ORIGINAL ARTICLE

# A site-specific intraoperative measurement of bone-to-implant contact during implant insertion: A study on bovine ribs using a computerized implant motor

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**Abstract**    *Background/purpose:* The aim of the current *in vitro* study was to determine if there was a correlation between the integrals (I) of the function cutting resistance/depth, obtained using a computerized implant motor, and the bone-to-implant contact (BIC) percentages of dental implants inserted in bovine ribs.
*Materials and methods:* Segments of bovine ribs were used, and a total of 21 perforations were performed. A total of 21 dental implants were inserted in the prepared bone sites. A computerized implant motor ("Torque Measuring Motor") was used to assess, before implant insertion, the values of the bone cutting resistance. The data of bone density obtained by the implant motor were statistically correlated with the BIC percentages.
*Results:* A significant positive linear correlation was found between the integrals measured by the implant motor and the BIC assessed by histomorphometry ($r = 0.78$, $n = 21$, $P < 0.0001$). Indeed, the increase of the integral values recorded by the reader matched with the increase of BIC percentages measured by histomorphometry. Pearson correlation coefficient for linear regression ($R^2$) between values assessed by the surgical motor and histomorphometry was 0.61 ($P < 0.0001$), indicating that 61% of the data points were aligned with the regression line.

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*Conclusion:* The instrument under testing seems to provide a reliable quantitative estimator, the integral, of the final BIC achieved at implant insertion, and therefore of the implant primary stability, and could represent a significant aid for a proper planning of rehabilitations with the use of dental implants.

## Introduction

Primary stability of a dental implant, i.e., the lack of mobility in the osseous site after the insertion of the implant, is strongly correlated with the quality of the receptor bone site.[1] In fact, it has been reported over many years in the dental literature that there is an increase of implant failures in bone sites characterized by low quality and quantity of bone.[2] Primary stability certainly plays a relevant role in obtaining a predictable result in the implant treatment.[1−3] Primary stability is strictly correlated to the mechanical relationship between the implant surface and the recipient bone, and this interlocking serves to avoid the occurrence of micromotions at the interface, which could have a deleterious effect on the peri-implant tissues.[3] Several factors contribute to achieving an optimal primary stability: implant design, thread design, macrogeometry and microgeometry of the implant, length, shape, surface features, quantity and quality of the bone receptor site, different techniques for the preparation of the bone site and for the placement of the implant (i.e., diameter of the drills used, depth of the preparation, tapping or not of the implant site), relative rigidity of the involved structures.[1,3−5]

One of the most important parameters to measure bone quality is to evaluate bone density, which is thought to be a predictor and main conditioner of primary stability.[5] An in-depth evaluation of the bone structure before implant insertion is necessary for planning e treatment.[5] The different bone densities of the portions of the jaws could play an important role in the planning, in the preparation of the bone implant site, and in the loading modalities of the implant (immediate, early, or delayed).[5] An improved knowledge of the bone density differences could help the clinicians to make a correct preoperative diagnosis and realize a treatment according to the necessities of each patient.[2,6] It has already been said that primary stability is the key to a successful outcome of the implant treatment and so its accurate prediction, before or during surgery, will play a valuable role.[7] There is then a need for a reliable and easy-to-use system to quantify, preoperatively, the bone quality, but, unfortunately, such technique or equipment does not exist. In a previous in vitro study from our laboratory, a significant positive linear correlation was found between the bone density measured by a computerized implant motor, and the bone density evaluated by histomorphometry.[8] The increase in the values of the bone density strongly correlated with the increase of the percentage of the bone trabeculae observed in the histological slides.[8] In a clinical set, moreover, the measuring system

under testing allowed to distinguish different and clinically significant anatomical zones according to their different bone density.[9]

An evaluation of the bone density, in a site-specific way, seems then to be possible. Primary stability has been found to be a prerequisite for the osseointegration of dental implants and, in fact, in a study primary stable implants showed increasing percentages of bone-to-implant contact (BIC), whereas, on the contrary, an absence of osseointegration was reported for implants with no primary stability.[10] Higher values of BIC percentages have been reported to be strictly correlated to a better primary stability.[11] It was decided to determine, using the same computerized implant motor, whether a significant correlation existed between the integral values and the BIC of implants inserted *in vitro* into bovine ribs, under the hypothesis that implant insertion was a dynamic process, whose final result was the sum of the local modifications changing at the bone-implant interface whereas the implant screws deepened into the previously prepared bone site. BIC assessment through histomorphometry, however, was just a direct measurement of such interaction: its outcome being an estimate, from two-dimensional measurements, of the whole contact area between the implant and the bone tissue.

The goal of the current *in vitro* study was, therefore, to investigate if there was a relationship between the Integral of the resistance/depth function, obtained by the implant motor, and the BIC percentages of dental implants inserted into bovine ribs.

## Materials and methods

This *in vitro* study was performed at the Implant Retrieval Center of the Department of Medical, Oral and Biotechnological Sciences of the University of Chieti-Pescara, Chieti, Italy. Five segments of bovine ribs where it was possible to clearly define the cortical and the cancellous bone were used. The periosteum was removed from all bone segments, and the samples were regularized using a diamond saw (Precise 1 Automated, Assing, Rome, Italy).[12]

A total of 21 bone implant sites were performed. A computerized implant motor called "Torque Measuring Motor" (TMM2) (IDI Evolution, Concorezzo, Milano, Italy), was used for the intraoperative analysis of the density of the different osseous sites. The measurements were done using a special reading drill (Patented by IDI Evolution, Concorezzo, Milano, Italy), to assess, before implant insertion, the values of the bone cutting resistance.

Briefly, the procedure was as follows. A definition of the insertion depth and direction of the perforations was done. A first drill with a diameter of 2.2 mm was used for the perforation of the cortical bone, and, then, a second tri-flute drill with a diameter of 2.3 mm was used for bone site preparation up to a depth of 12 mm. Then, with a 3.0-mm-diameter drill, the direction and depth of the perforation was performed and the cortex of the upper portion of the bone specimens was removed. The surgical procedures were undertaken by experienced operators (DDS and PA) with the use of the manufacturer's drills. The "read mode" was put on the display of the implant motor, and the reading drill (3 × 8 mm in the cutting portion), with a preset torque and speed (35 Ncm, 35 g/min), was used to evaluate the bone density of the bone site up to a pre-defined depth. The measurements were displayed both as numbers and as graphs.

The surgical motor was used to make the following evaluations:

- Cm (average torque) (Ncm): the average torque of the resistance in function of depth;
- Cp (peak torque) (Ncm): the point of highest resistance in function of depth (i.e., the maximum torque measured along the bone tunnel);
- I (Ncm): the integral of the function resistance/depth (i.e., the area bounded by the resistance/depth function graph);
- P: depth measured as tenths of a millimeter;
- Graph of the torque (ordinate) / depth (abscissa);
- N: sequence numbers of the different measurements.

The device, moreover, grouped average torque values (Cm) to distinguish four bone density classes (IDI 1-4) from the more to the less dense as follows: IDI 1: cm > 12; IDI 2: $8 \leq cm \leq 11$; IDI 3: $3 \leq cm \leq 7$; IDI 4: cm < 3.

These measurements were performed for each implant site. Dental implants (IDI, Evolution) were then inserted in each of the different prepared sites (Fig. 1). A total of 21 implants were inserted. After implant placement, the bone specimens were immersed in 10% buffered formalin and processed to get thin ground sections with the Precise 1 Automated System (Assing, Rome, Italy).[12] A dehydration of the specimens in an increasing series of alcohol concentrations was followed by an embedding in a special resin (LR White, London Resin, Berkshire, UK). After polymerization, the samples were cut along their longitudinal axis with a high precision diamond disc at about 150 μ and ground down to about 50 μ. The slides were stained with acid fuchsin and toluidine blue. Histologic and histomorphometry analysis was performed under a light microscope (Laborlux S, Leitz, Wetzlar, Germany), connected to a high-resolution video camera (3CCD, JVC KYF55B,JVCs, Milan, Italy), and interfaced with a monitor and PC (Intel Pentium III 1200 MMX, Intels, Santa Clara, CA, USA). A digitizing pad was connected with this optical system (Matrix Vision GmbH, Oppenweiler, Germany) with a histomorphometry software package furnished with image capturing capabilities (Image-Pro Plus 4.5, Media Cybernetics Inc., Immagini & Computer Snc, Milano, Italy). Histomorphometrical evaluation of the BIC percentages was performed for all implants.
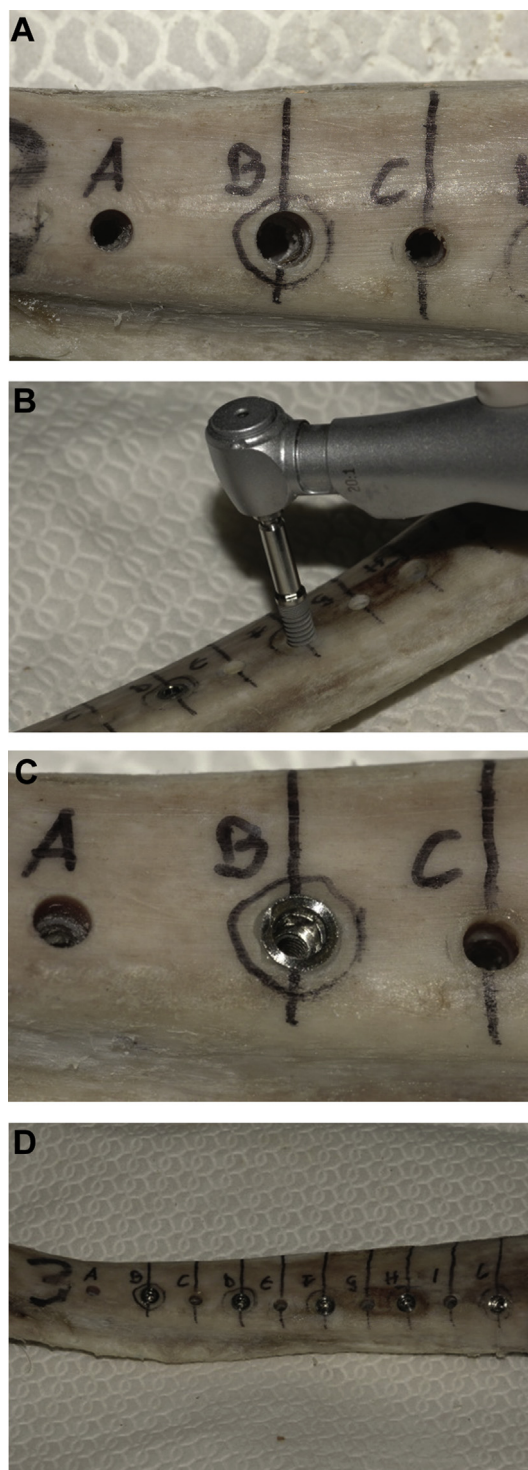


**Figure 1** Surgical procedure. (A) Implant site preparation on a bovine bone rib. (B) Implant placement. (C) Implant placed. (D) Block section with five implants placed.

## Statistical analysis

Data were reported as mean ± standard deviation (SD). Histomorphometrical measurements of BIC were statistically compared with the corresponding values of the Integral obtained with the device. Pearson correlation

coefficient (r value), between the histomorphometric data and integral (I) values recorded by the implant motor, was calculated. The correlation was considered significant when P < 0 05.

## Results

Distribution of the bone density recorded by the implant motor in the selected samples and the respective assessment of histomorphometric parameters were summarized in Table 1. D1 bone density was found in 5 (23.8%), D2 in 4 (19.04%), D3 in 6 (28.57%), and finally, D4 in 6 (28.57%) of 21 samples.

The histomorphometric measurements showed that the samples classified, by the implant motor, as D1 had a 43.4 ± 4.39% (range 37—49%) BIC, the ones classified as D2 a 34.75 ± 4.85 (range 30—41%) BIC, the ones classified as D3 a 25.83 ± 4.53 (range 18—32%) BIC, and finally, the ones classified as D4 a 14 ± 3.94 (range 10—21%) BIC (Table 2) (Figs. 2 and 3).

A significant positive linear correlation was found between the integral measured by the implant motor and the BIC assessed by histomorphometry ($r = 0.78$, $n = 21$, $P < 0.0001$). Indeed, the increase of integral values, recorded by the reader, matched the increase of the percentages of BIC, measured by histomorphometry. Pearson correlation coefficient for linear regression ($R^2$) between values assessed by the surgical motor and histomorphometry was 0.61 ($P < 0.0001$), indicating that 61% of the data points were aligned with the regression line.

## Discussion

The classification of bone quality has been based on different techniques: bone volume fraction using histomorphometry, clinical evaluation by insertion torque (IT) force, peak insertion torque (IT), removal torque (RTV), resonance frequency analysis (RFA), and subjective tactile sensation by the clinician during drilling of the bone sites, conventional radiographs, computed tomography (CT), quantitative computed tomography, cone beam computed tomography, and dual-energy X-ray absorptiometry (DXA).[6,13—28] Histomorphometry has been used for a long time as a standardized method to provide an evaluation of the bone microstructure.[28] It is, however, a costly, time-consuming technique, it is destructive and provides information about the bone quality only after the surgical procedure. CT is a widely used technique to obtain images of

**Table 2** Mean ± standard deviation of bone to implant contact percentage and its correspondence to the bone density class identified by the implant motor.

| IDI | Bone to implant percentage (± SD) (%) |
|---|---|
| I.D.1 | 43.4 ± 4.39 |
| I.D.2 | 34.75 ± 4.85 |
| I.D.3 | 25.83 ± 4.53 |
| I.D.4 | 14 ± 3.94 |

IDI = intraoperative density index; SD = standard deviation.

the jawbones before surgery[5]; it enables the ability to obtain, preoperatively and in a noninvasive way, a site-specific measurement of the values of the mineral density of the bone before implant insertion.[5] Hounsfield units (HU) are routinely used to objectively determine the bone density.[29—31] To this end a radiologic classification based on the HU has been proposed: bone type 1 (> 850 HU), bone types 2 and 3 (500—850 HU), bone type 4 (0—500 HU).[5] Although CT is an established method to assess bone density in implant planning, high radiation exposure, complexity of image analysis, restricted accessibility, and relatively high cost limit its use in the daily practice.[18,32,33] More recently, cone beam computed tomography (CBCT) is increasingly replacing CT in implant dentistry because of its lower radiation dose, fast scanning time, and lower number of image artifacts, compared to CT. Different evaluations of its effectiveness have been reported in the literature. A strong correlation has been found between the bone density evaluated by CBCT and the bone volumetric fraction obtained by micro-CT,[34] whereas no correlation was found, in another study, between CBCT and histology.[35] These discordant results could be ascribed to the fact that the HU derived from CBCT and from CT are not identical.[7] All these considerations reveal that a need exists for a more reliable and objective method to quantify in a simple and clear way the density of bone tissue in order to plan an implant rehabilitation strategy.[36]

In a previous *in vitro* study it was found that there was a strong correlation between the bone density measured by a computerized implant motor, and the bone density evaluated by histomorphometry.[8] Primary stable implants showed increasing percentages of BIC, whereas, on the contrary, an absence of osseointegration was reported for implants with no primary stability[10]; thus, primary stability has been found to be a prerequisite for the osseointegration of dental implants. Based on these observations, it was decided to investigate, using the same computerized implant motor, if a significant correlation existed between the integral values and the BIC of implants inserted *in vitro* into bovine ribs. The hypothesis underlying the choice of this specific parameter to be tested, as far as its correlation with the BIC was concerned, originated from the observation that the final bone-implant interaction (i.e. the BIC) was the result of a dynamic action, the insertion of the implant in the recipient bone: as this action was performed, two effects occurred. First, the microscopic bone boundary surrounding the implant dynamically and progressively modified as the fixture screwed into the bone

**Table 1** Sample distribution and their correspondence to the bone density class identified by the implant motor.

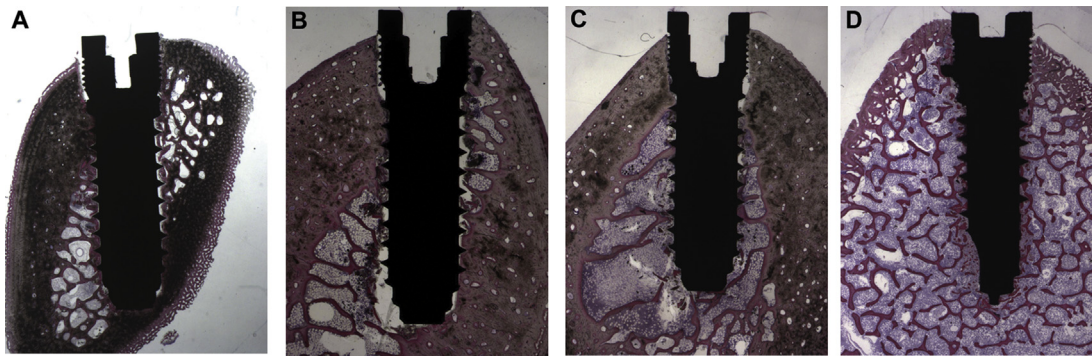| Index of density (I.D.I) | Samples distribution (%) |
|---|---|
| I.D.I.1 | 23.80 |
| I.D.I.2 | 19.04 |
| I.D.I.3 | 28.57 |
| I.D.I.4 | 28.57 |

IDI = intraoperatory density index.

**Figure 2** (A) Photomicrograph of an implant placed in ID1 bone tissue. Thick cortical bone and marrow spaces with several bone trabeculae. (B) Photomicrograph of an implant placed in ID2 bone tissue. Thick cortical bone and wide marrow spaces with bone trabeculae. (C) Photomicrograph of an implant placed in ID3 bone tissue. Cortical bone and wide marrow spaces with few bone trabeculae. (D) Photomicrograph of an implant placed in ID4 bone tissue. Thin cortical bone and wide marrow spaces with fine bone trabeculae. (Toluidine blue and acid fuchsin 12×.)
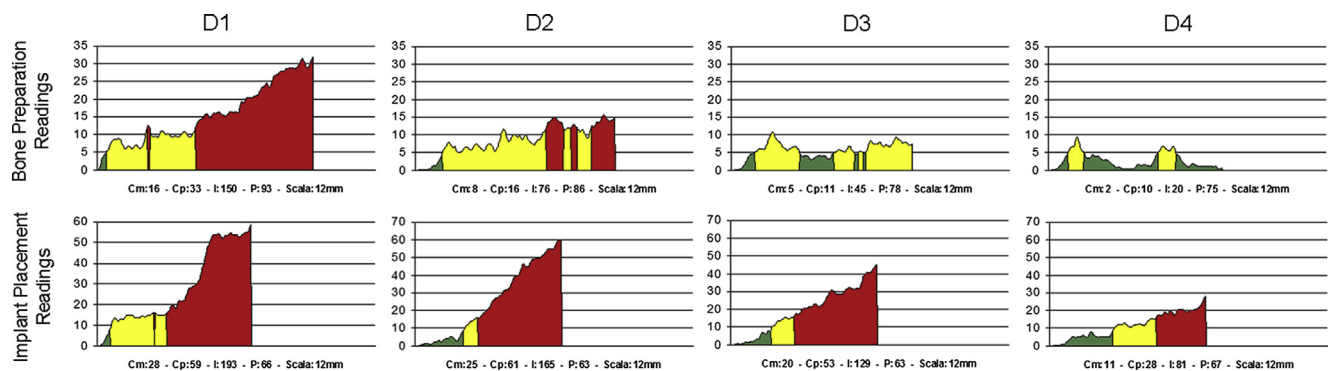


**Figure 3** Graphs showing ID1-4 bone classes' readings before and after implant insertion.

tunnel. Second, the more the implant deepened, more implant surface got in touch and interacted with the surrounding bone; finally, the whole implant surface would contribute to the primary stability of the implant itself. In other words, the implant-bone interaction was expected to change during insertion and increase by instantaneous infinitesimal amounts — as the implant screwed into the bone tunnel — in an additive way. It is therefore reasonable to suppose that the integral of the torque/depth function — which was proportional (save a multiplicative constant) to the sum of each infinitesimal variation of the instantaneous torque along all the implant tunnel depth, could be a proper estimator of the final bone-implant interaction, the BIC, as the result of the dynamic action that led to the fixture insertion in its final position. Results of the current study show that this hypothesis, i.e., the existence of a direct and linear correlation between the integral, as defined previously, and the BIC, is present. The integral, then, measured by the computerized implant motor, seemed to be a reliable quantitative predictor of the final BIC and primary stability, given the relationship between the two values.[9,10]

The integral of the torque/depth function at implant insertion, measured by the computerized implant motor under testing, significantly correlated with the final BIC of the fixtures placed. Within the limits of the *in vitro* model applied, and of the reduced sample size, it could be concluded that this integral seems to be a reliable estimator of the final BIC achieved at implant placement. Finally, the instrument under testing could represent a valuable preoperative and intraoperative diagnostic tool, providing additional helpful information to the surgeon, quantitatively measuring the bone quality of the site where the implant will be placed, allowing the implant positioning strategy to change intraoperatively in order to maximize the final BIC, and to achieve the desired primary stability, and to tune the rehabilitation strategy, such as the loading time and the final prosthesis type.

## Conflicts of interest

The authors have no conflicts of interest relevant to this article.

## Acknowledgments

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