). Interestingly, HRT seemed to exert a protective effect as it

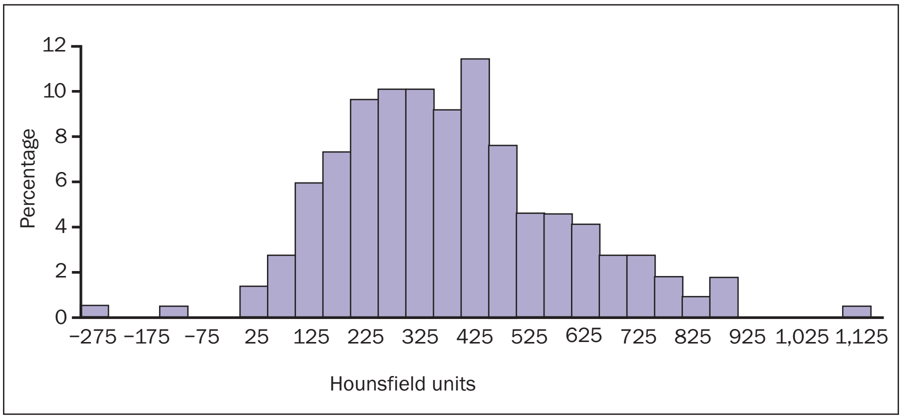

Fig 2 Distribution of bone density measured in HU. A total of 219 edentulous sites were used for this analysis.

Table 1 Correlation of Demographics to HU

	n	Range	Mean	SD	*P*
Gender					
Male	72	−240 to 939	429	208	.326
Female	147	−141 to 1,159	400	200	
Jaw					
Maxilla	99	−240 to 870	429	208	.650
Mandible	120	56 to 1,159	404	197	
Side					
Right	110	−240 to 868	392	195	.193
Left	109	59 to 1,159	428	209	
Zone					
1	87	180 to 1,159	537	192	<.001
2	132	−240 to 806	326	162	
Menopause*					
+	82	−141 to 1,159	390	203	.422
−	63	56 to 845	418	199	
HRT†					
+	46	99 to 1,159	406	210	.344
−	65	−141 to 868	370	193	

*Data for menopause were available for 145 of 147 sections (64 of 65 subjects).
†Data for HRT were available for 111 of 147 sections (49 of 65 sections).
Age had no association with Hounsfield values as determined by linear correlation (r = .099, P = .146).

Table 2 Housfield Values in Anterior (Zone 1) and Posterior (Zone 2) Maxillary and Mandibular Sites

	n	Range	Mean	SD
Maxilla				
Zone 1	45	207 to 870	517	177
Zone 2	54	−240 to 806	333	199
Mandible				
Zone 1	42	180 to 1,159	559	208
Zone 2	78	56 to 636	321	132

Mandible zone 1 = maxilla zone 1 > maxilla zone 2 = mandible zone 2 (P < .001).

related to tooth loss (14.8 missing teeth per person in the subjects receiving HRT versus 17.6 in the untreated group); however, because of the small sample size, no statistical analysis was performed.

Evaluation of edentulous segments measuring 10 to 30 mm in 100 of 101 subjects yielded a total of 219 segments for measuring bone density based on the Hounsfield scale (in 1 subject the available edentulous segment was less than 10 mm). The distribution of Hounsfield values in these 219 segments is presented in Fig 2.

Statistical analysis did not show any significant relationships between Hounsfield values and demographic data (gender, age, jaw, side, menopause, HRT). Statistical significance was observed only when comparing zones 1 and 2 (Table 1).

A more detailed comparison of the Hounsfield values was also made for the 4 regions of the alveolar process (Table 2). Zone 1 in the mandible had the highest mean density value (559), followed by maxillary zones 1 (517 HU) and 2 (333 HU). Zone 2 in the mandible had the lowest mean density value (321 HU). ANOVA showed that that the Hounsfield values differed significantly between zones (P < .001) but not between the maxilla and mandible (within a zone, P = .55; cumulative, P = 0.26).

Figure 3 shows the frequency distribution of implant sites with respect to bone quality. Bone quality (as defined by Lekholm and Zarb) was assessed by 2 examiners who evaluated each site twice. Each of the 4 evaluations was made independently. Bone quality scores did not significantly differ within each examiner, and were significantly correlated (examiner 1, r = 0.72; examiner 2, r = 0.93, both P < .001). The averages of the 2 replicate values for each examiner did not agree, with a mean bias of 0.31 units (P < .001), although they were moderately correlated (r = 0.65, P < .001).

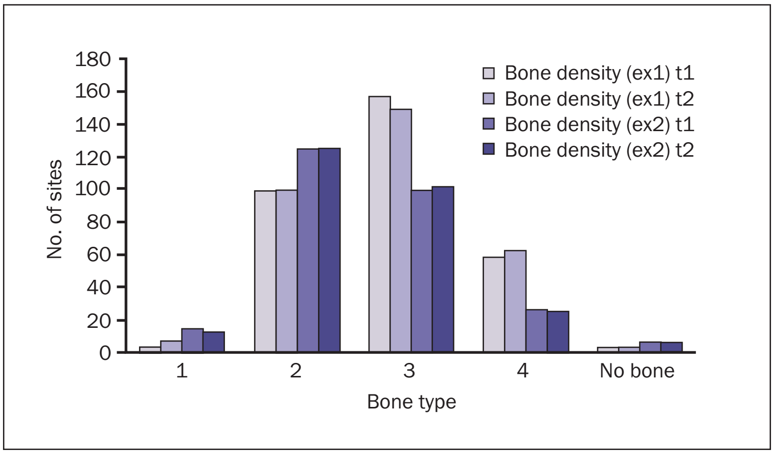

Fig 3 Distribution of bone density based on the Lekholm-Zarb classification, as evaluated by 2 independent examiners on 2 separate occasions. Each examiner visually evaluated 3 sequential sections of each site in order to make a bone quality determination. A total of 319 sites were evaluated.

Bone density for each implant site was measured for patients who had had implant treatment. Since comparison of subjective assessment of bone quality to its corresponding mean Hounsfield value required 100% agreement in both examiners, a smaller sample size for evaluation was produced (107 sections). In this sample, comparison of bone density measurements distances of 0.25 mm and 1 mm circumferentially from the implant outer surface revealed a very good linear correlation (r = 0.97, P < .001) with a small but significant bias (the 1-mm samples were 27.9 HU greater on average; P < .001) (Fig 4). Because of this and the extensive overlap of Hounsfield values for bone types described by the clinicians, the set of values generated for the 0.25 mm distance from the implant surface was used to calculate mean Hounsfield values for the different bone types (Fig 5). Comparison of bone types with ANOVA show that type 4 had significantly lower Hounsfield values than the other 3 types (P < .001), which did not differ. In addition, 2 sites presented with negative Hounsfield values. These sites were classified as having “no bone,” and guided bone regeneration procedures before or at the time of implant placement were planned for these patients.

Ninety-four of the examined patients had a total of 340 implants placed in the 4 regions of the mouth. Implants were either from the Brånemark (n = 116; Nobel Biocare, Göteborg, Sweden) or Osseotite (n = 224; 3i/Implant Innovations, Palm Beach Gardens, FL) system. One hundred seventy-seven implants were placed in the maxilla (101 in zone 1 and 76 in zone 2), whereas 163 were placed in the mandible (61 in zone 1 and 102 in zone 2). However, record review did not show significant implant failure (12 failures at stage 2) to grant an adequate sample for statistical evaluation of implant success in correlation to the Hounsfield index of bone density.

DISCUSSION

The traditional use of an orthopantogram of the alveolar process is considered adequate to screen anatomical sites, but it is generally insufficient to evaluate bone quality. Only lateral cephalometric films provide a rough estimate of the bone quality in the anterior regions of the maxilla and the mandible. Techniques such as histomorphometry of bone biopsies[19] or densitometry,[26] although reliable and quantitative measures of bone density, are not routinely feasible for the practice of implant dentistry. The majority of studies examining the bone quality at the implant site used subjective evaluation based on either the Lekholm-Zarb classification or the clinical hardness classification by Misch.[17]

With the development of the CT scan and associated analysis software, clinicians have a tool to assess bone quality at the site of implant placement. Presurgical evaluation and knowledge of the Hounsfield value for the proposed implant site could help the clinician optimize primary stabilization and long-term success, especially in low-density bone. In the present study, an attempt was made to establish objective criteria for evaluation of bone density, using the Hounsfield index.

The Hounsfield index is a standardized and accepted scale for reporting and displaying reconstructed CT values. It is the measure of x-ray attenuation and varies according to the density of the tissues. The denser the tissue, the higher the CT number, which ranges from –1000 HU (air) to 1000 HU (dense bone). Since the values are directly related to the tissue attenuation coefficients, a correction element was built in to make the comparison of CT values obtained from different CT scanners feasible.[27]

Norton and Gamble[24] used 32 reformatted CTs of either completely or partially edentate patients and

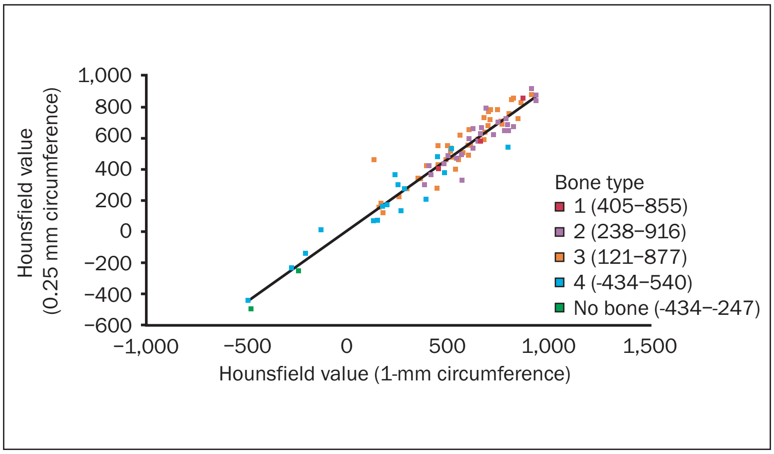

Fig 4 Correlation of bone type to Hounsfield scale. Only sites where the examiners had 100% agreement were selected (107 sites). For each site, a Hounsfield value at 0.25 mm (y-axis) and 1.00 mm (x-axis) from the simulated implant was calculated and plotted as one dot. The black line reflects the linear correlation between the 0.25-mm and 1.00-mm values.

assessed bone quality by measuring Hounsfield densitometric readings of an area 1 mm wide around the implant body at the proposed placement site. A total of 139 implant sites were evaluated using a standard size (3 × 11.5 mm) implant. The recorded mean Hounsfield value ranged from 77 to 1421. Although the landmark separating anterior from posterior region was not specified, bone density ranges for the anterior mandible, anterior maxilla, posterior mandible, and posterior maxilla were provided. In this study, bone types 2 and 3 were combined into 1 group because of the difficulty of differentiating the 2 during subjective evaluation or quantitative bone measurement.

In the present study, Hounsfield values ranged from –240 to 1159 HU when 219 edentulous sites (100 CT scans) 10 to 30 mm in length were evaluated (Table 1). A total of 44 zone 1 and 54 zone 2 maxillary sites were analyzed, whereas for the mandible 42 zone 1 and 78 zone 2 sites were available. The distribution of bone densities as measured in HU irrespective of the region of the jaw is presented in Fig 2. In the Norton and Gamble study,[24] a standard 3.5 × 11-mm implant was used to allow the software to calculate density values, and in some cases, the cortical plate was engaged. Therefore, it is possible that higher Hounsfield values were reported because of the inclusion of cortical bone in the measurements. However, the true representation of the implant site should be independent of the cortical plates. The findings of Jaffin and Berman[15] support the postulate that density and architecture of the trabecular bone are crucial to the stability of an implant, justifying the present methodology.

Previous studies, using different approaches, have shown discrepancies between findings related to normal gender- and age-related bone changes.[28–33] These discrepancies have been linked to hormonal factors and masticatory muscle strength. Kribbs and associates[3] failed to show an age-related difference in mandibular bone mineral density between normal

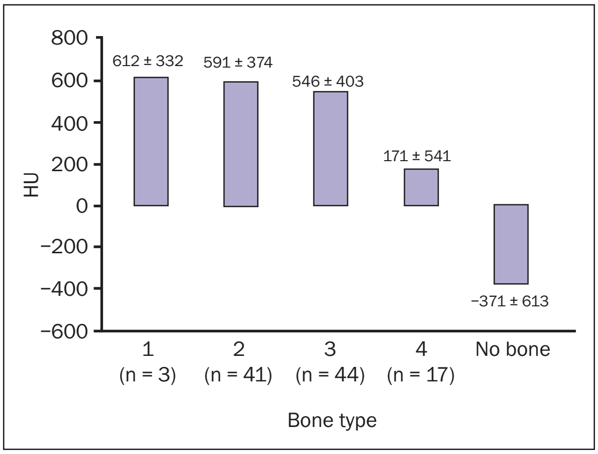

Fig 5 Mean bone density in HU by bone type (types 1 through 4). The values on the tops of the bars represent means ± SDs.

and osteoporotic women. To the best of the authors' knowledge, there is no published study evaluating bone density using the Hounsfield scale in relation to age or gender. In this study, there was no statistically significant association between the Hounsfield values of bone density measurement with certain demographic parameters of the population studied (Table 1). The only significant difference observed was that between bone density as measured by HU in zones 1 (anterior) and 2 (posterior).

In the early literature on dental implants, it was proposed that jaw site affects the outcome of osseointegration. The most successful site for the Brånemark System implant was the anterior mandible, followed by the anterior maxilla.[34] In general, the posterior zones of both arches were considered to have poorer bone quality. However, the posterior mandible was considered more favorable than the posterior maxilla because of increased buccal cortex, despite the low trabecular density. In the present study, where trabecular density alone was evaluated, significantly higher values were recorded for areas mesial to the mental foramina for the mandible and mesial to the anterior border of the sinus for the maxillary arch (ie, zone 1). Furthermore, no significant differences between the posterior maxilla and mandible were detected, even though the posterior maxilla had a slightly higher mean density than the posterior mandible (Table 2).

To assess bone density using the Hounsfield index, accuracy and reproducibility of subjective bone evaluation was established. To the authors' knowledge, no other study has evaluated intra- and interexaminer variability when bone quality is assessed based on the Lekholm-Zarb classification. For this study, 2 different examiners assessed radiographic bone density, and each evaluation was repeated once (Fig 3). Although there was relatively good intraexaminer correlation, there was significant disagreement in the assessment of bone quality between the 2 examiners. This finding underscores the subjective nature of the Lekholm-Zarb classification. Furthermore, bone density measurements 0.25 mm and 1.00 mm circumferentially from the implant surface using implant sizes considered optimal for each specific site were evaluated. The 2 sets of data showed good linear correlation, with the values at 1 mm being slightly higher (Fig 4). For subsequent analyses, the values at 0.25 mm were used, based on the postulate that the quality of the bone in closer proximity to implant is more important in establishing primary stability. It should be noted, however, that this widely accepted postulate does not take into account any changes that might occur after implant placement.[35]

Correlation of visual radiographic density to the Hounsfield scale was considered for further evaluation only when both examiners were 100% in agreement (agreement between 4 of 4 measurements). Interestingly, significant overlap between values for the 3 denser bone types was obtained (Fig 4). The only distinctive categories were areas of "no bone present" and type 4 bone. The present findings were in agreement with the findings of Trisi and Rao,[18] who compared the histomorphometry of trabecular bone to subjective perception of drilling resistance as classified by Misch.[17] They reported a strong correlation for bone types 1 and 4. However, there was a great variation for bones classified as types 2 or 3, and to show statistically significant results, they had to eliminate data for these bone classifications.

In the present study, although there was significant overlap for bone types 1 through 3, it was decided not to eliminate or combine any categories in order to set the mean values for each bone type. As expected, only type 4 bone was significantly different from each of the other 3 bone types, with a mean Hounsfield score of 171 ± 541 (0.25 mm from implant) and 185 ± 319 (Fig 5). This finding falls within the range of values proposed by Norton and Gamble,[24] where values ranged from 0 to 500 HU for type 4 bone.

Overall, anatomic or clinical studies evaluating bone density based on Hounsfield values are sparse in the literature. Duckmanton and associates[23] in a case-report evaluation of a maxillary CT scan reported that cancellous bone with densitometric readings of less than 100 HU was considered to be poor quality in regard to the ability of the bone to provide primary stability for the implant. A group of orthopedic surgeons and engineers[36] used Hounsfield values to design custom femoral stems. According to them, bone with values beyond 600 HU is generally not removable by conventional reamers, indicating a highly dense trabecular pattern. The present data support the postulate that a density of 180 HU or less is clearly representative of low-density bone. The distinction of type 4 bone using the Hounsfield scale as a reliable and objective method could be important, since numerous reports have considered bone density in the recipient site to be an important factor for long-term success of osseointegrated implants,[1,2,15,20] which could have significant repercussions on clinical practice.[22,37,38]

It is important to note, however, that based on the limited information available from the dental implant and orthopedic literature, there is no absolute contraindication for implants in osteoporotic or "poor quality" bone.[5] Orthopedic treatments of fractures in osteoporotic patients often involve implants and fixation devices. Although the healing pattern and repair might differ at different sites, implant design should aim to promote a stable bone implant-interface as well as stability in less dense osteoporotic bone.

CONCLUSIONS

Within the limits of this retrospective study, the results suggested that only bone quality type 4 could be significantly correlated with the quantitative HU measurement of bone density. From the clinician's perspective, this is the type that is of importance, since it can be associated with an increased failure rate.

The majority of clinicians use CT scans primarily to evaluate the quantity of the bone available and the height of the alveolar ridge in relation to vital anatomic structures. However, knowledge of Hounsfield values as an objective method of evaluating bone density for a proposed implant site could alert the surgeon to modify the treatment plan so that primary stability in bone of less density is ensured and a longer healing period is planned.

Future studies should improve on this retrospective study by implementing a prospective design, evaluating success/failure of implants in correlation to HU, and including patients with established diagnoses of osteoporosis in the sample.

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