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Clinical study on the insertion torque and wireless resonance frequency analysis in the assessment of torque capacity and stability of self-tapping dental implants

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SUMMARY Resonance frequency (RF) analysis is a non-invasive, objective and sensitive technique developed for implantology where it measures the stability of the implant in osteotomy site. Although many studies were performed by the previous electronic version of RF analyzer, a very limited number of studies were carried out with the new magnetic wireless version. The aim of the study was to evaluate the relation between insertion torques, primary and secondary stability of self-tapping tapered implant systems. Thirteen subjects were treated with 42 endosseous implants using two-stage surgical procedure. The maximal insertion torque values were recorded prior to RF analysis during surgery. Six months after surgery, the secondary stability values were measured by the RF analysis. The average maximal insertion torque and primary and secondary magnetic RF values were 33 ± 11 N cm and 66 ± 12 ISQ and 71·9 ± 6 ISQ for 42 implants respectively. The correlation between insertion torque and RF values were indicated to be statistically significant ($P < 0{\cdot}01$). Significantly higher maximal insertion torque, and primary and secondary magnetic RF values were achieved in mandibular sites compared with maxillary areas ($P < 0{\cdot}01$). No significant differences were measured for all parameters when both systems were compared with each other ($P > 0{\cdot}05$). There was a strong correlation between the insertion torque, primary and secondary magnetic RF values of self-tapping tapered endosseous implant used. Further studies are needed to understand the impact of the wireless magnetic RF analysis technique in clinics.

KEYWORDS: dental implants, insertion torque, stability, resonance frequency analysis

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Introduction

The use of endosseous dental implants to restore the missing teeth is an alternate treatment method and has become increasingly widespread (1, 2). The long-term success for implant therapy requires both procedure and patient-related parameters (i.e. bone quality, volume of local bone, implant stability and clinical peri-implant indices) (3–6). It is clear that primary stability (initial stability) plays an essential role in successful osseointegration. Primary stability is a function of local bone quantity and quality, the surgical technique used and the geometry of the dental implant. Secondary stability is the result after the formation of woven and lamellar bone around the dental implant body as a secondary bone contact (7–9).

Various non-invasive stability measurement techniques [i.e. tapping, insertion torque, the mobility measuring device (Periotest)* and vibration methods] were used to measure the stability of endosseous dental

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implants (10–14). One of the quantitative methods is the insertion torque; recording the torque required to seat the implant into the osteotomy site, and it furnishes worthy information about the quality of the local bone (11). Tapered implants have a higher insertion torque than cylindrical implants due to a greater frictional surface, where continuous machine-inserted implants had less insertion torque values than discontinuous manual insertion values, and it was also stated that implant design might have an importance on the initial stability in bone (1, 15–17). Vibration analysis is another method performed using transient excitation and continuous excitation, and the mobility measuring device (Periotest)* is an instrument designed to evaluate the tooth mobility by measuring the dampening characteristics of the periodontal ligament, in which the values are between −8 and +50. Nevertheless, using this device to quantify the mobility of the dental implant seems to be not as broad as the natural tooth mobility values, where a successful dental implant may quantify a value between −5 to +5 (18) or from −6 to +2 (19), which might cause a poor sensitivity in the measurement of implant stability (18–20).

Resonance frequency (RF) analysis is a recent, non-invasive, reliable, easily predictable and objective method developed for dental implantology, where the device quantifies the primary and secondary stability of implants (1, 14, 21). The implant/bone interface is measured from RF as a reaction to oscillations exerted onto the implant/bone contact, where the unit of measurement is recorded as implant stability quotient (ISQ) (7). As well as its previous electronic cable version (Osstell),† a newer magnetic wireless RF analyzer (Osstell Mentor)†, is also commercially available (22–24). The wireless magnetic device uses the ISQ as a measure, ranging from 1 to 100. Several *in vitro*, animal and clinical studies were performed using the cable version and a few was published about the wireless version (23, 25–28). A recent long-term follow-up clinical study compared the association between the newer magnetic wireless RF analyzer and the previous electronic RF analyzer with cable in terms of endosseous implant stability (22). The authors concluded that although a direct comparison of two devices was not possible, a modest correlation was found between two devices (22). Furthermore, it was also demonstrated that the newer wireless magnetic analyzer seemed to be a suitable, sensitive and reliable device to determine implant stability, which can detect vertical bone loss around implant body in millimetre increments ranging between 0 and 5 mm (23).

The fact that implant surface geometry and surface type may have an influence on primary and secondary stability of the dental implant has been propounded (15). To provide a precise basis for clinical procedures of implant placement, in which the design of the implant, immediate placement and immediate/early loading have an increasing popularity, recent studies focused on initial stability of the implants have growing interest. As well as its previous version with cable, the newer wireless magnetic RF analyzer, measures implant stability during the placement and at various time-points during the treatment. However, interpretation of the implant stability in terms of this newer magnetic wireless RF analysis method is still lacking scientific background. Therefore, the new magnetic wireless RF analyzer was used to evaluate the primary and secondary stability of dental implants in the present study. The aim of this clinical study was to clarify the possible association of different primary stability measurement methods including insertion torque and the wireless magnetic RF analysis in ISQ values.

Materials and methods

Subject selection and surgical procedure

This study was conducted in accordance with the Helsinki Decleration of 1975, as revised in 2000, in Gazi University, Turkey, between November 2007 and December 2008. Thirteen partially edentulous subjects (6 males and 7 females) seeking prosthodontic rehabilitation were included. The mean age of the subjects was 43·5 years (age range: between 19 and 68 years). Their medical conditions were unremarkable; none was known to have any allergies or metabolic bone diseases. After thorough clinical examinations and radiographs, including panoramic and periapical analysis, all subjects were provided with detailed information regarding surgical and prosthetic procedures and the experimental design. Prior to surgical procedure, local anaesthesia was given at the surgical site, full-thickness flaps were reflected and dental implant osteotomy sites were prepared according to the manufacturers' instructions. According to the procedure for two-stage surgery,

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partially edentulous subjects were provided with a total of 42 dental implants, first implant system (Straumann Standard Plus Implant)[‡] with sand-blasted, large-grit, acid-etched surface (mandibular sites, $n = 7$; maxillary sites, $n = 9$) with 10 mm length (4·8 mm diameter, $n = 3$; 4·1 mm diameter, $n = 3$; 3·3 mm diameter, $n = 3$) and 12 mm length (4·8 mm diameter, $n = 3$; 4·1 mm diameter, $n = 3$; 3·3 mm diameter, $n = 1$) and second implant system (MIS Seven Implant)[§] with sand-blasted, acid-etched surface (mandibular site, $n = 16$; maxillary site, $n = 10$) with 8 mm length (5 mm diameter, $n = 2$), 10 mm length (3·75 mm diameter, $n = 2$, 4·2 mm diameter, $n = 2$, 5 mm diameter, $n = 2$), 11·5 mm length (3·75 mm diameter, $n = 4$; 4·2 mm diameter, $n = 3$; 5 mm diameter, $n = 1$) and 13 mm length (3·75 mm diameter, $n = 5$; 4·2 mm diameter, $n = 3$; 5 mm diameter, $n = 2$) at anterior and posterior sites of mandibular ($n = 22$) and maxillary areas ($n = 20$). Cover screws were placed, and surgical flaps were closed with sling sutures. To minimize bleeding and swelling, an extra-oral cold compress was applied. Six months after first surgery, surgical flaps were reflected and healing abutments were placed. The same surgeon performed all surgical treatments. All subjects were given fixed metal-ceramic crowns 6 months after surgery.

Insertion torque and resonance frequency measurements

After the preparation of osteotomy sites, dental implants were placed into the implant bone sockets using a calibrated torque wrench, where the wrench enabled measurement of torque during the surgical insertion of the implants. The maximal insertion torque value of each implant after the each implant was fully seated was recorded (29).

Immediately after implant insertion, the magnetic wireless RF analyzer was used for direct measurement of the endosseous implant stability (14, 22). The RF analysis technique analyzes the RF range (110–10000 Hz) of a peg which can be attached to the implant with the aid of a cylindrical plastic holder provided by the company, 4–5 N cm of torque was enough. The probe of wireless RF analyzer, Osstell Mentor[†] was held perpendicular to the jaw line as indicated by the manufacturer for one buccal measurement. The ISQ value was presented on the screen on the analyzer. The RF values were converted to ISQ by the analyzer automatically. Implant stability quotient values ranging between 1 and 100 demonstrated that the higher the ISQ, the more stable was the dental implant (7). The same surgeon measured the ISQ values of all implants at surgery (primary stability) and 6 months after first surgery prior to prosthesis delivery (secondary stability). All stability measurements were repeated three times for each implant site, in which a mean value from three measurements was used.

Survival criteria

The implant survival was judged on the following criteria suggested by Albrektsson and Zarb (3): absence of mobility, absence of painful symptoms, absence of peri-implant radiolucency during radiographic evaluation and absence of progressive marginal bone loss.

Statistical analysis

A statistical software (SPSS 11·5·0)[¶] was used for statistical analysis. The Shapiro–Wilk's test was used to test the normally of distribution for the ISQ values. Mann–Whitney *U*-test was used to explore the differences between ISQ values. Spearman's rho test was utilized to evaluate the correlation between insertion torque and ISQ values. A value of $P < 0·05$ was considered statistically significant.

Results

Thirteen patients whose mean age was 43·5 years received 23 mandibular implants and 19 maxillary implants in this study. No implants were lost up to prosthesis delivery. A statistically significant difference in insertion torque value was found between mandible and maxilla ($P < 0·001$) (Fig. 1). Also, there were significant differences in ISQ values between mandible and maxilla at surgery ($P < 0·001$) and prosthesis delivery ($P < 0·01$). When anterior and posterior regions were considered, the insertion torque and ISQ values, both at the surgery and prosthesis delivery, did not differ significantly ($P > 0·05$) (Fig. 1).

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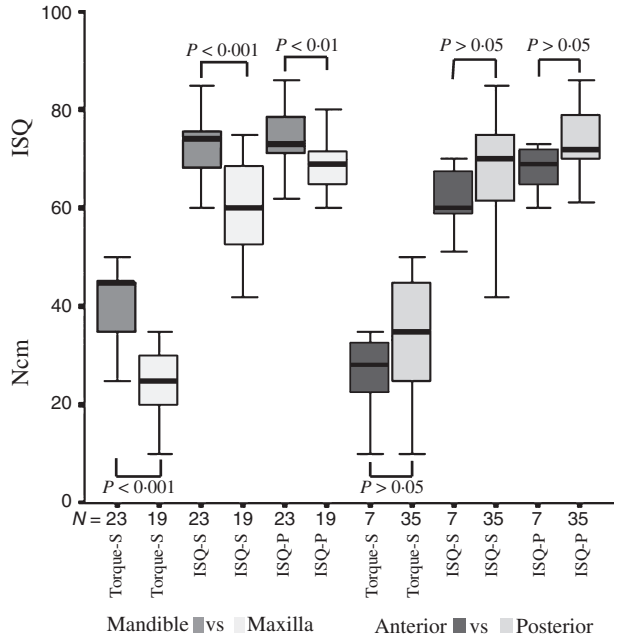


Fig. 1. Average insertion torque and implant stability quotient (ISQ) values according to the different regions of the mouth.

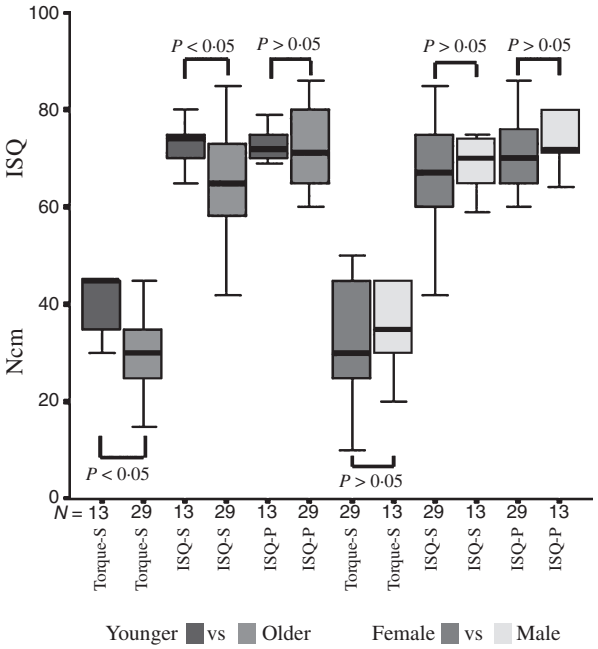


Fig. 2. Average insertion torque and implant stability quotient (ISQ) values according to age and gender.

The statistically significant differences in the insertion torque value ($P < 0{\cdot}05$) and ISQ values at the surgery ($P < 0{\cdot}05$) were noted between younger (38 ± 9s.d.) and older (53 ± 5s.d.) patients, while the ISQ value at prosthesis delivery was not significant between younger (mean age: 34·5 years, ranged from 19 to 50 years) and older patients (mean age: 59·5 years, range: 51 to 68 years) (Fig. 2). Although the insertion torque and ISQ values at the surgery and prosthesis delivery were higher in males than females, they did not show any statistical significance ($P > 0{\cdot}05$) (Fig. 2).

The insertion torque and ISQ values at the surgery and prosthesis delivery were 32 ± 12s.d. N cm, 66·5 ± 16s.d. ISQ and 74 ± 7s.d. ISQ for the first implant system while the corresponding values were 33 ± 9s.d. N cm, 65·8 ± 9s.d. ISQ and 70·6 ± 6s.d. ISQ for the second system respectively. When the type of implants were considered, no significant differences in insertion torque ($P > 0{\cdot}05$) and ISQ at the surgery ($P > 0{\cdot}05$) and prosthesis delivery ($P > 0{\cdot}05$) were observed between the first and the second implant system.

When all 42 implants were considered, the insertion torque and ISQ values at the surgery and prosthesis delivery were 33 ± 11s.d. N cm, 66 ± 12s.d. ISQ and 71·9 ± 6s.d. ISQ respectively. Significant correlations were noted between the insertion torque and ISQ values at the surgery ($r = 0{\cdot}78$, $P < 0{\cdot}001$), the insertion torque and ISQ values at the prosthesis delivery ($r = 0{\cdot}46$, $P < 0{\cdot}01$) and ISQ values at the surgery and prosthesis delivery ($r = 0{\cdot}54$, $P < 0{\cdot}001$).

Discussion

Endosseous implants are successful treatment options for the replacement of missing dentition. It is apparent that primary stability is a pivotal factor at the time of insertion, which depends on the surface geometry of the dental implant, surgical technique used and local bone quantity and quality, for the long-term success of endosseous dental implants (7, 14, 21). Invasive (i.e. reverse torque) and non-invasive (i.e. vibration and RF analysis) methods are frequently used in clinics to evaluate the bone/implant interface. Various implant surfaces and designs were also modified to reduce the surgical trauma during placement, and enhance primary and secondary stability (15, 17, 30, 31).

Insertion torque and previous electronic RF analyzer with cable were used during the surgery to analyze the primary stability and the relationship with each other (4, 11, 14, 17, 20). The magnetic version of the RF analyzer is a recently manufactured sensitive and non-invasive device that quantifies the stability without a

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cable, in which Alsaadi *et al.* (32) reported that very limited number of studies was presented with the wireless version. They tested the sensitivity of the analyzer by making a comparison with the mobility measuring device in a clinical setting, wherein the results of both devices were analyzed by making a comparison with the quality of bone, insertion torque and the tactile sense of the practitioner using two-stage surgery protocol with a self-tapping implant system (TiUnite Dental Implant, MK III)** and concluded that wireless RF analyzer and mobility measuring device measurements were related to bone quality of the subjects (32). Valderrama *et al.* (22) compared association of the ISQ values between previous electronic cable version (ranged between 61·9 ISQ at baseline and 63·2 ISQ at 12 weeks follow-up) with the wireless magnetic version (70·6 ISQ at baseline and 75·9 ISQ at 12 weeks follow-up), and demonstrated that values achieved correlated with each device during follow-up. However, this association was moderate and wireless device demonstrated 8–12 ISQ values higher than the cable version, in which the practitioners should not make a direct comparison between these devices (22). When the sensitivity of the wireless analyzer was concerned, it was concluded that performing peri-implant circular vertical defects using 1 mm increments (1 to 5 mm defects) around one-stage dental implants resulted with a statistically significant implant stability loss in ISQ values for 3·7 mm (from 72·6 ISQ to 57·2 ISQ) and 4·8 mm diameter (76·5 ISQ to 63·4 ISQ), where the authors stated the wireless device seems to be promising to detect the bone defects around implants (23). The present study was undertaken to evaluate insertion torque and primary stability of dental implants with new wireless magnetic RF analyzer and determine whether a correlation existed between them. An average insertion torque (33 ± 11 N cm), surgical RF value (66 ± 12 ISQ) and prosthesis delivery RF value ($71{\cdot}9 \pm 6$ ISQ) were recorded for all implants at all osteotomy sites. Surgical technique such as pre-tapping was not performed, and also implants for both systems, Straumann Standard Plus Implant‡ and MIS Seven Implant§ had roughened surfaces. The present results are in agreement with other endosseous implant studies published earlier, which demonstrates an association between insertion torque, stability values, surgical procedure and implant type (13, 17, 33). Furthermore, significant relationships between insertion torque and ISQ were found at surgery and prosthesis delivery when all implants were concerned and mandibular areas presented higher insertion torque and ISQ values compared with maxillary regions. These findings are in agreement with the earlier studies, although a direct comparison among these studies was not possible, because the authors used different recipient areas, and the previous RF analyzer with cable different types of dental implant systems (11, 13, 30, 34).

Turkyilmaz *et al.* (13) presented a significant correlation between insertion torque and RF values measured with the previous cable version of RF analyzer in another self-tapping implant system placed in the mandible. Al-Nawas *et al.* (35) compared two different implant systems with different designs, and they reported that insertion torque values were significantly higher for the newer surface design (TiUnite Dental Implant, MK IV)** compared with the previous surface design (TiUnite Dental Implant, MK III)** of the same first implant system, and no differences were noted between the first implant system, TiUnite Dental Implant, MK III and MK IV compared with the second implant system Straumann Standard Plus Implant‡ on the basis of ISQ values at the time of placement measured by the electronic cable version of RF analyzer. They further stated that insertion torque and ISQ values of cylindrical implants were significantly lower than the values of self-tapping implants (Straumann Standard Plus Implant)‡ and the authors concluded that the differences between these parameters seemed to be influenced more by the type of implant system used and transducers used to analyze ISQ values (35). The present study also demonstrated that the maximal insertion torque, ISQ values achieved at surgery and prosthesis did not differ significantly between female and male subjects. However, higher insertion torque values and ISQ values during surgery were recorded in younger subjects compared with older ones. Turkyilmaz *et al.* (13) presented higher insertion torque and ISQ values with self-tapping implant system (TiUnite Dental Implant, MK III)** in male subjects compared with females, in which older patients had higher values compared with younger ones. Van Steenberghe *et al.* (36) reported that poor bone quality generally realized in older patients often did not provide primary stability; however, they also concluded that the age and gender of the patients had no effect on early implant failures.

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All of these differences may be explained with different bone qualities at implant sites and different systems and surgical procedures used during surgical applications.

It is also suggested that primary stability and insertion torque values are also dependent on the system used (1, 17), and self-tapping tapered implant design brings higher initial stability than parallel wall cylindrical implant systems (20). O'Sullivan *et al.* (1) presented that surface geometry had a great importance, in which the design of the implant had the ability to increase the interfacial stiffness at the implant/bone interface analyzed by insertion torque and RF analysis with electronic version. We are in agreement with the previous studies that within the limitations of the present study, higher insertion torque was achieved for both implant systems (1, 14, 17, 20). Furthermore, both implant systems used in this clinical study are basically tapered implants which cause lateral compressive stresses in the bone during implant placement that turns in high primary stability, and ISQ values achieved presented significant correlation with the insertion torque values at the time of surgery and prosthesis delivery, which may be considered that magnetic wireless RF analyzer presented similar results with earlier studies published with the electronic RF analyzer with cable (6, 8, 22).

Moreover, when the direction of the probe orientation of the RF analyzer is considered, Veltri *et al.* (26) performed a clinical study which measured the stability of dental implants using the previous cable device in nine patients who received 55 implants. They measured the stability for dental implants by placing the transducer buccally, distally, palatally and mesially, and reported that the mean ISQ values for different orientations demonstrated different results; buccal position: 61 ISQ, palatal position: 63 ISQ, distal position: 71 ISQ and mesial position: 71 ISQ (26). A recent human fresh cadaver study by Seong *et al.* (37) also measured the stability of implants by placing the transducer buccolingually and mesiodistally, in which three repetitions were performed for each direction. They presented similar conclusions with Veltri *et al.* (26) and Seong *et al.* that mesio-distal positioning (67·7 ISQ) of the transducer resulted with increased ISQ values compared with bucco-lingual (64·2 ISQ) orientation. It was suggested that a standardized transducer orientation should be considered during the measurement of the RF values (26). Therefore, based on the previous suggestions; we preferred to measure the primary and secondary stability values by holding the wireless probe buccolingually, and repeated the measurements three times to get a mean ISQ value.

As a conclusion, there was a strong correlation between the insertion torque and RF values of self-tapping tapered endosseous implants used. Insertion torque and RF values at surgery and 6 months after surgery presented significantly higher values at mandibular sites compared with maxillary areas. Within the limitations of the study, both systems did not present any differences in insertion torque and magnetic RF values during surgery and 6 months after surgery. Further studies are needed to understand the association of insertion torque and stability values determined by the new wireless magnetic RF technique.

References

1. O'Sullivan D, Sennerby L, Meredith N. Measurements comparing the initial stability of five designs of dental implants: a human cadaver study. Clin Implant Dent Relat Res. 2000; 2:85–92.
2. Guckes AD, Scurria MS, Shugars DA. A conceptual framework for understanding outcomes of oral implant therapy. J Prosthet Dent. 1996;75:633–639.
3. Albrektsson T, Zarb GA. Determinants of correct clinical reporting. Int J Prosthodont. 1998;11:517–521.
4. Turkyilmaz I, Tözüm TF, Tümer C, Ozbek EN. Assessment of correlation between computerized tomography values of the bone, and maximum torque and resonance frequency values at dental implant placement. J Oral Rehabil. 2006;33:881–888.
5. Ekfeldt A, Christiansson U, Eriksson T, Lindén U, Lundqvist S, Rundcrantz T *et al.* A retrospective analysis of factors associated with multiple implant failures in maxillae. Clin Oral Implants Res. 2001;12:462–467.
6. Turkyilmaz I, Tözüm TF, Tumer C, Ozbek EN. A 2-year clinical report of patients treated with two loading protocols for mandibular overdentures: early versus conventional loading. J Periodontol. 2006;77:1998–2004.
7. Meredith N. Assessment of implant stability as a prognostic determinant. Int J Prosthodont. 1998;11:491–501.
8. Tözüm TF, Türkyilmaz I, Yamalik N, Tümer C, Kilinç A, Kilinç K *et al.* The effect of delayed versus early loading on nitric oxide metabolism around dental implants: an 18-month comparative follow-up study. Int J Oral Maxillofac Implants. 2007;22:53–62.
9. Tözüm TF, Turkyilmaz I, Yamalik N, Karabulut E, Türkyilmaz AS, Eratalay K. Analysis of the possibility of the relationship between various implant-related measures: an 18-month follow-up study. J Oral Rehabil. 2008;35:95–104.
10. Tözüm TF, Güncü GN, Yamalik N, Turkyilmaz I, Güncü MB. The impact of prosthetic design on the stability, marginal bone loss, peri-implant sulcus fluid volume, and nitric oxide metabolism of conventionally loaded endosseous dental

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implants: a 12-month clinical study. J Periodontol. 2008; 79:55–63.
11. Turkyilmaz I. A comparison between insertion torque and resonance frequency in the assessment of torque capacity and primary stability of Brånemark system implants. J Oral Rehabil. 2006;33:754–759.
12. Payer M, Kirmeier R, Jakse N, Wimmer G, Wegscheider W, Lorenzoni M. Immediate provisional restoration of XiVE screw-type implants in the posterior mandible. Clin Oral Implants Res. 2008;19:160–165.
13. Turkyilmaz I, Tümer C, Ozbek EN, Tözüm TF. Relations between the bone density values from computerized tomography, and implant stability parameters: a clinical study of 230 regular platform implants. J Clin Periodontol. 2007;34:716–722.
14. Sennerby L, Meredith N. Implant stability measurements using resonance frequency analysis: biological and biomechanical aspects and clinical implications. Periodontol 2000. 2008;47:51–66.
15. Cochran DL. A comparison of endosseous dental implant surfaces. J Periodontol. 1999;70:1523–1539.
16. Steigenga JT, al-Shammari KF, Nociti FH, Misch CE, Wang HL. Dental implant design and its relationship to long-term implant success. Implant Dent. 2003;12:306–317.
17. Rabel A, Köhler SG, Schmidt-Westhausen AM. Clinical study on the primary stability of two dental implant systems with resonance frequency analysis. Clin Oral Investig. 2007; 11:257–265.
18. Meredith N, Friberg B, Sennerby L, Aparicio C. Relationship between contact time measurements and PTV values when using the Periotest to measure implant stability. Int J Prosthodont. 1998;11:269–275.
19. Teerlinck J, Quirynen M, Darius P, van Steenberghe D. Periotest: an objective clinical diagnosis of bone apposition toward implants. Int J Oral Maxillofac Implants. 1991;6:55–61.
20. Sakoh J, Wahlmann U, Stender E, Nat R, Al-Nawas B, Wagner W. Primary stability of a conical implant and a hybrid, cylindric screw-type implant *in vitro*. Int J Oral Maxillofac Implants. 2006;21:560–566.
21. Sennerby L, Meredith N. Resonance frequency analysis: measuring implant stability and osseointegration. Compend Contin Educ Dent. 1998;19:493–498. 500, 502; quiz 504.
22. Valderrama P, Oates TW, Jones AA, Simpson J, Schoolfield JD, Cochran DL. Evaluation of two different resonance frequency devices to detect implant stability: a clinical trial. J Periodontol. 2007;78:262–272.
23. Tözüm TF, Turkyilmaz I, McGlumphy EA. Relationship between dental implant stability determined by resonance frequency analysis measurements and peri-implant vertical defects: an *in vitro* study. J Oral Rehabil. 2008;35:739–744.
24. Oh JS, Kim SG, Lim SC, Ong JL. A comparative study of two noninvasive techniques to evaluate implant stability: Periotest and Osstell Mentor. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107:513–518.
25. Turkyilmaz I, Sennerby L, Tümer C, Yenigul M, Avci M. Stability and marginal bone level measurements of unsplinted implants used for mandibular overdentures: a 1-year randomized prospective clinical study comparing early and conventional loading protocols. Clin Oral Implants Res. 2006;17:501–505.
26. Veltri M, Balleri P, Ferrari M. Influence of transducer orientation on Osstell stability measurements of osseointegrated implants. Clin Implant Dent Relat Res. 2007;9:60–64.
27. Degidi M, Piattelli A, Gehrke P, Carinci F. Clinical outcome of 802 immediately loaded 2-stage submerged implants with a new grit-blasted and acid-etched surface: 12-month follow-up. Int J Oral Maxillofac Implants. 2006;21:763–768.
28. Esposito M, Grusovin MG, Willings M, Coulthard P, Worthington HV. Interventions for replacing missing teeth: different times for loading dental implants. Cochrane Database Syst Rev. 2007;18:CD003878.
29. Standlee JP, Caputo AA, Chwu MY, Sun TT. Accuracy of mechanical torque-limiting devices for implants. Int J Oral Maxillofac Implants. 2002;17:220–224.
30. Friberg B, Sennerby L, Meredith N, Lekholm U. A comparison between cutting torque and resonance frequency measurements of maxillary implants. A 20-month clinical study. Int J Oral Maxillofac Surg. 1999;28:297–303.
31. Yeo IS, Han JS, Yang JH. Biomechanical and histomorphometric study of dental implants with different surface characteristics. J Biomed Mater Res B Appl Biomater. 2008; 87:303–311.
32. Alsaadi G, Quirynen M, Michiels K, Jacobs R, van Steenberghe D. A biomechanical assessment of the relation between the oral implant stability at insertion and subjective bone quality assessment. J Clin Periodontol. 2007;34:359–366.
33. Payne AG, Tawse-Smith A, Thompson WM, Kumara R. Early functional loading of unsplinted roughened surface implants with mandibular overdentures 2 weeks after surgery. Clin Implant Dent Relat Res. 2003;5:143–153.
34. da Cunha HA, Francischone CE, Filho HN, de Oliveira RC. A comparison between cutting torque and resonance frequency in the assessment of primary stability and final torque capacity of standard and TiUnite single-tooth implants under immediate loading. Int J Oral Maxillofac Implants. 2004;19:578–585.
35. Al-Nawas B, Wagner W, Grötz KA. Insertion torque and resonance frequency analysis of dental implant systems in an animal model with loaded implants. Int J Oral Maxillofac Implants. 2006;21:726–732.
36. van Steenberghe D, Jacobs R, Desnyder M, Maffei G, Quirynen M. The relative impact of local and endogenous patient-related factors on implant failure up to the abutment stage. Clin Oral Implants Res. 2002;13:617–622.
37. Seong WJ, Holte JE, Holtan JR, Olin PS, Hodges JS, Ko CC. Initial stability measurement of dental implants placed in different anatomical regions of fresh human cadaver jawbone. J Prosthet Dent. 2008;99:425–434.

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