Preoperative Evaluation of Bone Quality and Bone Density Using a Novel CT/microCT–based Hard-Normal-Soft Classification System

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Purpose: To obtain more objective presurgical measurements of clinical interest, this study proposes a new method of measuring and classifying bone density. Materials and Methods: The density of bovine bone blocks of different qualities was first measured in Hounsfield units (HU) using computed tomography (CT). Next, bone cylinders corresponding to each examined area were retrieved. Bone quality was then measured by both histomorphometric microCT and by subjective evaluation of bone quality during drilling. Results: A statistically significant correlation was found between CT and microCT measurements. Based on this evidence, a new method of classifying bone density/quality into three classes of clinical interest was developed: hard/dense, normal, and soft (HNS). These statistical data also enabled the creation of a formula to convert ordinary CT values expressed in HU into bone volume percentages (BV%) to objectively measure bone density based on the HNS system. Conclusion: Stable implant placement depends upon measurements of bone quality/density that are site-specific, objective, and quantitative. To meet these standards, this paper reports an innovative method of classifying bone quality/density and then objectively measuring bone density based on this HNS classification system, using a simple, innovative mathematical formula that converts HU values into measurements of bone volume. Int J Oral Maxillofac Implants 2010;25:xxx–xxx.

Key words: bone classification, bone density, bone morphometry, bone quality, computed tomography, histomorphometry, microcomputed tomography

The density of edentulous jawbone is extremely variable.¹⁻² Bone morphology, quantity, and density have all been considered important predictors of implant success.³⁻⁶ Moreover, assessment of the degree of bone mineralization or bone quality before implant surgery is very important for treatment plan preparation.⁷⁻⁸ However, after tooth loss, atrophy of the edentulous ridges may reduce the available quality and quantity of bone for implants.⁹⁻¹⁰ Inadequate bone quality may also cause weak implant stability, excessive micromotion, and implant failure,¹¹⁻¹² especially when immediate loading is applied to implants.¹³⁻¹⁸ Most techniques previously proposed to determine bone density and quality are generally performed during or after surgery,¹⁹⁻²⁹ However, steps have been taken to improve these conditions. For example, in 1985, Lekholm and Zarb²⁰ classified bone quality into four types (Q1, Q2, Q3, Q4) based on the amount of cortical versus cancellous bone. Bone quality that scored in the range of Q2 and Q3 was associated with good prospects for implant success, easier implant placement, better primary fixation, and the use of standard instruments and components.¹⁰,³⁰,³¹ In contrast, bone quality scores falling outside this range tended to result in higher failure rates or reflect poor bone quality or excessive loading.¹³,³²⁻³⁸ More recently, an objective quantitative assessment of bone quality was proposed, but this could be done only intraoperatively.²¹
groups have also determined bone quality with precise quantitative methods using histomorphometry of bone biopsies,\textsuperscript{7,9,38,40} densitometry, digital analysis of microradiographs,\textsuperscript{21,22} and ultrasound.\textsuperscript{23} However, none of these methods, although reliable, can be routinely applied by practicing implant surgeons.

Similar to bone quality, bone density classifications have also been previously published.\textsuperscript{5} However, other than suggesting subjective methods or examination during surgery, these investigators did not explain how to measure bone density.\textsuperscript{5,5,7} A notable example is Misch\textsuperscript{5,20} who defined four bone density classes based on clinical density. To accomplish this, Misch used comparative methods of differing resistance to drilling. In 1999, Trisi and Rao,\textsuperscript{7} using the Misch system, tried to establish a quantitative threshold of bone volume (BV%) among four classes: D1, D2, D3, and D4. They observed a statistically high degree of variation among classes D2 and D3. Therefore, they suggested combining D2 and D3 into one group, thus classifying bone density into three groups of clinical interest: D1, D2/D3, and D4. The importance of measuring bone density prior to implant placement has been widely underestimated until recently.\textsuperscript{8,15,38,41} Consequently, computed tomography (CT) has been suggested\textsuperscript{8,15,16,24,25} as a routine measure to presurgically and accurately measure bone dimensions prior to implant treatment.

A method for an objective quantitative classification of bone density that can be applied preoperatively was recently proposed by Norton and Gamble.\textsuperscript{8} This method uses CT assessment of bone density in Hounsfieled units (HU). It is site-specific, quantitative, and more objective, since there is less dependence on operator experience. The Norton and Gamble\textsuperscript{8} method uses interactive software for implant planning to first make a bone quality assessment in accordance with the Lekholm and Zarb scale.\textsuperscript{19} Then, HU bone density is measured in the region of interest. Significantly, Norton and Gamble found a strong correlation between HU values and sites classified as Q1 and Q4, while groups Q2 and Q3 did not show such a correlation. They therefore proposed unifying groups Q2 and Q3, much the same as Trisi and Rao\textsuperscript{7} had done for the Misch\textsuperscript{5,20} classification system in unifying groups D2 and D3. Interestingly, Norton and Gamble\textsuperscript{8} also found a strong correlation between their HU values and high variation in the sites classified as D2/D3 by Trisi and Rao.\textsuperscript{7}

Morphometry has been used to evaluate the density of bone and to determine osseointegration of dental implants, bone volume, bone structure, and bone formation. It has also been used to obtain information about bone tissue mechanics and strength.\textsuperscript{28,34,39,42–44} Another dimension has been explored in osteoporosis studies, where bone connectivity, which represents the number of nodes and struts between the trabeculae in cancellous bone, is an important index of bone strength.\textsuperscript{26,40,42,43,45} Traditionally, both bone morphometry and connectivity have been assessed in two-dimensional histologic sections.\textsuperscript{40} However, a better strategy may be the implementation of three-dimensional (3D) procedures\textsuperscript{46} or, more recently, microCT.\textsuperscript{26,43} In dental implant research, microCT was recently applied\textsuperscript{27–29} for the minimally invasive assessment of bone structure in 3D by providing a quantitative measurement of bone density and connectivity.\textsuperscript{27,28} This represents the “gold standard” for clinical CT-based measurements of bone structure. Because microCT requires taking a bone biopsy, it cannot be used routinely in clinical practice. Therefore, the aim of the present study was to validate CT assessment of bone density in HU as an objective method of measuring bone density before implant surgery. The accuracy of bone density assessment in HU was then verified using microCT. Based on these findings, the study also proposes a novel bone classification system, dividing bone density and/or quality into three classes of clinical interest: H = hard; N = normal; and S = soft (HNS). It is further proposed that this HNS classification system forms the standard against which preoperative bone density measurements may be objectively made, using a novel, simple mathematical formula to express HU values in BV%.

MATERIALS AND METHODS

Sample Preparation

One hundred fresh bovine bone specimens were retrieved from the femurs and hips of animals slaughtered in a local meat packing house. The material properties of bone are frequently discussed in terms of density.\textsuperscript{5,7–9,19,39} Cortical bone is dense and compact, while cancellous (or trabecular) bone is spongy and porous.\textsuperscript{5,7,19,39} The degree of density or porosity in bone results in enormous variations in bone mechanical properties.\textsuperscript{39,42,47} Bovine femur and hip specimens were selected because they are commonly used as models in bone biomechanics.\textsuperscript{47} In addition, using the HU scale, bovine femur and hip contain areas of radiodensity within the limits usually also found in humans.\textsuperscript{41} Nonvital bone has a different appearance on CT scans when compared to vital bone found in human patients.\textsuperscript{39,42,47} However, for this study, the difference can be considered insignificant because comparisons were done only among nonvital bone was samples, while vital bone was not analyzed. The bone pieces were cut into blocks. These
blocks were then prepared, differentiating between different bone qualities and using maximal dimensions of $100 \times 150 \times 300$ mm. From the bone blocks, seven were randomly selected. Three to five holes, each $3$ mm in depth, were drilled into each bone block, using a bone bur $3$ mm in diameter. A total of 23 holes were drilled in the bone blocks selected for the experiment. To create landmarks that would be visible in CT slices, the holes were filled with radiopaque gutta-percha (Fig 1). To orient the bone blocks, a radiolucent landmark that would be visible on radiographs was obtained by burring one side of each block with a $3$-mm-diameter bone bur.

**CT Examination**

The bone blocks were examined with a spiral CT machine (Esaote, type A-TOM-XR fast ring, Hitachi) and software commonly used in dental implant planning. Visual images (Fig 2) and a volumetric measurement of bone density were obtained (Fig 3). With the appropriate pointer included in the CT software, the bone density was evaluated directly underneath each radiopaque landmark. This was accomplished by calculating the HU value in a region of interest (ROI) measuring $3$ mm in diameter and $5$ mm in length (Table 1). To precisely find the measured area, a bone sample was taken along the extent of each radiopaque landmark. A total of 23 bone cylinders corresponding to the points measured in the CT were retrieved using a $3$-mm (internal-diameter) trephine bur.

**MicroCT Processing and Measurement**

MicroCT was then used to evaluate all bone cylinders to obtain an accurate 3D bone morphometric assessment. The specimens were scanned with a high-resolution microCT system ($\mu$CT 40, Scanco Medical) in multislice mode. Each 3D image dataset consisted of approximately 400 microCT slice images ($1,024 \times 1,024$ pixels with 16-bit grey levels). The specimens were scanned in high-resolution mode with an $x$-, $y$-, and $z$-axis resolution around $20$ $\mu$m. The voxel size was $15 \times 15 \times 15$ $\mu$m$^3$. The morphometric parameters calculated by microCT were bone volume percentage (BV%), trabecular thickness (TbTh), trabecular number (TbN), trabecular separation (TbS), and connectivity density (CD).

**HNS Bone Classification**

On retrieval of bone cylinders from the blocks, bone quality was classified into three groups following the method previously proposed by Trisi and Rao. Bone density was divided into three classes as previously
mentioned (H, N, and S). It was necessary to find the limits in HU that correspond to the clinical bone values of H, N, and S. Accordingly, a correlation was sought between bone density as measured by microCT and bone density as measured using standard CT. According to Trisi and Rao, dense or hard bone (H) was above BV% values of 76.54, while soft bone (S) was below BV% values of 28.28. Normal bone (N) was between 28.28% and 76.54%. The Spearman rank correlation test was performed to determine whether the values obtained by the two different techniques were, in fact, correlated, as the raw data otherwise indicated skewed values. This was a randomized study conducted in a blind fashion.

**CT Morphologic Analysis**

CT morphologic analysis was carefully performed to distinguish between two different types of cancellous, or trabecular, bone within the values of normal bone. These correspond to Q2 and Q3 in the Lekholm and Zarb classification system. They include (1) strong trabecular bone with thick trabeculae and numerous interconnections and (2) weak trabecular bone with thin trabeculae and few interconnections between trabeculae. MicroCT morphologic analysis was also performed to verify the precision of the CT observations and further analyze the bone structure in two and three dimensions.

**RESULTS**

Several microCT 2D slices and a 3D reconstruction of each specimen were obtained. The 3D reconstruction gave a precise representation of each bone cylinder retrieved and allowed morphologic exploration of the architecture of the bone specimen (Fig 4). The 2D slices allowed the identification of the three different bone densities: H (hard/dense bone), N (normal bone), and S (soft bone) (Fig 5). Two types of N bone were found: N bone with thick and well-interconnected trabeculae and N bone with a small number of interconnections between trabeculae. Results are summarized in Tables 1 and 2 and Fig 6. To better understand the clinical implications of bone quality/density evaluation, a phantom of an implant was virtually applied over the CT section corresponding to each bone quality/density. By virtually tracing the points of the implant shape in contact with mineralized bone, it was possible to show the bone contact that would be expected in each bone type (Fig 7).

**Bone Density Evaluation**

Evaluation of bone density via drilling resistance showed homogeneous values in all groups of HNS bone density. However, this result contradicts Misch because groups D2 and D3, which correspond to N bone, failed to show homogeneity of values. In fact,
Fig 4  A 3D microCT image created from a representative sample of the examined cylinders. This sample was retrieved from a block of cancellous bone. The quality/density of this bone sample was identified as N (normal) upon visual evaluation and during bone drilling (original magnification ×10).

Fig 5  Two-dimensional microCT image comparing samples of different qualities using HNS classification (original magnification ×10): H bone (hard/dense = D1 bone), N bone (normal = D2 to D3 bone), and S bone (soft = D4 bone). The H bone is very dense, with very good mechanical properties. The N bone shows several bony and well-interconnected trabeculae, forming a sturdy structure. The S bone shows very thin and poorly interconnected trabeculae, resulting in a structure with very weak mechanical properties. (Mineralized bone is gray.)

Table 2  HNS Bone Classification According to Thresholds Proposed by Trisi and Rao7 and Calculated with Approximations Using Conversion Mathematical Formule

<table>
<thead>
<tr>
<th>HNS</th>
<th>CT</th>
<th>MicroCT</th>
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<tr>
<td>H = Hard/dense = D1</td>
<td>&gt; 1,000 HU</td>
<td>&gt; 76.54 BV%</td>
</tr>
<tr>
<td>N = Normal = D2–D3</td>
<td>&gt; 400 and  &lt; 1,000 HU</td>
<td>&gt; 28.28 BV% and &lt; 76.54 BV%</td>
</tr>
<tr>
<td>S = Soft = D4</td>
<td>&lt; 400 HU</td>
<td>&lt; 28.28 BV%</td>
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Fig 6  Values of BV% versus HU.

Fig 7  Software elaboration of samples shown in Fig 5. A phantom of an implant was virtually applied over the CT section corresponding to each bone quality/density (original magnification ×10): hard/dense (H), normal (N), and soft (S). Virtually tracing in red color the points of the implant shape in contact with mineralized bone and in green the points not in contact with mineralized bone helps show the expected bone contact in each bone type. This technique can be useful in treatment planning to determine the bone-implant contact that could be achieved at implant insertion. (Mineralized bone is gray). [AU: Figs 5 and 7 are flipped L-R versus each other so that they do not match. Flip one so that the orientations are the same?]

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groups D2 and D3 showed a large range of values. This suggests that dividing bone into three groups, as opposed to four, is more effective and appropriate.

**MicroCT Morphologic Evaluation**

MicroCT morphologic analysis allowed the examination of 400 2D sections and a 3D reconstruction of each sample. Three-dimensional analysis showed that hard bone was mainly of a dense lamelluar structure, interrupted by vascular canals and by a few spaces most likely occupied by soft hemopoietic or fatty tissue; these were radiolucent. Normal bone appeared to be mainly composed of thick trabeculae. In some samples, the trabeculae were well interconnected, whereas other samples gave evidence of less interconnected, bony trabeculae. Based on these results, the morphologic observations confirmed the CT results. Moreover, morphometric measurements showed different values of connectivity among samples in the same group of normal bone. This is a clear sign of the presence of samples of different bone strength within the normal group. Morphologic analysis of soft bone samples showed very thin trabeculae that were poorly interconnected, forming a structure with apparently very weak mechanical properties. Two-dimensional microCT analysis confirmed the 3D analysis and visually showed the pronounced differences in density between the three different groups.

**Statistical Findings**

Correlation analysis of the results obtained by CT versus those from the microCT showed that $r = 0.9587$ and $r^2 = 0.9191$. Figure 6 shows the relationship between BV% and HU and demonstrates that more than 90% of the observed counts were linearly related ($P < .0001$, indicating an extremely significant correlation). The run test indicated that there was not a significant departure from linearity. Following the bone quality classification of Trisi and Rao,7 from the values obtained, 6 of the samples could be included in class H (hard/dense bone), 14 in class N (normal bone), and 3 in class S (soft bone). The mean values for BV%, as measured with microCT, were as follows: type H: 89.50% ± 16.81%; type N: 43.16% ± 7.88%; and type S: 26.79% ± 5.08%. The bone density evaluation during drilling showed the following distribution: 5 samples corresponded to type H bone, 16 to type N bone, and 2 to type S bone.

The measurements made with CT and microCT were highly correlated. Only about 5% of the counts were not expected. In contrast, measurement of bone density during drilling is less precise and more operator-dependent. This can result in potential errors, especially around the thresholds between two groups (between H and N or N and S). Therefore, for any given set of HU values in the areas around the thresholds between H, N, and S bone, precisely which classification group applies is uncertain. This problem is solved in the following way: The H and S bone types are more critical from a clinical point of view. Thus, to ensure safe implant placement, the thresholds between H and N or N and S should be calculated by a factor of 10% toward (ie, in the direction of) N. In this way, it is relatively certain that almost all (99.98%) the measurements of S bone will be in the S group, and almost all (99.98%) the measurements of H bone will be in the H group. It is true that some of the samples belonging to the N group will be found in the S and H groups. However, this is less important for safe implant placement because the N group is the safe zone. Moreover, all the samples moved from N to S and from N to H are, in reality, in the zone very close to the thresholds. In other words, these samples have mechanical properties at the extreme limits of group N.

**Mathematical Models**

A mathematical analysis of the data allowed the creation of a formula (formula A) enabling the precise calculation of BV% from CT bone density, as measured in HU. The formula is based on the findings derived from the CT and microCT measurements, graphs, and related analysis and is given as: $BV% = 0.04 \times HU + 14.5$. Reversing the data and deriving another function by the same method, a second formula (formula B) is obtained to calculate HU from microCT bone density measurement in BV% and is given as: $HU = 20.5 \times BV% - 190$.

**Proposed HNS Clinical Bone Density/Quality Preoperative Classification System**

The results of this study allowed the authors to propose a clinical evaluation system for a preoperative bone quality/density evaluation. This method recommends the use of CT sections and can be performed either customized on prints of CT slices or using computer software for implant planning. On the prints of the CT sections selected for implant insertion, it is possible to apply a 1:1 transfer of the implant on
transparent acetate paper. With ink markers in three different colors (for example, red, green, and yellow), it is possible to trace along the implant outline the parts of the implant in contact with H, N, and S bone. This method allows the clinician to simultaneously examine available bone quantity and both bone quality and density. It allows better planning of implant insertion by providing a view of the distribution of available bone quality and density around the implant (Fig 8).

The problem with a customized measurement technique is that several measurements are needed to calculate with good approximation the mean density of the bone surrounding the implant, and this work requires additional time on CT evaluation. In contrast, the use of proper software for implant planning is much easier and faster, and it provides a comparable result through virtual insertion of the implant shape in the CT slide selected for implant placement. The software is also more accurate, since it allows visual evaluation of bone quality around the virtual implant in 2D sections and a 3D reconstruction and it also allows the measurement of bone density in HU in several points along the implant contour, resulting in a unique bone quality and density evaluation. Software techniques actually also allow automatic 3D evaluation of bone density and allow the acquisition of more reliable data by virtually moving the implant into different positions during treatment planning. With the CT + software technique shown here, it will be possible to automatically and instantly calculate bone density and bone-implant contact while virtually moving the implant into the bone structure. Both software and the customized technique allow the acquisition of accurate BV% values using the HU/BV% conversion formula.

**DISCUSSION**

Continuously improving radiographic technologies have resulted in CT examinations with higher resolution and lower doses of radiation. Intraoral and panoramic radiographs are also useful, but they do not permit reliable, precise bone density measurement. Implant treatment planning benefits from the use of computer software, which can now evaluate CT images of bone available for implant placement. In spite of this, the use of CT to estimate the degree of bone density is rarely implemented by surgical practitioners. As previously mentioned, it is not possible to predict the subtle differences between bone quality Q2 and Q3 or bone density D2 and D3 when applying either the Lekholm and Zarb or Misch classifications, respectively. For this reason, Trisi and Rao and Norton and Gamble demonstrated that subjective methods of evaluating bone quality and density assessment are useful only when clinically assessing up to three classes of bone quality or density. Therefore, the present paper has introduced a novel bone quality/density classification system that divides bone into three classes: H = hard, N = normal, S = soft (HNS classification). Structural differences among these three bone classes may be discerned by drilling resistance during implant site preparation or by visually evaluating CT sections.
Human alveolar bone varies enormously in terms of available quantity, quality, and density\textsuperscript{2,5,7,8,19,20,41}; for this reason, in the same CT section it is possible to detect either bone quality or all three bone density classes together. For example, in the mandible, it is often possible to find a thick cortex made of a layer of dense bone, while in the central part it is possible to find both soft and normal bone. There are many reasons why the HNS classification system is superior to those previously introduced by Misch\textsuperscript{5,20} or Lekholm and Zarb,\textsuperscript{14} particularly for the chairside practitioner. First, implant site preparation depends on accurate and reliable analysis of bone quality, density, and quantity. For example, when bone is type \textit{N} (D2 and D3, in Misch's classification), many papers suggest standard implant site preparation with drills\textsuperscript{3,4,10,30} in contrast, when bone is type \textit{H} (D1, in Misch) or \textit{S} (D4, in Misch)\textsuperscript{,2} different implant site preparation techniques are recommended. In hard bone, for instance, larger drills, tapping devices, and piezoelectric devices for bone surgery\textsuperscript{38,53} have been proposed, along with techniques to enhance vascularization.\textsuperscript{54} When bone is soft, the use of various bone expansion devices such as osteotomes is often suggested.\textsuperscript{35-37} In addition, the importance of presurgical assessment of bone quality for soft bone, for example, was previously reported by Norton and Gamble.\textsuperscript{6} They statistically divided the mouth into four main regions of interest: (1) anterior mandible, corresponding to Q1 (above 850 HU); (2) posterior mandible/anterior maxilla, corresponding to Q2/3 (between 850 and 500 HU); (3) posterior maxilla, corresponding to Q4 (under 500 HU); and (4) tuberosity, Q4 (under 0 HU), also called the “failure zone.” This indicates that some areas of the mouth are safer than others for implant surgery. For example, the anterior maxilla (Q2/3) is safe, while the posterior maxilla (Q4) is not. This, in turn, suggests the utility of the HNS system, which can suggest implant site preparation techniques to be used and simplify surgical decision making as well as postsurgical treatment planning.

There is another reason why classifying bone using the HNS system is superior to previous classification systems. Namely, studies investigating implant insertion, loading, and survival have indicated that soft bone and hard bone each have a higher risk of implant failure.\textsuperscript{5,14,15,18,20,35,38,41} On the other hand, normal bone, or N (D2 and D3 in Misch's classification or Q2 and Q3 in the Lekholm and Zarb classification) seems to represent a safer zone.\textsuperscript{5,7,20,53} In fact, hard/dense bone, or H (D1 in Misch or Q1 in Lekholm and Zarb) may exhibit improved implant stability, but it is often less vascularized and hard to drill through and tap.\textsuperscript{35,38,54} In addition, during implant site preparation, it is easier to involuntarily heat dense bone.\textsuperscript{35,37,38} In hard bone, there is also a lack of blood supply.\textsuperscript{54} This may prevent blood clot formation at the implant surface, an essential requirement for achieving osseointegration.\textsuperscript{11,54} Similarly, soft bone, or S (D4 in Misch, Q4 in Lekholm and Zarb) can be damaged easily during implant site preparation or implant insertion because of its weaker mechanical properties.\textsuperscript{5-8,11,56} When the BV% is low (S bone), the mechanical properties of bone are significantly impaired, as confirmed by histomorphometric, clinical, and biomechanical studies.\textsuperscript{4-6,9,11,18,34,39,40,47,56}

In a recent study, Park and coworkers\textsuperscript{41} observed, using software and CT to evaluate and measure cortical bone density, huge differences in the density of the cortical alveolar bone of the maxilla and that of the mandible. They observed that the cortical bone density of the maxilla ranged approximately between 810 and 940 HU, while the cortical bone density of the mandible ranged between 800 and 1,580 HU. This study highlights the importance of the presurgical information that can be obtained by CT alveolar bone evaluation when selecting sites and placement methods for implants and also mini- or microscrew implants in the dental arch.

A key objective of the present report is to establish the utility of CT measurement of bone density in HU as an integral part of the presurgical assessment of the degree of bone mineralization. With such a preoperative appreciation of bone quality/density, the oral surgeon will be able to choose the best implant site preparation technique, implant positions, and components, as well as establish a treatment plan that is appropriate for local anatomic conditions. Briefly, precise preoperative measurement of bone density in values of BV% gives the practitioner an unqualified advantage during implant planning. Specifically, the practitioner can objectively choose the implant characteristics that are most appropriate, as noted earlier. This is particularly important when bone is dense or soft or when an immediate load is applied. For example, an osteoconductive surface, which enhances bone-implant contact during the healing period, may be required only when bone is soft.\textsuperscript{57} When bone is dense, expected bone-implant contact is always optimal.\textsuperscript{57} Moreover, soft bone has weak mechanical properties. Therefore, trabecular features cannot be ignored during implant site preparation, as placement in close contact with cortical walls would be preferable. Obviously, for soft bone, the use of implants enhancing stability is indicated, eg, longer and wider implants equipped with larger and nontraumatic threads. Conversely, when bone is hard, safe implant site preparation is ensured by the use of sharp burs, cold irrigation, and avoidance of bone compression during implant insertion.
To completely accomplish this aim within the context of CT/microCT capabilities, a BV/HU conversion formula (formula A) has been developed for use in clinical practice. This is an innovative tool with which the practitioner can precisely assess the degree of bone density and quality and, conversely, the degree of bone mineralization by conversion of HU values into BV% (formula B). Thus, both CT and microCT measurements and the BV/HU conversion formulae can be applied to software used for implant planning. This will provide a means of automatically computing mean values of BV% from the CT images of the regions of the area selected for implant placement. While the formula to convert HU into BV% (formula A) is precise, the Hounsfield scale may vary slightly according to the scanner employed. In this study, a spiral CT device was used.

In contrast to the classification systems of both Misch and Lekholm and Zarb, the present study developed its HNS classification system by an in vitro study, which evaluated in a quantitative manner the differences between CT measurements in HU and microCT for bone density assessment. The creation of formulas A and B takes these results a step further and gives the practitioner added potential for implant success. That is, with the HNS classification system and the mathematical model, the practitioner can preoperatively determine site-specific implantation placement, among other essential surgical/post-surgical requirements.

In terms of computed bone density values, then, HNS cannot be compared to the studies of either Trisi and Rao or Norton and Gamble. These differences result from the fact that the bone examined and analyzed was taken from cows and is therefore different in quality, structure, and distribution from human alveolar bone. This factor would not allow the actual thresholds of clinical interest among the three groups (H, N, and S) to be determined in this study. It should be noted that the reference threshold values of bone density between the H, N, and S classes are those first proposed by Trisi and Rao and Norton and Gamble. Nevertheless, further clinical and biomechanical studies are needed to precisely determine the actual threshold values of clinical interest.

In summary, bone density was previously demonstrated to be correlated with bone morphometry and biomechanical tests on implants. The results of the present study show that standard CT technologies provide clinicians a number of advantages. Specifically, bone density measurements can now be made before implant surgery, at the time of the evaluation of bone quality and quantity. This will facilitate choosing the best implant sites. It will also affect site preparation technique, implant positions, and components, as well as establishing a treatment plan according to local anatomic conditions. The enabling tools are (1) the new HNS classification system of bone density, used as a standard against which to apply (2) formula A and/or formula B, the equations that convert HU derived from CT/microCT values into BV% and the reverse. Further research based on the results of the present study may lead to more advanced uses for CT, including the realistic estimation of areas selected for potential implant placement in terms of bone strength, better timing of implant loading, and better choice of load to be applied. Further studies are also required to elucidate the still-unknown correlation between implant stability and bone density and establish corrected thresholds for H, N, and S bone (see Table 2).

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