Improvement in the Initial Implant Stability Quotient Through Use of a Modified Surgical Technique

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To ensure similar primary implant stability measured by resonance frequency analysis (RFA) could be obtained in different jawbone densities by using a specific surgical drilling protocol and, to correlate those RFA measurements with factors related to the implant design, width, and length, we are performed a 1-year prospective clinical study was carried out using 27 subjects. A total of 67 hydrophilic titanium implants were placed using a standard 2-stage implant placement protocol. The bone type at each implant site was determined by evaluation of a preoperative, high-resolution cone beam computerized tomography (CBCT) scan. A modified drilling protocol was used in softer bone (types 2, 3, and 4) that allowed for greater implant thread contact with the surrounding bone. The implant stability quotient (ISQ) was measured at 4 different times during the study: initially it was determined immediately after implant placement, then again at stage 2 uncovering surgery, then at 6 months' postplacement and, and finally at 1 year postplacement. Data collected immediately after implant surgery demonstrated a high correlation ($R^2 = .99$) between the ISQ and bone type classification. An overall trend toward a higher ISQ was found over the 1-year study period for all types of bone. Implants remained clinically and radiographically stable during the 1-year study period. Our data allow conclude that the primary stability of 2-staged loaded implants placed in different bone types can be optimized by applying this surgical drilling protocol during the implant placement. The ISQ method was found to be a reliable predictor of implant stability.

Key Words: implant stability quotient, bone density, bone quality, primary implant stability

INTRODUCTION

Dental implants have become a widely recognized and routine treatment modality for replacing missing teeth in the majority of dental applications. In fact, they constitute one of the most predictable treatment options to replace missing teeth, with a long-term implant survival rate of up to 95%–98%.[1,2] Implant stability can be defined as the absence of clinical mobility, which is also the suggested definition of osseointegration. Implant stability is a prerequisite for the long-term clinical success of osseointegrated implants. Primary implant stability is provided mechanically by macro-retentions engaging in the bony walls of the implant bed and is dependent on factors related to the properties of the bone, the design of the implant, and surgical technique. During healing, this primary stability will be replaced by a biological bonding of newly formed bone to the implant surface and is then termed secondary stability, which is greatly dependent on tissue response to the surgery and implant material.[3] Achieving and maintaining implant stability are prerequisites for successful clinical outcome with dental implants.[4]

Several techniques have been suggested for the determination of implant stability, including the insertion torque, percussion test, antirotational torque, Perio-Test, and resonance frequency analysis (RFA).[5] The insertion torque used to place the implant during the surgical stage has been recognized as a valuable predictor of the implant primary stability since Brånemark first introduced the concept of implant osseointegration. However, the insertion torque is an intraoperative parameter that allows a single measurement of primary stability and cannot be used for evaluating secondary stability. The percussion test constitutes the simplest but probably the most inaccurate test and involves the tapping of a dental instrument handle against the implant or attached abutment. Application of a reverse or unscrewing torque has been proposed for the assessment of implant stability at the time of abutment connection. However, due to its invasive nature and lack of clinical practicality such a technique has fallen into disrepute.[4]

Other techniques, such as the Periotest and RFA, aim to provide an objective measure of implant stability and osseointegration that is noninvasive and does not damage the implant–tissue interface.[4] The use of RFA as a noninvasive clinical method to measure implant stability and osseointegration was first described by Meredith et al.[6] The electronic RFA device (Osstell, Integration Diagnostics AB, Goteborg, Sweden)

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measures implant stiffness as a determinant of implant stability[6,7] and is thought to be an accurate and precise tool that progressively replaced other methods in implant research.[8] The resonance frequency in Hertz is then converted to implant stability quotient (ISQ) units by computer software. Hence, stability values are expressed in ISQ units, which range from 1 (low stability) to 100 (high stability).[5]

Implant stability quotient by RFA (ISQ, Osstell, Integration Diagnostics AB), unlike the insertion torque, not only provides clinically relevant information about implant stability at initial placement, but also can be used to assess stability at any time thereafter.

Several factors, including the characteristics of the surgical site, the patient, and the implant surface have been thought to influence RFA measurements.[9] Although extensive research has been done to further determine the correlation between these factors and RFA measurements, the results, however, remain highly variable. For example, several authors[3,10–13] showed that ISQ values correlated well with bone quality as defined by Lekholm and Zarb.[14] Lack of significant correlation between ISQ values and microcomputer tomographic analysis of bone volume density or trabecular connectivity has also been reported.[15] Also, RFA measurements have not been shown to correlate with insertion torque[16–21] but did show a correlation with cortical bone thickness[22] and the cutting resistance at the time of implant placement.[23] Implant surface chemistry and finishing did not seem to influence the ISQ values[21,24,25] nor did implant diameter.[10,25] ISQ values have been reported to be predominantly influenced by the bone structure and, to a lesser degree, by implant length.[3,26] Implant length, however, was found to enhance the primary implant stability, as longer implants provided more bone–implant contact area.[3,27–29]

The success of treatment with dental implants is clearly influenced by both the quality and the quantity of available bone at the implant site.[30] Areas of poor bone quality, both cortical and cancellous, have exhibited higher failure rates and weaker primary stability values.[2–4,12] Thus, it has been assumed that bone quality is directly related to bone mineral density, which, in turn, affects primary implant stability.[31]

In addition, Misch suggested that computerized tomography (CT) can be used for the objective quantification of direct density measurements of bone, expressed in Hounsfield units (HU).[30] Ever since Schwarz et al[33] introduced cone beam computerized tomography (CBCT) as a preoperative imaging examination technique, its use has been increasingly popular in implant dentistry.[31] CBCT provides a 3-dimensional, cross-sectional analysis of the mineral density of jaw bone in specified sites, as well as allows for the direct linear measurement of the bone in those dimensions.[31]

Studies have shown that ISQ values increase with time after implant placement. This might be related to the increase in the stiffness of an implant in the surrounding tissues that occurs during the healing phase. ISQ values increased significantly during the healing phase before reaching a plateau between 6 and 8 weeks.[35]

Hence, the main purpose of this study was to see if a modified drilling protocol for implant placement could yield similar primary stability levels (ISQ values) in all 4 types of alveolar bone.

Material and Methods

Study design and participants

This present study was conducted according to the ethical principles that govern medical research and human subjects, as stated by the Helsinki Declaration (2002 version, http://www.wma.net/e/policy/b3.htm). The study protocol and the informed consent form were approved by the University of Seville Experimentation Ethics Committee (Spain). All patients who participated in this study were selected within the Oral Surgery Master's Degree Program at the School of Dentistry, University of Seville (Spain).

Between January and July of 2013 patients were admitted to the study according to several inclusion criteria. Subjects must be between 18 and 65 years of age with the diagnosis of partial edentulism eligible for standard 2-stage dental implant placement in completely healed sites. Subjects must have the ability to understand and sign the informed consent before starting the study, demonstrate controlled oral hygiene and be systemically healthy (ASA classification I or II). Subjects with a medical history positive for alcohol or drug abuse, severe systemic illness that contraindicates implant placement, or who had been on IV bisphosphonate treatment during the past 2 years were excluded.

Preoperative and surgical protocols

Patients were classified into 4 study groups according to the bone mineral density at the implant site (Type 1, 2, 3, and 4). For this purpose a preoperative CBCT scan (ProMax 3D cone-beam computed tomography, PLANMECA, Helsinki, Finland) was taken and the corresponding histomorphometric analysis performed. The bone mineral density at the implant site was calculated in HU using the ICAT VISION computer software (ICAT VISION software package CENTRO ICAT, Madrid, Spain). In addition, the CBCT scan helped to determine proper implant size for each patient prior to surgical placement.

A broader based volume CBCT scan was performed with a rotation of 360° for data acquisition. The size of imaging volume was selected at a height and diameter of 160 mm × 160 mm. The voxel size was .2 mm and the exposure factors were 82 kV and 10.0 mA. A series of axially sliced image data were exported to a personal computer in DICOM 3.0 format.

Using the interactive Romexis software (PLANMECA, Helsinki, Finland), a 10 mm × 3.5 mm implant was then placed in each edentulous area, and the bone density surrounding its entire circumference to a depth of 1 mm (default setting) was mapped.

The reference values of bone density for each bone type are shown in Table 1. In this study the protocol described by Mah et al (specifically designed for the Planmeca ProMax 3D 82 kV 10 m) was used, as well as the bone quality classification described by Hao et al.[30]

On the day of implant placement all patients received 2 hours preoperatively 2 g amoxicillin/125 mg clavulanic acid or 600 mg clindamycin if allergic to penicillin). All implants were placed under local anesthesia (2% lidocaine 1:80:000 epinephrine, Normon EFG , Madrid, Spain). A full-thickness mucoperiosteal flap was elevated to expose the implant sites by means of a standard supracrestal incision. Table 2 and Figure 1 depict

Table 1

Reference values of bone density for each bone type*

Bone Quality According to Lekholm and Zarb[14]	Norton and Gamble Bone Density Scale (HU)	Bone Density According to CBCT in This Study (HU)
Bone type 1	>+850	>+600
Bone type 2	+500~+600	+600–+400
Bone type 3	+500~+850	+400–+200
Bone type 4	0~+500	<+200

*HU indicates Hounsfield units; CBCT, cone beam computed tomography.

the corresponding implant drilling protocol used to surgically prepare the implant sites in all four of the study groups. For implants placed in type 1 bone, the original manufacturer's drilling protocol was not modified. For implants placed in type 2 bone, the final twist drill was taken down 75% of the final implant length. For implants placed in type 3 bone, the final twist drill was taken down 50% of the final implant length and for those placed in type 4 bone, the final twist drill was taken down 25% of the final implant length. This modification of the original manufacturer's drilling protocol was utilized in this study with the intention of forcing more of the implant threads into direct contact with alveolar bone thus promoting a higher implant-to-bone ratio for implants placed into softer bone (types 2, 3, and 4).

Cylindrical implants (ELEMENT INICELL, Thommen Medical AG, Waldenburg, Germany) were surgically placed by one surgeon following manufacturer's recommendations for a 2-stage procedure. After implant placement, the surgical sites were closed with a polyamide nonresorbable suture (Supramid 4/0, SUPRAMID, S. Jackson, Inc, Alexandria, Va). The sutures were removed 10 days postoperatively. All patients were instructed to follow a soft diet during the first 7 days after

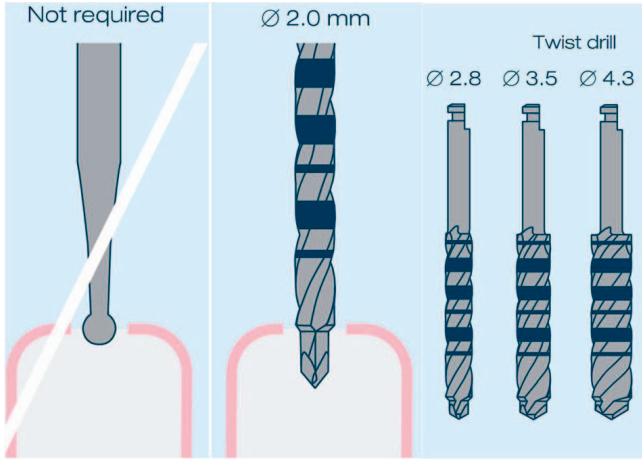

Figure 1. Surgical implant drills used in this study.

surgery and prescribed a .12% chlorhexidine mouthwash to be used 3 times per day for 14 days after surgery.

At 4 months after implant placement all implants were surgically uncovered under local anesthesia (2% lidocaine 1:80 000 epinephrine, Normon EFG, Madrid, Spain), and a corresponding healing cap placed. One month after 2-stage surgery all implants were loaded with temporary screw retained prosthesis. The final restorations were delivered 1 year after the surgical implant placement. All implants were restored with screw retained final prosthesis.

RFA measurements

The electronic RFA was used to measure implant stability. The third-generation Osstell device (Osstell ISQ, Osstell, Integration Diagnostics AB) was used to obtain ISQ measurements at initial implant placement, second stage surgical uncovering, 6-month and 1-year intervals. RFA measurements were performed in 4 locations around each implant: midbuccal, midlingual/palatal, midmesial, and mid-distal). A mean value for these 4 locations was then calculated. ISQ values at 6 months and 1 year were obtained following the removal of the temporary restorations.

Statistical analysis

Comparative analyses were performed using statistical software (SPSS statistics v. 23, IBM). Differences between ISQ values of various bone densities were compared using 1-way ANOVA. Pairwise comparisons were subsequently conducted using the Bonferroni's post hoc test.

Results

Twenty-seven patients (14 female and 13 male; mean 52.66 ± 10.65 years) were included in this study. Ten patients were smokers (3–21 cigarettes/d). Ten patients had a history of previous periodontal disease, and 7 of the 10 patients with history of periodontal disease were smokers. A total of 67 implants (ELEMENT INICELL Thommen Medical AG) were placed in fully healed sites. Thirty-three implants were placed in

TABLE 2

Drilling protocol used according to type of bone and implant size

Implant Diameter	Bone Type 1	Bone Type 2	Bone Type 3	Bone Type 4
3.5	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm (to 75% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm (to 50% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm (to 25% of final implant length)
4.0 mm	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm (to 75% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm (to 50% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm (to 25% of final implant length)
4.2 mm	2.0 pilot drill mm - 800 rpm 2.8 twist drill mm: 600 rpm 3.5 twist drill mm: 500 rpm	2.0 mm twist drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 3.5 mm twist drill: 500 rpm (to 75% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm (to 50% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm (to 25% of final implant length)
5.0 mm	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm 4.3 mm twist drill: 400 rpm	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm 4.3 mm twist drill: 400 rpm (to 75% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm 4.3 mm twist drill: 400 rpm (to 50% of final implant length)	2.0 mm pilot drill: 800 rpm 2.8 mm twist drill: 600 rpm 3.5 mm twist drill: 500 rpm 4.3 mm twist drill: 400 rpm (to 25% of final implant length)

mandibular sites and 34 implants were placed in maxillary sites. Twenty-five implants were 3.5 mm in diameter, 18 implants were 4 mm in diameter, 14 implants were 4.2 mm in diameter, and 10 implants were 5.0 mm in diameter; with regard to the implant length, the majority (25) of the implants were 9.5 mm, 23 implants were 11 mm, 18 implants were 12.5 mm, and only 1 implant was 8 mm. With regard to bone type, 42 implants were placed in type 1 bone, 16 implants were inserted in type 2 bone, 8 implants were inserted in type 3 bone, and 1 implant was inserted in type 4 bone (Table 3).

The overall ISQ value changes observed during the study period are illustrated in Figures 2 and 3. The ISQ measurements remain remarkably stable throughout the study. A slight increase in stability was seen toward the end of the study at 1-year follow up.

There was no statistically significant relationship between implant stability and bone type when comparing ISQ values obtained in the 4 groups at implant placement, 3 month, 6 month, and 1 year intervals ($P \leq .05$: Table 4).

We found no statistically significant differences in the ISQ value in relation to the implant diameter ($P \leq .05$; Table 5).

Similarly, no statistically significant correlation between the ISQ value and implant length was observed when comparing the results obtained after surgical implant placement, 3-month, 6-month, and 1-year intervals ($P \leq .05$; Table 6). All 67 implants remained clinically and radiographically stable throughout the 1-year study period.

DISCUSSION

Bone quality has been suggested as one of the main factors influencing implant therapy success. Areas of lesser bone quality, both cortical and cancellous, have exhibited higher failure rates and weaker primary stability values.[3,31]

Subsequently, several methods have been suggested for

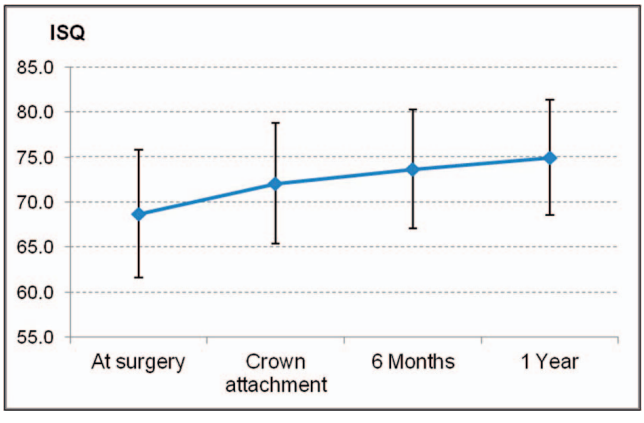

FIGURE 2. Overall implant stability quotient (ISQ) changes throughout the study period.

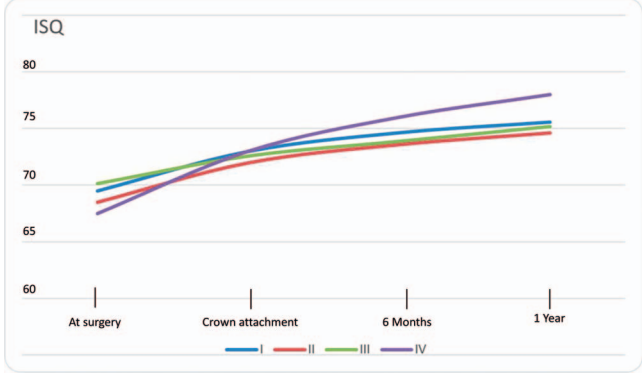

FIGURE 3. Overall implant stability quotient (ISQ) changes throughout the study period by bone type.

Table 3

Bone density distribution in all 4 study groups*

REGION	TYPE 1	TYPE 2	TYPE 3	TYPE 4
AMd	10	4	0	0
AMx	9	5	0	0
PMd	14	4	1	0
PMx	9	3	7	1
Total	42	16	8	1

*AMd indicates anterior mandible; AMx, anterior maxilla; PMd, posterior mandible; PMx, posterior maxilla.

the assessment of implant stability at different points during implant therapy. These include but are not limited to subjective assessment of bone resistance to drilling, percussion testing, antirotational torque measurement and radiographic interpretation of bone quality. However, due to the fact that these demonstrate either a lack of accuracy, too much subjectivity, or too high level of invasiveness, they are not often used repeatedly in the clinical setting.[9]

The RFA device (Osstell ISQ, Osstell, Integration Diagnostics AB) that measures implant stifness as a determinant of implant stability is thought to be both precise and accurate and has progressively replaced other methods to assess implant stability in implant research. ISQ values falling within a wide range (57–74) have been considered normal during implant placement.[10,15,26] This is in accordance with the measurements obtained in this study.

In 2010, Sim et al[3] found that the ISQ values were predominantly influenced by the bone structure and, to a lesser extent, by implant length, which suggests that predictive ISQ values could not be accurately used to insure implant stability.[3] Nevertheless, a consensus regarding a normative ISQ range has not yet been established.[36]

The controversy over the variable literature on RFA becomes even more amplified when considering immediate restoration/loading protocols.[9] Several clinical studies have intended to determine a safe ISQ threshold to identify implants that are amenable to immediate loading and predict those at a higher risk of failure. In an animal study, Al-Nawas et al.[37] suggested that an ISQ threshold value of 65.5 at implant placement, with a sensitivity of 83% and a specificity of 61%, may predict implant loss. Other clinical studies suggested that implants with ISQ values above 65 at the time of placement were suitable for immediate loading.[38,39] On the other hand, ISQ values of 42,[43] 60[44], or 62[47] at implant placement have also been suggested as threshold values for immediate loading. These conflicting results across the different clinical studies utilizing RFA have perplexed the profession with regard to the acceptable normative ISQ values for immediate restoration/loading.[9]

According to this data, the mean ISQ value of 69 obtained immediately after surgery in this study would have theoretically allowed for more than 50% of the implants, regardless of the bone quality found at the surgical site, to be immediately loaded. We believe this relatively high ISQ value of 69 was achieved by the application of a modified drilling protocol to each bone type.

Held et al[43] described a more pronounced, continuous increase in ISQ with time in a sample of thirty five hydrophilic implants placed in bone types 3 and 4. Their ISQ values taken immediately after implant surgery (43) were substantially lower than those found in this study (69). After 1 year their ISQ value was 73, which is quite close to what was obtained in study (75). We believe this finding correlates positively with the fact that a specific modified drilling protocol was used in each bone type with the purpose of increasing the bone-to-implant contact ratio during surgical placement. This could be responsible for the higher ISQ measurements (69) obtained in our study immediately after implant placement.

As previously described, several studies have demonstrated a positive correlation between bone quality and implant primary stability.[2,3,4,44] Ostman et al[12] studied the ISQ value at the time of implant surgery in 905 Nobel Biocare dental implants. They demonstrated a positive correlation between bone quality and primary stability with greater stability observed in males and posterior regions. This study, however, does not allow for conclusions to be drawn regarding clinical treatment outcomes since measurements were taken only at the implant surgery and further evaluation of implant stability throughout the postoperative stages and prosthetic loading was not evaluated. These results presented by Ostman et al[12] correspond well with those by Merheb et al, Miyamoto et al, and Friberg et al,[22] who concluded that RFA measurements correlated well with cortical bone thickness and the cutting resistance at the time of implant placement respectively.[9,22] In this study we found similar ISQ values for all 4 types of bone at implant placement (Table 1), which is most likely due to the use of a modified drilling protocol. As stated already, bone quality at implant insertion is one of the most important determinants of implant long-term survival and success. The purpose of the modified drilling technique was to compensate for areas of less dense bone by drilling the implant site in a specific way that resulted in a slightly narrow apical portion

Table 4

Relation between type of bone by HU and ISQ on surgical day, 3 month, 6 month, and 1 year intervals*

Type of Bone	N	Surgery Day	3 Months	6 Months	1 Year
I	42	69.47 ± 6.65	72.96 ± 6.55	74.61 ± 6.22	75.55 ± 6.11
II	16	68.5 ± 9.09	71.96 ± 8.33	73.56 ± 7.82	74.59 ± 7.50
III	8	70.12 ± 5.26	72.56 ± 5.36	73.87 ± 5.61	75.18 ± 5.28
IV	1	67.5	73.0	76.0	78.0
Total	67	69.29 ± 7.03	72.67 ± 6.75	74.29 ± 6.45	75.32 ± 6.26

*HU indicates Hounsfield units; ISQ, implant stability quotient.

TABLE 5

Relation between the implant diameter and ISQ on surgical day, 3 month, 6 month, and 1 year intervals*

Diameter (mm)	N	Surgery Day	3 Months	6 Months	1 Year
3.5	25	67.82 ± 8.09	70.64 ± 7.78	72.26 ± 7.28	73.48 ± 7.04
4	18	70.41 ± 7.68	73.52 ± 7.44	74.94 ± 7.40	76.05 ± 6.99
4.2	14	69.82 ± 5.93	74.17 ± 5.13	75.71 ± 4.61	76.39 ± 5.25
5	10	70.2 ± 4.05	74.15 ± 3.43	76.25 ± 3.13	77.1 ± 2.80
Total	67	69.29 ± 7.04	72.67 ± 6.76	74.29 ± 6.45	75.32 ± 6.27

*ISQ indicates implant stability quotient.

of the implant bed. This would allow for an enhanced bone-to-implant contact ratio immediately after implant placement.

In this study, we found no significant correlation between implant length and RFA measurements. This is in accordance with the findings presented by Balleri et al[26] in 2002 and Liaje et al[44] in 2012, and Merheb et al[22] in 2010. In contrast, implant length has been found to enhance the primary implant stability as longer implants provided more bone to implant contact area.[3,27–29] Similarly, the implant diameter did not correlate with primary stability in our patient sample, nor did it in the studies conducted by Bischof et al[10] in 2004, Han et al[25] in 2010, and Merheb et al[22] in 2010. On the other hand, small diameter implants have shown significantly lower ISQ levels when compared with larger diameter implants.[44]

All implants used in this study were ELEMENT INICELL (Thommen Medical AG). This is a 2-piece, cylindrical implant with a hybrid abutment connection (internal hexagon with a stabilization ring and small abutment screw head). These implants also have self-cutting threads to allow optimal primary (mechanical) implant stability. The Thommen Implant System (sandblasted, thermal acid-etched surface) includes a chair-side conditioning step to be done immediately before surgical placement. This process allows for a more hydrophilic titanium surface (INICELL) and has been shown to facilitate early healing by insuring instant contact with blood which allows for more efficient protein absorption by the implant surface.[46] It is very possible that this implant conditioning step may have had some positive effect on enhancing primary stability in this study. Ironically, several authors have studied the influence of implant surface chemistry and finishing on primary implants stability and found no significant influence on ISQ values.[21,24,25]

Animal studies have shown that ISQ values increase with time after implant placement, and that this may be due to the increase in the stiffness of an implant in the surrounding tissues, which occurs during healing. Sennerby et al[34] found higher ISQ values in mandibular sites than in maxillary sites (ISQ 66 vs 58) following initial implant placement and at the 6onth postoperative interval.

A study published in 2010 by Simunek et al[47] described an ISQ drop for implants placed in denser bone over time, whereas implants with low primary stability tended to increase their stability. Studies were also done by Balshi et al[11] yielding similar results. None of the implants in this study showed an ISQ drop larger than 1 unit after implant insertion. This finding could be attributed to the modified drilling protocol used during implant placement.

In this study we intended to evaluate the correlation between the ISQ obtained immediately after implant insertion, the quality of bone found at the implant site and changes in implant stability from the time of primary bone contact to 1 year. One of the main findings of our study was that ISQ measurements obtained immediately after implant placement were successfully maintained throughout the study period on all 4 bone types with a plateau value of 69. The ISQ in Thommen implants has been evaluated in another study with a with a slightly different result.[44] Authors inserted 24 implants and measured the ISQ immediately after implant placement and at 1 week intervals thereafter up to 8 weeks. At that point the implants were then prosthetically loaded. A slight ISQ decrease of 3 units at 8 weeks was found. However, these authors reported a ISQ plateau value of 71.5, which corresponds well with the ISQ plateau value obtained in our study.

Bone mineral density was calculated using data from the preoperative CBCT scan. When evaluating or classifying the density of the bone, gray values (GVs) obtained from CBCT images are quantified as HU. Higher values oh HU were found in in areas of increased bone quality. A similar finding was reported in a study conducted by Merheb et al,[22] where a significant linear correlation between ISQ and HU values was

TABLE 6

Relation between the implant length and ISQ on surgical day, 3 month, 6 month, and 1 year intervals*

Length (mm)	N	Surgery Day	3 Months	6 Months	1 Year
8	1	65.5	70.0	72.0	73.0
9.5	25	70.44 ± 7.57	73.86 ± 7.25	75.6 ± 6.76	76.48 ± 6.22
11	23	67.60 ± 6.28	71.65 ± 6.10	73.21 ± 5.84	74.17 ± 6.28
12.5	18	70.05 ± 7.27	72.5 ± 7.12	74.0 ± 6.95	75.30 ± 6.51
Total	67	69.29 ± 7.03	72.67 ± 6.75	74.29 ± 6.45	75.32 ± 6.26

*ISQ indicates implant stability quotient.

demonstrated. The fact that this correlation was strongest at implant insertion concluded that the preoperative evaluation of the cortical thickness and HU of the cancellous part of the osteotomy site seems to be the most reliable implant stability predictor. Although the process of converting GV to HU with several CBCT scanners has been validated in the literature,[25] the applicability of Hounsfield units in CBCT has been put to dispute in a recent paper published by Pauwels et al[2] The authors argue that the lack of standardization is still a major problem for most CBCT devices.

In addition, recent research and clinical findings have shifted the paradigm of assessing bone quality from a density-based analysis to a structural evaluation of the bone with a healthy vascularized and well-structured trabecular bone being more clinically relevant in predicting the success of implant placement. These authors concluded that although improvements in CBCT imaging technology and advancements in GV correction have progressed, the main focus in research should be on the clinical validation of alternative parameters commonly used in microscopy and CT for the evaluation of bone structure, as they may be more suited to predict implant outcome than bone density alone.[2]

Conclusion

Within the limitations of this study it can be concluded that similar primary implant stability, measured by RFA, can be obtained in all 4 types of bone by using a modified drilling protocol. The ISQ was demonstrated to be a reasonable and reliable method for evaluating and monitoring implant stability, and, with further study, could be used as a predictor of long-term clinical success of implant therapy. Because ISQ values were not affected by bone structure, implant length or implant diameter, they should be considered as the method of choice for predicting implants stability, and or the possibility of early implant loading. The implant system used in this study consisted of a cylindrical design combined with a hydrophilic surface that supports early osseointegration. These features may have had a positive effect on implant stability, which would, in turn, increase the possibility of long-term success in clinical practice.

Abbreviations

CBCT: cone beam computerized tomography
CT: computerized tomography
GV: gray value
HU: Hounsfield units
ISQ: implant stability quotient
RFA: resonance frequency analysis

Acknowledgments

Following is the Ethics Statement and confirmation of patient permission: Approved by the Committee of Ethics of the University of Seville before start of study. Written and verbal informed consent was provided to and signed by every patient. All products used were CE labeled and tested within their approved indication range

Note

The authors report no conflicts of interest.

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