Correlation between the Bone Density Recorded by a Computerized Implant Motor and by a Histomorphometric Analysis: A Preliminary In Vitro Study on Bovine Ribs

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ABSTRACT

Purpose: The purpose of the present preliminary in vitro study on bovine ribs was to validate a new intraoperative site-specific classification of bone Density Index (IDI), obtained by an innovative computerized implant motor, by correlating these data with the data obtained by the histomorphometrical evaluation of the same samples.

Materials and Methods: Five segments of bovine ribs were used, and a total of 22 perforations were performed. A computerized implant motor ("Torque Measuring Motor") was used to evaluate the bone density, which was classified into four classes: ID1, ID2, ID3, and ID4. Histomorphometrical analysis of bone density, expressed as percentage of bony trabeculae over the total biopsy area, was also performed. The data of bone density obtained by the implant motor were statistically correlated with the histomorphometrical results.

Results: A significant positive correlation was found between the bone density measured by the implant motor and the bone density assessed by histomorphometry ($r = 0.89$, $p < .0001$). Moreover, a significant positive correlation in D1, D2, and D4, whereas a negative, not significant correlation in D3 was found.

Conclusion: Within the limitations of this in vitro study, the intraoperative site-specific classification of bone density, obtained with this innovative system, could be helpful for the clinician to tailor the surgical protocol to the different situations in implant dentistry.

KEY WORDS: bone density, bovine ribs, histomorphometry, implant, implant stability quotient, in vitro study, insertion torque, primary stability, resonance frequency analysis

INTRODUCTION

The long-term success of implant treatment depends on the achievement of a favorable primary stability, which in turn depends on adequate bone quantity and quality. Therefore, bone density at the implant site could be crucial, and it has been reported that it correlates with failure rates and primary stability.[1,2] Primary stability can be affected by bone quantity and density, topography of implant surface, and implant design.[3–5] It has been reported that primary stability decreased in poor bone density sites.[5]

The most popular current method for bone density classification was described by Misch and colleagues, who defined four bone density groups independent of the regions of the jaws, based upon macroscopic cortical

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and trabecular bone characteristics. Specifically, the density was defined as D1 if dense cortical bone was present; D2 if thick dense-to-porous cortical bone on crest and coarse trabecular bone was detected; D3 if thin porous cortical bone on crest and fine trabecular bone within was observed; and D4 if fine trabecular bone was present.[6]

Several methods for the assessment of bone density have been reported: conventional radiography, drilling resistance, insertion torque (IT) force, digital image analysis, and computed tomography (CT).[7–10] Bone quality and quantity can be evaluated on intraoral and panoramic x-rays, and CT scans could possibly assist in the preoperative implant planning; however, these radiographic methods cannot be used during the surgery. Primary implant stability in relation with bone density can also be evaluated by the implant stability quotient (ISQ), that is, the resonance frequency analysis[11,12] and with the Periotest™ value (PTV).[13,14] ISQ and PTV are noninvasive quantitative methods, and the quantitative data are obtained during implant placement. Also, the measurement of IT can be used for the evaluation of bone quality and primary stability at the time of implant insertion.[15] Several studies have reported that bone density correlated with cutting resistance, IT,[16–28] and implant stability measurements of PTV, ISQ, and IT.[29]

The achievement of information on bone density before implant insertion could be an advantage for treatment planning. Indeed, it can help the clinician in the implant site preparation (i.e., eventual underpreparation), in the selection of the most suitable implant systems (macro and micromorphology), and finally in the choice of the loading protocol. Therefore, the development of a device that, during surgery, can record measurements that can be correlated with bone density may contribute to the success of the implant treatment. In addition, the correlation between the clinical measurements of bone density and its histomorphometrical evaluation still remains to be better clarified.

The purpose of the present preliminary in vitro study on bovine ribs was to try to validate an intraoperative site-specific classification of bone density obtained by an innovative computerized implant motor, by correlating the data of the bone density recorded on animal bone tissue samples by the implant motor with the results of the histomorphometrical evaluation of the same samples.

MATERIALS AND METHODS

The study was performed at the Implant Retrieval Center of the Department of Medical, Oral and Biotechnological Sciences of the University of Chieti-Pescara, Italy. Five segments of bovine ribs with a clear defined cortical and cancellous bone were used. The blocks, covered by periosteum, were cleaned and regularized by a cutting diamond saw (EXAKT® Sawing-Grinding System; EXAKT, Norderstedt, Germany).

Since the hard tissue composition varied along the rib, on each bone segment 4/5 perforations were performed, moving from the most proximal to the most distal portion. A total of 22 perforations were carried out. A computerized implant motor named "Torque Measuring Motor" (TMM2) (IDI Evolution, Concorezzo, Milano, Italy) was used to evaluate the bone density. The measurements were performed by means of a dedicated reading drill (Patented by IDI Evolution), able to assess the value of bone cutting resistance, before implant insertion (Figure 1, A–B).

Briefly, the insertion depth and direction of the perforations were defined. A starter lozenge drill (diameter: 2.2 mm) was used to perforate the cortical

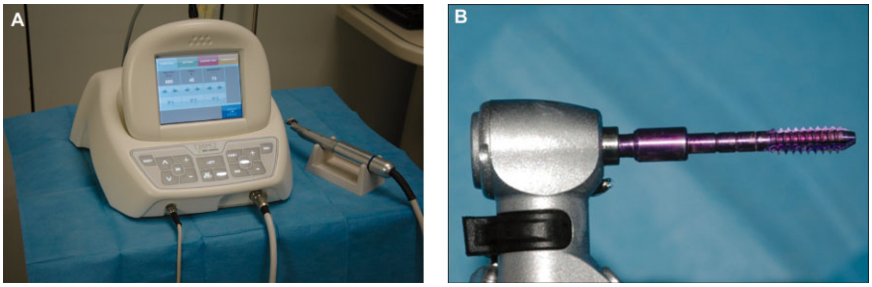

Figure 1 *A*, The computerized implant motor able to assess the value of bone cutting resistance and obtain a Intraoperative Density Index. *B*, Bone density reading drill mounted handpiece.

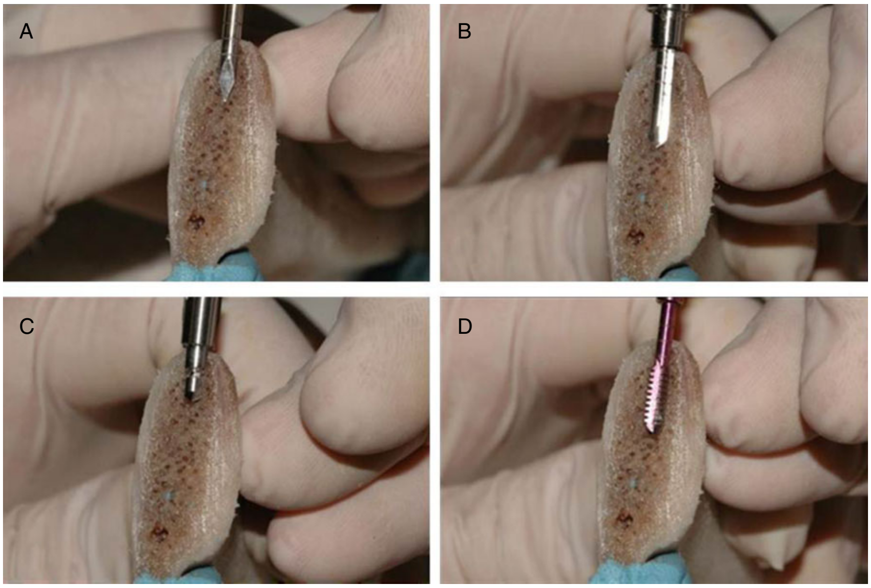

Figure 2 *A*, Cortical bone was perforated using a starter lozenge drill (diameter: 2.2 mm). *B*, Cutting depth of 12 mm was prepared using a triflute drill (diameter: 2.3 mm). *C*, Pilot drill to pinpoint the direction and depth of the perforation and to decorticalize the upper part of the bone samples. *D*, Reading drill to measure intraoperative density index.

bone, and a triflute drill (diameter: 2.3 mm) was used to prepare the site up to a depth of 12 mm. Subsequently, a pilot drill (diameter: 3.0 mm) was used to pinpoint the direction and depth of the perforation and to remove the cortex of the upper part of the bone samples (Figure 2, A–D). All surgical procedures were performed by experienced operators (D.D.S. and P.A.), using the preliminary drills provided by the manufacturer. After setting the “read mode” on the display of the implant motor, the reading drill (3 × 8 mm in the cutting portion), with a preset torque and speed (35Ncm, 35 g/Min), examined the bone density of the prepared bone tunnel up to a predefined depth. The measurements were displayed as numerical data and in the form of a graph.

The values assessed by the surgical motor were as follows:

- Cm (average torque) (Ncm): torque average of resistance in function of depth;
- Cp (peak torque) (Ncm): value of the point of maximum resistance in function of depth;
- I (Ncm): the integral of the function resistance depth;
- P: depth measured as tenths of a millimeter;
- Graph of the strength (ordinate)/depth (abscissa);
- N: sequence number of the measurement (Figure 3, A–D).

Based on the readings, Cm was used by the device for the correlation with the classification of bone quality proposed by Misch.[30] The Cm values ranging from 0 to 3N corresponded to D4 bone type; values ranging from 4 to 7N corresponded to D3 bone type; values ranging from 8 to 11N corresponded to D2 bone type; finally, values over 12N corresponded to D1 bone class. The values identified were called Intraoperative Density Index. Data collection was performed by a single operator (L.R.), trained in the detection method (Table 1).

The retrieved rib bone blocks were fixed by 10% buffered formalin and processed to obtain thin ground sections with the Precise 1 Automated System (Assing, Rome, Italy).[31] The specimens were dehydrated in an

TABLE 1 Correlation between the Classification of Bone Quality Proposed by Mish and the Value Identified by the Implant Motor and Called Intraoperative Density Index (IDI)

Classification of Bone Density (Mish *et al.*)	Torque Value (Cm) (Ncm)	Index of Density (IDI)	Samples Distribution (%)
D1	>12	ID1	22.72
D2	8–11	ID2	18.18
D3	4–7	ID3	31.81
D4	0–3	ID4	27.27

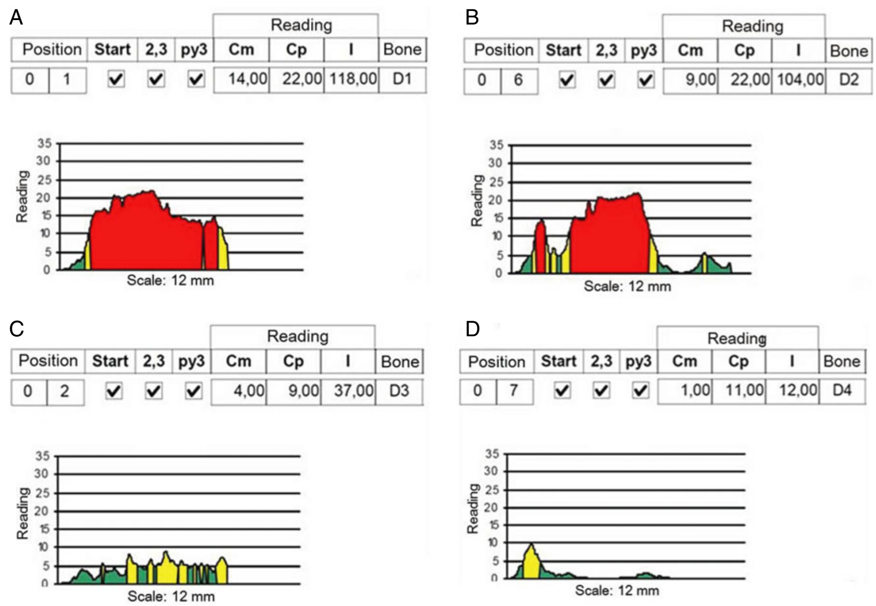

Figure 3 *A*, Graph showing ID1 bone class (Cm: 14, Cp: 22, I: 118). *B*, Graph showing ID2 bone class (Cm 9, Cp 22, I 104). The red color show the presence of cortical bone in the crestal and intermediate areas. *C*, Graph showing ID3 bone class (Cm 4, Cp 9, I 37): the values are remarkably lower. *D*, Graph showing ID4 bone class (Cm 1, Cp 11, I 13).

ascending series of alcohol rinses and embedded in a LR White resin (London Resin, Berkshire, UK). After polymerization, the specimens were sectioned along the longitudinal axis with a high precision diamond disc at about 150 microns and ground down to about 50 microns. The slides were stained with acid fuchsin and toluidine blue.

Histological observation and histomorphometrical evaluation were carried out using a light microscope (Laborlux S, Leitz, Wetzlar, Germany) connected to a high resolution video camera (3CCD, JVC KYF55B, JVCs, Milan, Italy) and interfaced to a monitor and PC (Intel Pentium III 1200 MMX, Intels, Santa Clara, CA, USA). This optical system was associated with a digitizing pad (Matrix Vision GmbH, Oppenweiler, Germany) and a histomorphometry software package with image capturing capabilities (Image-Pro Plus 4.5, Media Cybernetics Inc., Immagini & Computer Snc, Milano, Italy).

Histomorphometrical analysis of bone density, expressed as percentage of bony trabeculae over the total biopsy area, was performed (Figure 4).

Statistical Analysis

Data were reported as mean ± standard deviation. Histomorphometrical measurements were statistically compared with the corresponding values of bone density obtained with the device. Pearson's correlation coefficient (r value), between the histomorphometrical data and Cm values recorded by the implant motor, was calculated. The correlation was considered significant when $p < .05$.

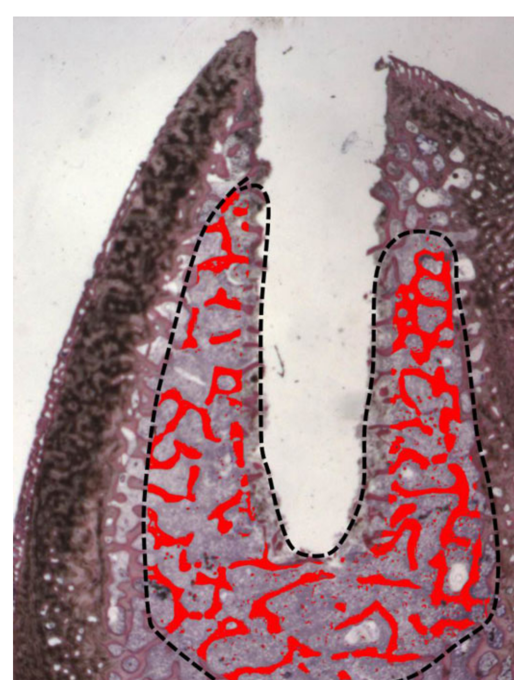

Figure 4 Histological image showing a ID4 sample. Histomorphometric analysis of bone density, expressed as percentage of bony trabeculae (red painted region) over the total biopsy area (inside the dotted line). (Toluidine blue and acid fuchsin 12X.)

TABLE 2 Distribution of the Values Read by the Implant Motor and the Respective Histomorphometric Analysis

Sample No.	Cm (Ncm)	Cp (Ncm)	I (Ncm)	ID	Total Area (μ2)	Bone Area (μ2)	Ratio of Bone Area (%)
1	14	22	118	ID1	20,748,128	3,818,715	39.8
2	16	32	192	ID1	54,779,956	11,928,025	38.6
3	16	28	127	ID1	74,808,376	16,225,594	53.4
4	20	34	174	ID1	66,263,244	13,704,654	66.3
5	19	37	161	ID1	16,796,898	4,881,977	52.8
6	9	22	14	ID2	14,809,525	3,770,219	36.4
7	11	28	103	ID2	14,205,133	5,530,041	43.8
8	9	16	87	ID2	11,422,031	4,164,263	41.6
9	9	16	89	ID2	15,178,302	6,043,434	39.1
10	5	14	47	ID3	11,404,406	3,250,384	29
11	7	22	73	ID3	18,134,898	5307,780	25.5
12	5	20	52	ID3	55,095,644	13,338,039	38.9
13	6	14	63	ID3	15,329,738	6,717,678	28.5
14	4	9	37	ID3	12,519,875	4,832,271	24.1
15	7	14	65	ID3	16,365,136	8,746,087	26.9
16	6	6	13	ID3	14,216,378	7,942,735	21.2
17	0	1	1	ID4	23,867,458	15,820,560	18.4
18	0	3	4	ID4	12,235,817	6,458,001	21.7
19	0	5	5	ID4	9,662,758	2,332,362	21.7
20	1	6	12	ID4	19,551,616	5,271,007	20.7
21	2	8	22	ID4	7,678,574	3,196,530	29.2
22	1	11	12	ID4	11,556,437	4,521,505	24.2

Cm, average torque; Cp, peak torque; I, integral of the function resistance depth; IDI, intraoperative density index.

RESULTS

Distribution of bone density recorded by the implant motor in the selected samples and the respective assessment of histomorphometrical paramenters were summarized in Table 1. D1 bone density was found in 5 (22.72%), D2 in 4 (18.18%), D3 in 7 (31.81%), and finally, D4 in 6 (27.27%) out of 22 samples (Table 2).

The histomorphometrical measurements showed that the samples classified, by the implant motor, as D1 had a 51.13% ± 10.45 (range 38.6–66.3%) bone density, the ones classified as D2 a 40.22% ± 3.19 (range 36.4–43.8%) bone density, the ones classified as D3 a 27.72% ± 5.6 (range 21.2–38.9%) bone density, and finally, the ones classified as D4 a 22.65% ± 3.71 (range 18.4–29.2%) bone density (Figure 5, A–D; Table 3).

A significant positive linear correlation was found between the bone density measured by the implant motor and the bone density assessed by histomorphometry ($r = 0.89$, $n = 22$, $p < .0001$) (Figure 6). Indeed, the increase of bone density recorded by the reader matched with the increase of the percentage of bone trabeculae measured by histomorphometry. Pearson's correlation coefficient for linear regression (R^2) between values assessed by the surgical motor and histomorphometry was di 0.80 ($p < .0001$), indicating that 80% of the data points were aligned with the regression line.

By analyzing the linear correlation between the bone density measured by the implant motor and the

TABLE 3 Mean ± SD of Bone Trabeculae Percentage over the Total Biopsy Area and Its Correspondence to the Bone Density Class Identified by the Implant Motor

Intraoperative Density Index (IDI)	Bone Trabeculae Percentage (± SD) (%)
ID1	50.18 ± 11.39
ID2	40.22 ± 3.19
ID3	27.72 ± 5.60
ID4	22.65 ± 3.71

SD, standard deviation.

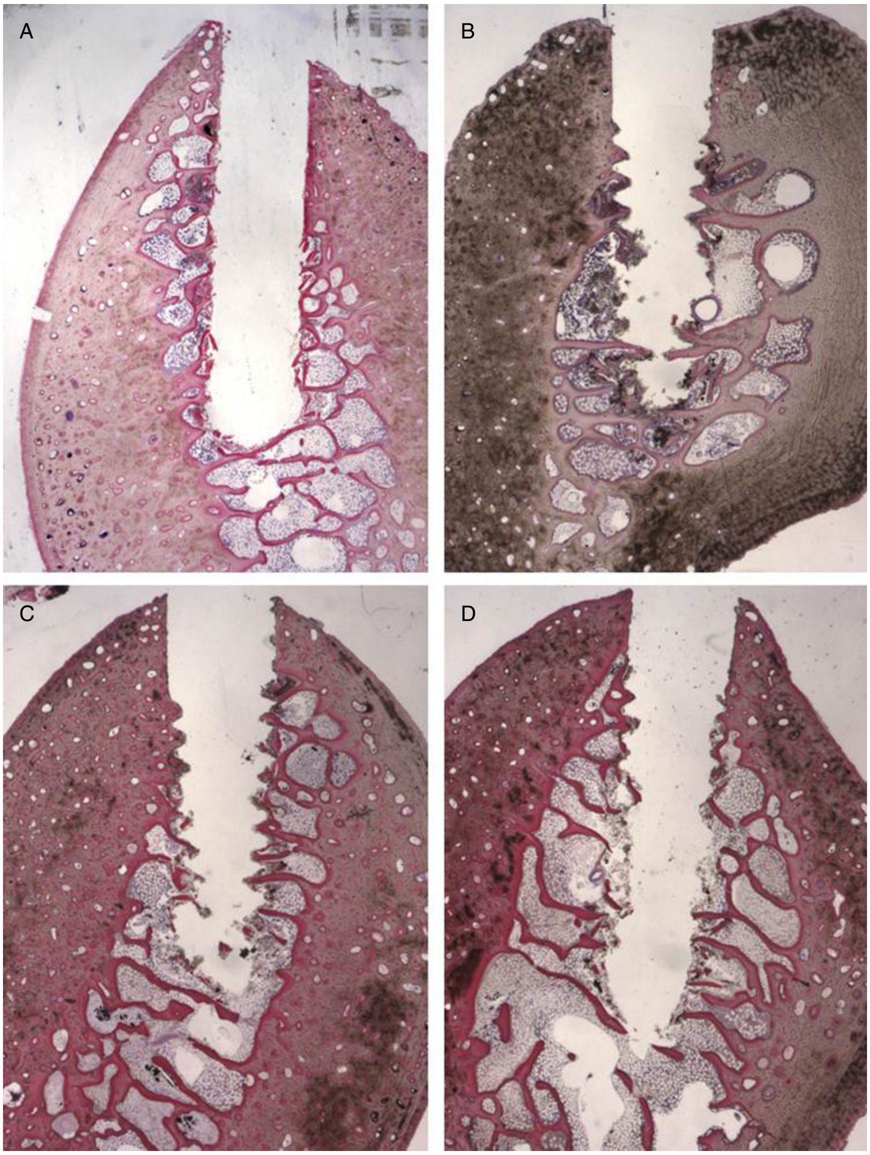

Figure 5 *A*, Photomicrograph of the ID1 bone tissue. Cortical bone with several osteons can be observed in the outer portion of the specimens, whereas the trabecular bone is mostly present apical portion. *B*, Photomicrograph of the ID2 bone tissue. The external cortical is formed by compact bone, whereas in the middle portion trabecular bone with small and wide marrow spaces can be seen. *C*, Photomicrograph of the ID3 bone tissue. Cortical bone is thin and far from the milling area. Trabecular bone with wide marrow spaces can be largely observed in the whole milling area from coronal to apical portions. *D*, Photomicrograph of the ID4 bone tissue. Trabecular bone with wide marrow spaces can be found in the sample. (Toluidine blue and acid fuchsin 12x.)

bone density assessed by histomorphometry, it was found that there was a significant positive correlation in D1 ($r = 0.83$, $n = 5$, $p < .03$), D2 ($r = 0.74$, $n = 4$, $p < .12$), and D4 ($r = -0.83$, $n = 6$, $p < .01$); only in D3 there was a negative, not significant linear correlation ($r = -0.22$, $n = 7$, $p < .31$) (Table 4).

DISCUSSION

The success of implant treatment largely depends on bone quantity and quality.[32,33] These factors influence not only the selection of implant systems, in particular the design or geometry of their surface, but also the choice of the surgical procedure.[34] Primary stability of implants is linked to the bone density, and, therefore, the preoperative bone density assessment has been recognized as of paramount important in the use of immediate loading protocols.[35]

In a literature review on the assessment of the diagnostic accuracy of clinical methods to evaluate bone density, quantity, or quality before and during surgical procedure, the Authors concluded that the scientific evidence of the clinical methods currently used for the

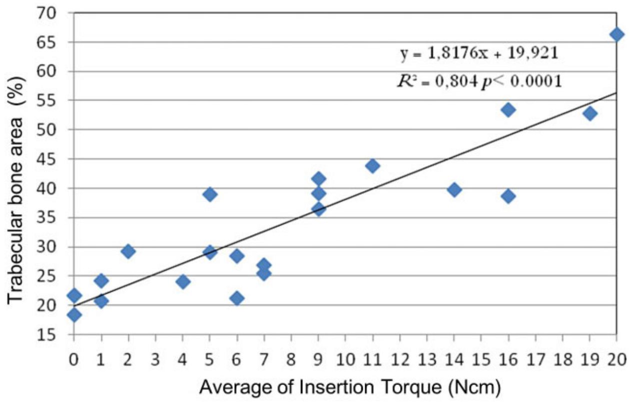

Figure 6 Scatter plots showing a significant positive linear correlation between the bone density measured by the implant motor (Ncm) and the bone density assessed by histomorphometry (r = 0.89, $n = 22$, $p < .0001$). Pearson's correlation coefficient for linear regression (R^2) between values assessed by the surgical motor and histomorphometry was the 0.80 ($p < .0001$), indicating that 80% of the data points are aligned with the regression line.

above evaluations was very poor.[36] Indeed, radiologic or tomographic preoperative diagnosis techniques, particularly when using cone-beam technology, achieved high quality standards, but they did not allow a site-specific analysis due to the lack of homogeneity of the bone tissue and the different planes of analysis.[7–10,37] CT has been used for the assessment of bone quality prior to surgery and provides direct density measurements given in Hounsfield units (HU). The units are based on a linear scale defined only by 2 points: the attenuation of dry air, set at −1,000 HU, and the attenuation of pure water at 25°C, set at 0 HU. Cortical bone may show HU values in the range +1,000 to +1,600. Trabecular bone shows lower HU values. Negative readings might indicate that the trabecular bone has been mostly replaced by fat.[8] A good correlation of CT data with clinical parameters, such as IT has been shown,[9] although there are few concerns regarding this method. A concern as

TABLE 4 Pearson's Correlation Coefficient (r) between the Values of Average Torque (Cm) and Bone Trabeculae Percentage over the Total Biopsy Area

	ID1 ($n = 5$)	ID2 ($n = 4$)	ID3 ($n = 7$)	ID4 ($n = 6$)
(r)	0.83	0.74	−0.22	0.83
p Value	<.03*	<.12	<.31	<.01*

*Statistically significant.

regards the radiation dosage, with a higher risk of hypothetical mortality based on absorbed radiation when compared with conventional tomography, quoting mortality risks ranging from 8×10^{-6} to 56×10^{-6} dependent on gender and age.[37] In addition, remarkable differences in Hounsfield values are reported in different regions of the jaws, therefore, bone density data obtained from various regions of the jaws may not be fully representative. Indeed, some bone measurements within the tuberosity regions may reflect the high fat content of the marrow in this area, thus reducing density values to below that of water; whereas the upper limit seen would appear to be of the order of[1]1800 HU for dense cortical bone in the mandibular symphysis.[37] On the other hand, the intraoperative evaluation of bone quality during the preparation of implant socket can only give a rough indication due to its subjectivity and to the different bone densities found along the implant sites.[38] To overcome these limitations, the development of a method that can objectively assess the bone quality seemed to be relevant.

The computerized implant motor used in the present study could read the cutting friction and distinguish the bone quality in a site-specific fashion. The intraoperative data obtained enable the clinician to select the most appropriate implant system for the anatomy of the implant site (macro and micromorphology of the implant surface). In addition, these data will help the surgeon in the implant site preparation, defining the necessity of any eventual underpreparation and/or compaction, assisting in the choice of a one-stage or two-stage protocol, with or without the use of taps and cortical drills. Finally, the system will help to make a decision on the implant torque, on the bone compression, and, therefore, on the achievement of primary stability.

In the present study, segments of bovine ribs have been used as the animal model because it has been documented in the literature that they have been employed in studies where methods of evaluation of bone density and implant stability were correlated.[39–41]

In a recent study, the computerized implant motor has been tested on 1,254 patients in order to evaluate the possible correlation of the proposed classification with clinical implications; the authors concluded that the classification allowed a rapid and intuitive selection of implant systems and enabled a prosthetic rehabilitation with a high prognostic value.[42] In a pilot study, on

230 patients and 622 implants, on the evaluation of bone density and implant stability by means of the computerized implant motor, the bone densities obtained were compared with those detected during the surgical interventions according to Trisi and Rao[43] classification (hard [H], medium [M], and soft [S]). It was concluded that the 199 sites classified as hard bone matched with the ones identified as D1 by the implant motor, as well as the 131 sites classified as soft corresponded with the ones classified as D4.[44]

In the present study a high statistically significant correlation has been found between histomorphometric data and bone density values recorded by the implant motor ($r = 0.89$). Specifically, D1 and D4 samples showed a highly significant positive correlation ($r = 0.83$); in D2 samples the values were again positively correlated ($r = 0.74$) although not significantly, whereas in D3 a linear negative not significant correlation was found ($r = -0.22$). The latter result can be due to the high variability of the percentage of bone trabeculae found in D3 bone, with values ranging from 38.9% to 21.2%. In addition, in the present study a wide range of distribution of histomorphometrical data in each bone density class has been detected, with an overlapping of values of adjacent classes. This can also explain the lack of significance in the correlation of D2 and D3 classes. Indeed, the real bone density, which has been conventionally classified into four different classes, appeared as a continuous gradient with intermediate values, which could overlap between adjacent classes.[43] The graphical representation of the site-specific density developed by the system was very helpful for the clinician because it showed up the areas of greater or lesser resistance along the surgical site by the degree of corticalization (crestal, intermediate, and apical). This could help the clinician in the preparation of the implant site.

In the histomorphometrical analysis conducted in the present study, the percentages of bone trabeculae were similar to those reported by Trisi and Rao,[36] who did a correlation between a clinical, manual evaluation of bone quantity and the histomorphometric evaluation of bone density: the results showed 76.54% ± 16.19 bone trabeculae for D1 bone, 66.78% ± 15.82 for D2, 59.61% ± 19.55 for D3, and finally 28.28% ± 12.02 for D4.

Further studies on a greater samples size should be conducted and the system should be also in vivo investigated in different clinical situations to better test its practical implication and verify the outcome on human bone tissue.

CONCLUSION

Within the limitations of this in vitro study, the intraoperative site-specific classification of bone density obtained with this innovative system seemed to be helpful for the clinician as a guide in the implant treatment protocol.

CONFLICT OF INTEREST AND SOURCE OF FUNDING STATEMENT

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