Predicting Primary Implant Stability Using the Trabecular Bone Score

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Abstract

Background

Biological and mechanical factors are critical determinants during both the surgical and the restorative phases of implant treatment. Primary implant stability at the time of surgical placement is a critical step toward osseointegration and treatment success. Currently, there are limited pre-operative methods to reliably predict primary stability prior to surgery. The purpose of this study was to compare the implant stability and bone quality as assessed at the time of surgery to findings obtained from pre-surgical estimations of alveolar trabecular microarchitecture obtained through a novel software system's analysis of periapical radiographs.

Methods: Standardized pre-surgical radiographs were collected from sites prior to implant placement (n = 109). From these images, a "trabecular bone score" was calculated using proprietary software that has been shown in other medical applications to provide information reflecting bone microstructure and skeletal fracture resistance. At time of implant placement, the surgeon recorded the implant stability quotient (ISQ) value from resonance frequency analysis, insertion torque value (ITV), and bone quality (BQ) as detected by tactile sensation. Data analysis was completedusing the Pearson correlation coefficient and a one-way ANOVA testing followed by post hoc tests to detect significance between groups.

Results

Mean TBS measurements for all implant sites was found to be 0.731 ± 0.12438 with values ranging from 0.492 to 1.144. A Pearson correlation between TBS and ISQ averages was found to be 0.09111 ($p = 0.3461$). ANOVA testing of ITVs classified into three respective groups (≥ 35Ncm^3, 34-21 Ncm^3, and, ≤ 20 Ncm^3) and tested to TBS was performed ($p=0.1895$) ANOVA testing of BQ separated into four respective groups (D1, D2, D3, D4) and tested to TBS was performed ($p=0.1077$). Pearson correlation testing was also performed relating TBS to patient age, which show a weak negative linear relationship ($p=0.240$)

Conclusions

Within the limitations of the present study, TBS values were not found to correlate to the current clinical measurements of implant stability.

Keywords

Primary implant stability, radiographic evaluation, implant treatment planning, surgical imaging, bone quality assessment

Background:

Dental implants have been increasingly utilized by clinicians for the replacement of teeth and the skeletal anchorage of fixed and removable dental prostheses. Since their implementation into dentistry, there have been constant and ongoing efforts attempting to improve both surgical and restorative predictability and ultimate success of implant therapy. There are multiple critical factors that play a role in implant success. These factors, both biological and mechanical, are critical determinants to both the surgical and restorative phases of treatment. A prime example of this concept is the importance of implant stability at time of surgical placement[1, 2.] Poor primary stability of the implant has been demonstrated to increase the risk of early failure by fibrous encapsulation[3]. Over the years, various biological and mechanical properties have been seen to influence an implant's mechanical "primary" stability at surgical placement [4, 5.] These factors are, but are not limited to, implant system design and dimensions, patient bone quality and quantity, surgical protocol, and surgical technique [6, 7, 8, 9, 10, 11.] Today, it is generally accepted that without adequate primary implant stability that secondary stability by the bone regeneration around the implant surface, commonly referred to as "osseointegration", cannot be achieved [12,13] . It has been suggested that during post-surgical healing, the lack of mechanical interlocking may lead to micromotion of the implant and consequently to fibrotic encapsulation [3, 14].

The concept of primary implant stability can be broadly defined as an implant exhibiting no clinically visible mobility at time of implantation [15, 16]. This is immediate mechanical stability that is the result of the mechanical engagement of the bone-to-implant interface when the implant is inserted into the surgically prepared osteotomy. Primary implant stability and lack of implant micromovement is a significant prerequisite for ultimate osseointegration, various loading protocols and overall implant success[17, 18, 19]. As previously mentioned, primary implant stability is affected by a multitude of anatomical, mechanical and biologic factors. Bone quality and density has been determined to affect primary stability during implant placement [20]. Therefore, quality of bone at surgical sites, whether heavily corticated or sparsely trabeculated, greatly affects the primary stability and overall success for implant placement [21, 22, 23]. For implant dentistry, a common accepted bone quality classification index proposed by Lekholm and Zarb at al. (1985) allows clinicians to classify bone quality based on anatomical variations of cortical and trabecular bone. Other methods to classify bone quality has been proposed by Misch et al 1988, where the bone quality is determined by location and given tactile analogs to various densities of wood.

Currently, there are few methods used in practice to clinically evaluate primary stability [26]. Two non-invasive techniques are resonance frequency analysis(RFA) [27, 28] and the observable insertion torque values (ITV) [29, 30]. RFA measures pulse vibrations of an electromagnetically-activated transducer screwed into the implant body once it is implanted into the bone. These measurements are displayed as a numerical value scale from 0 to 100 which is referred to as the implant stability quotient (ISQ). ISQ values have been shown to demonstrate a positive relationship of the implant to bone complex through histomorphometric studies [31]. Because ISQ values are derived by vibratory movement of the implant, it is recommended to take two ISQ values at time of placement. RFA values are commonly taken at implant placement by orienting the RFA sensor (Osstell, Integration Diagnostic AB, Göteborg, Sweden) in two perpendicular planes in relation to the transducer in order to obtain measurement of bone-to-implant contact in both buccal-lingual and mesial-distal planes[32]. It has been expressed in the literature, however, that the true prognostic capabilities of ISQ readings can be of limited value. It has been shown that ISQ measurements dynamically change during bone remodeling around implants[33], thus initial ISQ value cannot be a sole predictive value for either future implant stability or instability[34].

Another technique used for evaluating initial implant stability is insertion torque. Insertion torque values provide a measurement of implant resistance to rotation of implant threads to that of the surrounding bone. Authors have found that this insertion torque relates to varying types of bone density and to degree of implant micromotion[35, 36, 37]. Low ITV has also been found to pose a risk of failure to immediately loaded implants, and some authors have proposed threshold ITVs as a pre-requisite for immediate loading [38, 39]. Insertion torque values, however, can be influenced by numerous factors related to surgical protocol, thread orientation, and degree of tapering of the implant body[8, 9, 40]. Additionally, in studies that evaluated submerged implants placed at a low ITV and given adequate time for healing, it was seen that ITV value at placement did not influence later stability [41, 42].

Pre-surgical assessment of bone quality is currently limited to radiographic image analysis of the available bone. Cone-beam computer tomography (CBCT) is one current radiographic method to pre-surgical planning. However, surgeons are still unable to reliably evaluate bone quality and trabecular microarchitecture accurately [43, 44, 45]. This limitation poses a challenge for surgical planning thus increasing the risk of surgical complications and the need for additional procedures. Trabecular Bone Score (TBS) is a textural index that utilizes gray-level pixel variations extracted from 2D X-ray images by quantifying local variations in gray level [46, 47]. The TBS is an indirect representation of trabecular bone microarchitecture by interpreting a three-dimensional structure's projection onto a two dimensional plane. Significant correlations have been identified between TBS and varying densities of trabecular microarchitecture. This technology has been applied to bone fracture risk assessment for osteoporotic patients and has shown to better predict bone strength than the standard measurement of bone mineral density by dual-energy X-ray absorptiometry (DXA) [48, 49]. Our group has previously shown a positive correlation between TBS and ISQ in a pilot study examining 13 mandibular implants [50]. The current study is aimed to explore this finding further by collecting a larger sample of values and include other factors that may be related to implant stability. If proven to be an applicable tool for pre-surgical assessment of bone quality, TBS could significantly contribute to aiding the predictability of implant surgery. An accurate pre-surgical assessment of bone quality may reduce the incidence of implant failure, increased predictability of implant surgery, and reduced risk of surgical complications.

The purpose of this study is to evaluate the relationship of TBS and primary implant stability as measured by clinical measurements and observations. The specific aims of the study are to: 1) assess correlation between TBS and implant stability quotient (ISQ) of dental implants using resonance frequency analysis (RFA) immediately after implant placement. 2) Assess the possible correlations between TBS and insertion torque value (ITV) as measured in Ncm[3]. 3) Assess the possible correlation between TBS and bone quality as detected by the surgeon haptic feedback.

Methods and Materials:

Institutional review board approval was obtained from the Institutional Review Board at Louisiana State University Health Sciences Center (IRB #9468). 73 subjects were enrolled in this study. All subjects were patients who were in need of dental implants. Inclusion criteria: Healthy patients in need of one or more implants that could undergo dental implant surgery. Exclusion criteria: Patients who were deemed medically unfit for implant surgery and those who cannot comply with implant treatment protocol. Among those who participated in the study, additional demographic data collected included: medical history, gender, age, dental history and smoking status.

Surgical Data Collection:

Surgical data was collected and recorded at time of implant placement by the implant surgeon. 8 surgeon's findings were included in the study. Surgical data recorded included implant system, implant length and diameter, implant site and location. Bone quality was determined and categorized into four separate categories, D1, D2, D3, and D4, based upon the Lekholm and Zarb classification of bone quality. ISQ values were recorded once implants were placed at the desired depth. Two ISQ readings were taken from a buccal-lingual and mesial-distal directions. These

ISQ values were then later averaged to provide a single value per implant placement. ITVs were recorded by torque wrench with each value subsequently categorized into three respective groups: ≥ 35Ncm^3, 34-21 Ncm^3, and, ≤ 20 Ncm^3 as to reflect low, moderate and high degrees of insertion torque.

Image Acquisition:

A standardized 2D periapical radiograph of the implant site was obtained pre-surgically. Pre-surgical radiography is a standard treatment protocol prior to surgical implant placement, therefore no additional step in the overall treatment sequence was taken. Radiographs were standardized in terms of radiation energy (65 kv, 4ms, 0.125s). At each implant site, the x-ray tube (Preva DC Intraoral X-ray, Progeny® Dental) to digital x-ray sensor (DEXIS® Platinum Sensor, DEXIS LLC, Hatfield, PA) distance was positioned at a uniform length.

Image Analysis: Trabecular Bone Score

Radiographs obtained were converted to a DICOM file and then analyzed using Texture Research and Investigation Platform (TRIP) software provided by a third-party organization (MediMaps Group, Espace, France). This software was configured to the parameters established by the previous pilot study (Simmons 2014). The images were imported and a numeric TBS was computed from a manually selected region of interest. This selected region of interest was determined by the estimated implant osteotomy location and its approximate dimensions (Fig. 3).

Statistical Analysis:

Comparing TBS to ISQ averages and TBS to patient age, a Pearson's correlations coefficient was used to identify relationships between the mean values collected. Linear regression was also utilized between these parameters. ANOVA testing was utilized for evaluating the relationships between mean TBS to the respective ITV groups, mean TBS to bone quality group, and mean ISQ to implant system. A Fisher's exact test was performed to test the null hypothesis that no association between ITV and implant system existed.

Results:

Within the duration of this study, 109 implants were successfully placed with no complications reported. The following implant systems were used: Zimmer Tapered Screw Vent (n=61, Zimmer BioMet, Carlsbad, CA), Straumann Bone Level Tapered (n=14, Straumann Holding, Basel, Switzerland), Nobel Conical Connection

ReplaceTapered (n=28, Kloten, Switzerland), and Biomet 3i Osteotite T3 (n = 6, Zimmer BioMet, Carlsbad, CA). All implants were of tapered design and all were placed at the level of the bony crest or sub-crestally in relation to the remaining alveolar ridge. Implant diameters varied from 3.3mm to 6.0mm and implant length varied from 8.0mm to 13.0mm. All implants were reported as stable at time of placement.

Implant Stability Quotient (ISQ)

Mean ISQ value among all implants (n = 109) was 72.84 ± 6.26 with a median value of 73.50. Mean ISQ values between all implant systems: Zimmer (n=61) 74.77, Straumann (n=14) 73.82, Nobel (n=28) 69.78, and Biomet 3i (n = 6) 65.33 (Table 1, Fig. 1). ANOVA testing revealed a statistically significant relationship between ISQ averages and individual implant systems ($p < 0.0001$, see Table 3). Mean TBS values for all implant sites was found to be 0.731 ± 0.12438 with values ranging from 0.492 to 1.144. A Pearson correlation between TBS and ISQ averages was found to be 0.09111, which was not significant (p+ 0.3461) (Table 3). We also fit the data to a simple linear regression plot using TBS as a response variable and ISQ averages as the predictor (Table 4). The R squared coefficient of determination (R^2), which is the proportion of the variance in TBS that is predictable from ISQ averages, was found to be 0.00830 (Table 4). When fitted to a plotted linear regression line it can be seen that the data does not fit well (Fig. 2).

Insertion Torque Value (ITV)

Of the 109 implants placed, 72 implants were placed at a recorded torque of ≥ 35 Ncm^3, 28 implants placed with a recorded value of 34-21 Ncm^3, and 9 implants recorded with ≤ 20 Ncm^3 (Table 5). All implants were placed to their desired depths with a standardized torque wrench. Mean TBS values were allocated to each groups, respectively (Table 6).

ANOVA was used to evaluate the differences among the three torque groups and corresponding average TBS values. As the calculated p-value was found to be 0.1895, no statistical significance was found for TBS among the 3 torque groups. (Table 7).

ITV was then examined by individual implant system for correlation. A Fisher's exact test was performed to test the null hypothesis that there is no association between ITV and implant system. From this test a p-value of 0.0058 was found, thus showing a statistically significant association between ITV to implant system (Table 8.)

Bone Quality

Bone quality recorded successfully for all 109 implants at time of implant placement. Each site was classified to their respective bone quality as evaluated by the surgeon's tactile sensation. Of the 109 implants placed, 38 implants were placed in D1 quality bone, 31 implants were placed in D2 quality bone, 30 implants were placed in D3 quality bone, and 10 implants were placed in D4 bone. TBS values were averaged for each of the four bone quality groups (Table 9. 7). ANOVA testing was performed to evaluate for differences in TBS averages among bone quality groups. This resulted in a p-value of 0.1077, therefore failing to reject the null hypothesis (Table 10).

Age

Mean age of study participants was 58.2 years (range 22 – 77 years). When tested with the Pearson correlation coefficient, it was determined that age of the patient positively correlated to TBS values (p=0.0240) indicating a weak negative linear relationship (Table 11). Linear regression using TBS as a response variable and age as the predictor was also completed (Table 12). The R-squared coefficient of determination (R^2), which is the proportion of the variance in TBS that is predictable from age was found to be 0.046722. When fitted to a plotted linear regression, it can be seen that the regression line does not fit the data well (Fig. 12).

Discussion

In the present study, we obtained TBS values from pre-surgical peri-apical radiographs as to assess the microarchitecture of the alveolar trabeculae. From medical applications of this technology, we have seen its significance in predicting bone resilience to fracture beyond standard 2-dimensional x-ray imaging. In this study, TBS calculations based off our periapical radiograph ranged from 0.492 to 1.114, with a mean value of 0.731 ± 0.12438. In previous studies it was suggested that TBS value for postmenopausal women ≥ 1.350 would represent a normal microarchitecture and that scores of ≤ 1.200 could suggest a degraded microarchitecture[34]. To compute TBS values in these studies, however, radiographs were obtained through DXA. This technique uses two x-ray beams with different energy levels to obtain the radiograph used for TBS analysis. As the TBS scores calculated from the current study are seen to be significantly lower than TBS values found in other studies, there could possibly be limitation radiographic detail that a dental periapical radiograph could provide for TRIP analysis. Additionally, as DXA imaging is implemented with energy levels and exposure times different to that of standard dental x-rays, that may also may attribute to the discrepancy in TBS values. Technical limitations have been cited in previous studies, highlighting that TBS measurements are inherent to the radiograph acquisition process. One of these is image noise which is seen as random variation of brightness and contributes to degradation of image resolution. Addition of image noise has been seen to significantly decrease TBS values despite pixel size and can even render the TBS insignificant for analysis[50]. Image noise can be introduced into a radiograph through failures of x-ray tube positioning, sensor failure or discrepancies, or improper exposure time length. It has also been seen that in DXA studies image that the amount soft tissue present can also affect TBS the same as image noise. As both bone and soft tissues absorb x-ray energy, the amount of soft tissue thickness has been found to relate to TBS evaluation. For this study, no soft tissue intraoral or extraoral measurements were taken for consideration. Another limitation acknowledged in other studies, is the variability of TBS obtained from different DXA machines. A cross-calibration attempt to help ensure the same TBS results, across models was completed. Despite this, other variables have been seen to affect the software's ability to perceive correct bone texture. This may be evident in our study as the TBS measurements were calculated from a non-DXA source, thus may attribute to discrepancies.

The value of TBS indirectly evaluating alveolar bone quality was presumed to be reflected in our clinical findings of implant stability. It has been seen in histomorphometric studies that ISQ values are illustrative of the bone to implant interface. Using a Pearson test between TBS and ISQ averages we found no correlation (p= 0.3461). This finding may suggest that a multitude of other factors that have been previous cited to influence RFA measurements could have affected ISQ values [16, 52]. When examined for insertion toque values, ANOVA testing rendered TBS significance to the three tiered categories of insertion torque to be not statistically significant (p = 0.1895). Explanations for these findings may be attributed to surgical protocol employed by the surgeon at time of implant such as?????. We have seen that surgical variety in osteotomy preparation can directly affect the resulting ITV. In this study, we did not record surgical protocol nor whether the surgeon employed tapping techniques prior to implant placement. Additionally, we have seen that implant design positively influences insertion torque values [8, 9, 40]. When the concept of ITV relating to implant system was evaluated in the scope of this study, a Fisher's exact test provided a p value of 0.0058 agreeing with the findings that show a relationship between ITV and implant system. Comparing bone quality to TBS, averages among the four respective categories were evaluated. ANOVA testing was performed resulting in a p-value of 0.1077, suggesting the two parameters no not statistically correlate.. It has been mentioned prior radiographic image can be troublesome in providing accurate measurements of bone quality appreciated during osteotomy drilling [44, 45, 46]. TBS has been shown to improve the predictable risk of bone fracture in the postmenopausal woman through indirect analysis of bone flexural resilience. The definition of bone quality as defined by our study is that of resistance felt when drilling into alveolar bone. This differs from the medical research of TBS that analyzes the flexural strength and resistance of bone fracture. Although other research has shown correlation between implant stability in osteoporotic patients, in this study no correlation could be drawn between TBS and clinical assessments of bone quality [53]. Age has been shown to be a important finding in TBS research. It has been recognized in numerous studies that age has been negatively correlated to TBS values in spinal verterbrae [54, 55, 56]. Our findings also represented this trend; sing Pearson correlation coefficient, it was determined that age of the patient correlated to TBS values (p=0.0240) indicating a weak negative linear relationship.

Conclusions

In medical literature, TBS has been shown to provide useful information through the analysis of bone trabecular microarchitecture and bone fracture resistance. We have seen the importance of bone quality and density as it relates to implant treatment success. However, within the limitations of the present study, no significant correlation could be drawn between TBS values obtained from periapical radiographs to the clinical measurements of primary implant stability as observed in surgery. Further studies are needed to evaluate the use of TBS as treatment planning tool to better predict bone quality and primary implant stability.

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Authors' contributions

DS, AP, PM, TL contributed to the establishment of the concept of this work, drafting the paper, and final approval of the work. DL contributed to the establishment of the concept of this work, data acquisition and analysis, drafting the paper, and final approval of the work. YQ performed the statistical analysis and interpretation of data.

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Competing interests

Drs. AArchontia Palaiologou**,** Pooja Maney, David Long**,** Thomas Lallier, David Simmons and Ms. Liz Mayer declare that they have no competing interests.

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