



Factors Affecting Dental Implant Stability Measured Using the Ostell Mentor Device: A Systematic Review

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The insertion of endosseous dental implants to restore missing teeth is an increasingly widespread treatment option for achieving good aesthetic and functional outcomes.¹

Good stability, that is, the absence of clinical mobility,² has long been considered as an essential factor for implant success^{3–5} and a measure of the quality of implant anchorage in the alveolar bone.⁶ However, controversy has arisen in the recent years over the need to achieve good primary stability during the placement of implants to ensure their osseointegration. Some studies have demonstrated that primary stability is not required for osseointegration, providing clinical evidence that osseointegration is possible in implants with low primary stability and, conversely, that adequate integration is not always obtained by implants placed with a relatively high insertion torque.^{7–9} Primary stability has been described as the

Objectives: The aim of this study was to review the literature on factors that may affect dental implant stability as measured with the Ostell mentor device.

Materials and Methods: A systematic search of the literature was performed in Pubmed, Scopus, and Cochrane databases using dental implants, stability, and resonance frequency analysis as key words.

Results: The most relevant randomized controlled trials and clinical trials ($n = 39$) were selected from among 264 articles.

Conclusions: Many factors can affect dental implant stability as measured with the Ostell mentor device. This may be a useful instrument for deciding the timing of implant loading, but additional research is required to establish the reliability and predictability of resonance frequency analysis for the future osseointegration of dental implants, which remains controversial. (Implant Dent 2015;24:565–577)

Key Words: dental implants, stability, resonance frequency analysis, systematic review

absence of mobility in the bone bed immediately after implant placement,¹⁰ which is achieved through mechanical engagement between the implant surface and surrounding bone.^{6,11–14} Primary stability is influenced by multiple factors, including the materials used, for example, length/diameter and microscopic/macrospecific morphology of the implant; the local bone tissue characteristics, for example, bone quality/quantity and cortical bone thickness^{11,14–16}; and the surgical/placement technique, for example, drill size, implant size, pre-tapped or self-tapered implant, and the use of osteotomes.¹⁷

Although a good primary stability, related to the initial amount of contact with the bone, is not strictly necessary for the osseointegration of dental implants,^{7–9} it is a key condition for determining the selection of loading

protocol¹⁸ and is the most important factor in the decision to apply immediate loading.^{10,16,19,20}

Various techniques have been used for implant stability measurement at different clinically relevant time points. Until relatively recently, the quantitative measurement of primary stability was limited to invasive methods, for example, pullout and pushout tests and removal torque analysis. These destructive biometric tests, widely applied in *ex vivo* animal experiments, can also be used to determine the level of osseointegration after a healing period but are evidently not appropriate for clinical use.

Since 1996, resonance frequency analysis (RFA) has been available as a noninvasive and widely used method to quantify primary and secondary implant stability,^{2,6,15} which can be

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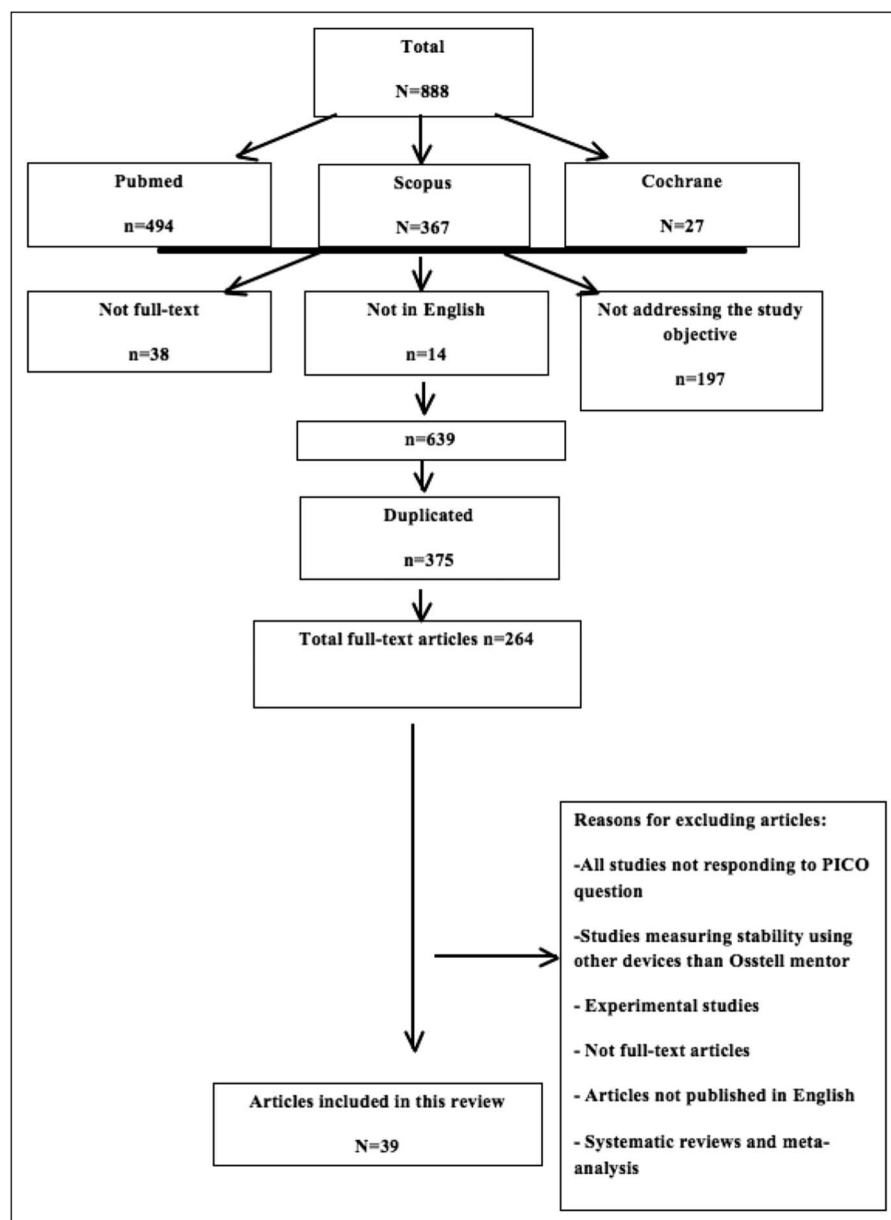


Fig. 1. Flow diagram of the literature search. After removing duplicated articles, articles not published in English, articles without full text, and those not addressing the study objective, 264 articles were selected for further reading and full application of inclusion/exclusion criteria.

used repeatedly in intraoperative and postoperative settings. The Ostell mentor device (Integration Diagnostics AB, Sävedalen, Sweden) uses RFA to measure implant mobility and stiffness, yielding the results as implant stability quotients (ISQs), which range between 1 (lowest stability) and 100 (highest). RFA has been proposed as a method to discern possible differences in healing patterns between immediately and conventionally loaded implants during the initial weeks of healing.²⁰

Additional investigation is required to establish the reliability and predictability of RFA in regard to the future osseointegration of dental implants, which remains controversial. However, there is no definitive threshold value to differentiate a stable and functional implant from a failing or failed implant, because most published articles only focus on the effectiveness of RFA to predict implant stability.^{21–23} In this regard, some authors have suggested that ISQ values are

not reliable to predict early implant failure, and that the true cutoff ISQ value to differentiate between success and early implant failure has yet to be determined.²⁴

The aim of this systematic review was to explore all factors that might influence dental implant stability as measured with the Ostell Mentor device.

MATERIALS AND METHODS

The PICO question of this systematic review was What are the factors that may affect dental implant stability as measured by the Ostell Mentor device?

Search Strategy

A systematic electronic search of the literature between January 2007 and December 2014 was conducted using PubMed, Cochrane Library, and Scopus biomedical databases. The search terms were “dental implants,” “resonance frequency analysis,” “RFA,” “primary stability,” “ISQ,” “bone quality,” “implant design,” “surface,” “types,” “stages,” “length,” “tapered shape,” “diameter,” “factors,” “technique,” “osteotome,” and “Ostell Mentor.” The aim was to include all randomized clinical trials (RCTs) and clinical trials related to factors potentially influencing the stability of dental implants as measured with the Ostell Mentor device. A manual search was also conducted of implant-related journals from January 2007 through December 2014, including *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *European Journal of Oral Implantology*, *Journal of Oral and Maxillofacial Implants*, *Implant Dentistry*, *Journal of Oral Implantology*, *Journal of Oral and Maxillofacial Surgery*, *International Journal of Oral and Maxillofacial Surgery*, *Journal of Prosthetic Dentistry*, *Journal of Clinical Periodontology*, *Journal of Periodontology*, *International Journal of Periodontics and Restorative Dentistry*, *International Journal of Prosthodontics*, and *Journal of Dental Research*. We used algorithms and search strategies that can be reproduced by any researcher.

Table 1. Relationship Between Dental Implant Design and Dental Implant Stability

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Ho et al ⁶⁹	64	NobelActive and Brånemark TiUnite Mk III implants (Nobel Biocare AB, Göteborg, Sweden)	At placement and after 1, 2, 3, and 6 mo	Highly retentive design (NobelActive) vs conventional-matched Brånemark implants	Higher mean ISQ values in conventional-matched Brånemark implants at all time points although the difference was only significant at 2 mo after implant placement ($P = 0.027$)
Gultekin et al ⁷⁰	93	Nobel Replace Tapered Groovy (Nobel Biocare AB)	At placement and after 3 mo	Implants with internal conical connection and back-tapered collar-carrying PS abutment vs those carrying a matched-platform abutment	Higher ISQ values in the matched-platform abutment group but only at implant placement ($P < 0.01$)
Nienkemper et al ⁶⁸	40	PSM Medical Solutions (Tuttlingen, Germany)	At placement and after 2, 4, and 6 wk	11-mm long vs 9-mm long implants	ISQ values in 11-mm long implants group was significantly lower ($P < 0.05$) at implant placement, but this difference disappeared at 4-wk postsurgery
Khandelwal et al ⁷¹	48	SLA and modified SLA (Straumann, Waldenburg, Switzerland)	At placement and after 2, 3, 4, 6, 8, 10, 12, and 16 wk	Standard SLA surface vs modified SLA surface	No significant difference in implant stability was observed between conventional SLA implants and modSLA implants at any time point
Abtahi et al ⁶⁷	32	Brånemark TiUnite Mk III implants (Nobel Biocare AB)	At placement and after 6 mo	Implant coated with thin fibrinogen layer containing 2 bisphosphonates vs noncoated implant	A larger increase in ISQ values ($P < 0.001$) from baseline to 6 mo in coated implants than in uncoated implants
Karabuda et al ⁶⁴	96	SLA and modified SLA (Straumann)	At placement and after 1, 3, and 6 wk	Standard SLA surface vs modified SLA surface	Higher ISQ values at loading in implants with modified SLA surface vs implants with standard SLA surface ($P < 0.05$)
Dursun et al ¹⁹	16	Revois (Curasan, Kleinostheim, Germany) and Tapered screw Vent (Zimmer Dental, Carlsbad, CA)	At placement and after 1, 3 and 6 mo	PS and SP implants placed using a nonsubmerged protocol	Higher ISQ values at baseline and after 6 mo in SP vs PS implants ($P < 0.05$)
Geckili et al ⁶⁶	54	TB implants (TiOblast; Astra Tech AB, Mölndal, Sweden) and FTB implants (OsseoSpeed; Astra Tech AB)	At placement and after 1, 2, 3, 4, 5, 6, 12, and 24 wk	Titanium dioxide grit-blasted dental implants with fluoride treatment (FTB) vs implants without fluoride treatment (TB)	FTB implants did not exhibit the early decreases in ISQ values seen in TB implants from baseline to 24 wk after surgery ($P < 0.05$)
Geckili et al ¹⁴	104	TB implants (TiOblast; Astra Tech AB) and FTB implants (OsseoSpeed; Astra Tech AB)	At placement	Titanium dioxide grit-blasted dental implants with vs without fluoride treatment (FTB)	No statistically significant differences in ISQ values between FTB and TB implants at the time of implant placement

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Table 1. (Continued)

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Lang et al ⁶²	208	SLA (Strauman)	At placement and after 3 mo	Cylindrical, screw-shaped vs novel-tapered transmucosal immediate implants	No statistically significant differences in primary stability between cylindrical standard and tapered design when implants are placed immediately in the fresh extraction sockets
Oates et al ⁶⁵	62	Standard SLA implants (Straumann)	At placement and after 1, 2, 3, 4, 5, and 6 wk	Standard SLA implants vs chemically modified SLA implants	No statistically significant differences in ISQ values between standard SLA active and modified SLA active surface at 6 wk after implant placement. An earlier shift in implant stability from decreasing stability to increasing stability (at 2 wk) in modified SLA surface vs standard SLA surface (4 wk) ($P < 0.001$)
Schätzle et al ⁶³	40	SLA and modified SLA (Straumann)	At insertion and after 1, 2, 3, 4, 5, 6, 7, 8, 10, and 12 wk	Standard SLA implants vs chemically modified SLA implants	Modified SLA surface shows significantly higher ISQ values vs standard SLA surface at 12 wk after implant placement ($P < 0.05$)

Study Selection Criteria

Inclusion criteria for the selection of studies were publication in English; RCT or clinical trial; study in humans; and the utilization of Ostell Mentor device to measure dental implant

stability. Exclusion criteria were failure to address the PICO question; utilization of device other than Ostell Mentor to measure implant stability; experimental study design; systematic review or meta-analysis; nonavailability of the

full text; and publication in a language other than English.^{25–61}

Review and Screening of Articles

The search for articles was conducted by 2 independent researchers.

Table 2. Relationship Between Surgical Techniques and Dental Implant Stability

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
da Silva Neto et al ⁷⁵	68	Conical implants with double-sandblasted and acid-treated surface and a Morse taper connection (Neodent, Curitiba, Brazil)	At placement and after 90 and 150 d	Implant bed preparation with conventional drilling vs piezoelectric surgery	Significantly increased ($P = 0.04$) ISQ values at implant placement and at 90 and 150 d for implants placed in beds prepared with ultrasonic devices
Blaszczyszyn et al ⁷²	25	tioLogic Dentaurem implants (Antwerpen, Belgium)	At placement and after 6 mo	Implant bed preparation with traditional burs vs ultrasonic tips (piezosurgery)	No significant difference in primary stability between the methods at implant placement or at 6 mo
García-Morales et al ⁷³	30	XIVE-S (Dentsply Friadent, Mannheim, Germany)	At placement and after 10 d and 3, 6, 9, and 12 wk	Implants exposed to LLLT (830 nm) vs simulated irradiation (placebo)	No increase in primary or secondary stability between methods at any measurement time point

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Table 2. (Continued)

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Stacchi et al ⁷⁷	40	NanoTite Parallel Walled Certain (Biomet 3i, Warsaw, IN)	At placement and after 7, 14, 21, 28, 42, 56, and 90 d	Implant bed preparation with twist drills vs ultrasonic tips (piezosurgery)	No significant difference in primary stability at implant placement between implants in beds prepared with twist drills vs ultrasonic devices
Shayesteh et al ⁷⁶	46	SLA (Straumann)	At placement and after 3 mo	Implant bed preparation with osteotomes vs conventional drilling	Significantly higher ISQ values ($P = 0.026$) at placement for implants placed in beds prepared with osteotomes
Marković et al ¹	102	Self-tapping BlueSky (Bredent, Senden, Germany) and non self-tapping Standard Plus (Straumann)	At placement and weekly for 12 wk	Self-tapping vs non self-tapping implants	Significantly higher ($P = 0.001$) implant stability values using lateral bone-condensing vs conventional bone drilling techniques both immediately postsurgery and at 6 wk
Turkylmaz et al ¹⁷	60	Brånemark TiUnite Mk III implants (Nobel Biocare AB)	At placement	Two control groups and 4 corresponding test groups using thinner drills to enhance primary implant stability	Significantly higher ($P < 0.05$) implant stability values using thinner drills for implants placed in the maxillary posterior region
Tallarico et al ⁷⁴	61	Brånemark TiUnite Mk III implants Groovy and Nobel Speedy Groovy (Nobel Biocare AB)	At placement and after 2 wk	1- and 2-stage implant placement protocols	No significant difference in ISQ values between the implant placement protocols at any postimplantation time point

Titles and abstracts (when available) of the studies gathered by all search methods were assessed by the same 2 examiners independently to determine whether study eligibility criteria were met. If the abstract contained inadequate

information for this purpose, the full article was obtained and reviewed before a final decision was made. Differences between the assessments were resolved by discussion or, if this proved impossible, through consultation with a third

examiner. The level of agreement between the reviewers on study inclusion was expressed with the kappa index. Search results were cross-checked to remove duplications. All studies meeting the eligibility criteria

Table 3. Relationship Between CBCT Bone Density Values and RFA-Measured Implant Stability, and the Influence of the Method Used to Measure Implant Stability

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Aksoy et al ⁸¹	23	Swiss plus (Zimmer Dental)	At implants placement	HU measured by CBCT and ISQ values	A significant correlation ($P = 0.015$) between mean HU and ISQ values was observed
Fuster-Torres et al ⁸²	82	TSA (Defcon implants; Phibo, Sentmenat, Spain)	At implants placement	HU measured by CBCT and ISQ values	A significant relationship ($P < 0.05$) between mean HU and ISQ values was observed
Merheb et al ⁷⁸	136	SLA (Strauman)	At implant placement and at implant loading	HU measured by CBCT and ISQ values	A significant ($P < 0.05$) linear relationship between ISQ and CBCT bone density (HU) values at implant placement and loading
Song et al ⁷⁹	61	Avana USII (Osstem, Seoul, Korea)	At implant placement	HU measured by CBCT and ISQ values	A strong correlation ($P < 0.025$) between HU and ISQ values

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Table 3. (Continued)

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Turkylmaz et al ⁸⁰	230	Brånemark TiUnite Mk III implants (Nobel Biocare AB)	At implant placement	HU measured by CBCT and ISQ values	A significant correlation ($P < 0.001$) between mean HU and ISQ values at implant placement
Oh and Kim ¹⁸	211	—	At implant placement	Periotest with resonance frequency analysis measurements	A significant negative correlation between ISQ values and Periotest values ($P < 0.01$)
Rabel et al ¹⁶	602	Ankylos (Dentsply Friadent) and Camlog root line implant (Camlog, Wimsheim, Germany)	At implant placement and after 3 mo	Maximum insertion torque with resonance frequency analysis measurements	No correlation between the mean insertion torque and the mean ISQ value immediately postimplantation or at 3 mo with either implant system ($r = 0.305$)
Simunek et al ⁶	940	Sandblasted, acid-treated and alkali-treated implants (STI-BIO-C; Lasak, Prague, Czech Republic)	At implant placement	Maximum insertion torque with resonance frequency analysis measurements	No significant relationship at implant placement between mean ISQ and insertion torque values

HU, Hounsfield units.

then underwent validity assessment and data extraction. The reasons for excluding articles from the review were recorded and discussed.

RESULTS

The search retrieved 888 articles: 494 through PubMed, 367 through

Scopus, and 27 through the Cochrane Library. No additional articles were yielded by the manual search. Figure 1 describes in detail the search strategy and results. After removing duplicated articles (375), articles not published in English (14), articles without full text (38), and those not addressing the study objective (197), 264 articles were

selected for further reading and full application of inclusion/exclusion criteria. We finally included 39 articles in our systematic review (33 through PubMed, 5 through Scopus, and 1 through Cochrane library). A kappa value of 0.92 was obtained for interreviewer agreement on the inclusion of publications.

Table 4. Influence of Loading Timing on ISQ Values and the Relationship Between Implant Stability and Bone Augmentation Techniques

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Kokovic et al ⁸⁶	72	SLA (Straumann)	At implant placement and after 6, 12, and 52 wk	ISQ values between IL and EL implants in the posterior mandible	No significant differences in ISQ values between IL and EL implants at any time point
Lee et al ⁸⁷	75	Titamax (Neodent)	At implant placement and after 4 and 8 mo	Implants loaded with a hybrid prosthesis with a conventional rigid bar splinting the implants vs those loaded with a semirigid cantilever extension system with titanium bars placed in the 2 distal abutment cylinders	No significant differences in mean ISQ values at baseline or after 8 mo follow-up
Cannizzaro et al ⁸⁴	120	Swiss plus, (Zimmer Dental)	At 6 wk and 1 y after implant placement	ISQ values between IL and EL implants (supporting bar-retained mandibular overdentures placed with flapless technique)	No significant differences in ISQ values between IL and EL implants at any time point
Cannizzaro et al ⁸⁵	108	Swiss plus, (Zimmer Dental)	At baseline and after 1, 2 and 3 y	ISQ values between IL and CL implants in partially edentulous patients	Significantly higher ISQ values ($P = 0.033$) at baseline in IL implants vs CL implants

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Table 4. (Continued)

Study	No. of Implants	Type of Implants	Time of Measurement	Comparison	Outcomes
Güncü et al ²⁰	24	Brånemark TiUnite Mk III implants (Nobel Biocare AB)	At implant placement and after 1, 3, 6, 9, and 12 mo	ISQ values between IL and CL implants placed in molar areas	No significant difference in mean ISQ values over a 12-mo follow-up between IL and CL implants in mandibular sites
Jackson et al ⁸³	20	Palatal implants (Strauman)	At implant placement and after 8 wk	ISQ values between IL and CL orthodontic palatal implants	Significantly lower ISQ values in IL vs CL at 8 wk ($P < 0.05$)
Al-Khalidi et al ⁹¹	64	Brånemark TiUnite (Nobel Biocare AB)	At implant placement and at abutment connection	ISQ values between dental implants placed in grafted vs nongrafted anterior maxillae	No significant differences in mean ISQ values at implant placement or at abutment connection
Borges et al ⁸⁹	—	—	At implant placement and after 6 mo	ISQ values between dental implants placed simultaneously in grafted sinus and non-grafted sinus (using autologous bone)	No difference in ISQ values at placement or after 6 mo between implants placed in grafted vs non-grafted sinus
Cannizzaro et al ⁸⁸	82	Tapered screw-vent (Zimmer Dental)	At implant placement and after 3 mo and 1 y	ISQ values between EL implants in maxillary sinus augmented with lateral approach using a xenograft and those in crestally augmented sinus using autogenous bone	No difference in ISQ values between the groups at any time point
Degidi et al ⁹²	80	XIVE implants (Dentsply Friadent)	At implant placement	ISQ values between dental implants placed in grafted areas vs nongrafted areas or postextraction sites	No significant difference in ISQ values between implants placed in grafted and nongrafted areas
Rasmusson et al ⁹⁰	260	TiOblast implants (Astra Tech AB)	At implant placement and after 6 mo	ISQ values between dental implants placed in grafted areas with different procedures and grafts	Significantly lower mean ISQ values in patients treated with LeFort I surgery in comparison with the other groups

CL, conventionally loaded implants; EL, early-loaded implants; IL, immediate-loaded implants.

Among the selected articles, 12 address dental implant design in relation to dental implant stability,^{14,19,62–71} 8 relate surgical techniques to dental implant stability,^{1,17,72–77} 5 report on the relationship between cone beam computed tomography (CBCT) bone density values and implant stability,^{78–82} 3 examine methods used to measure dental implant stability and bone quality,^{6,16,18} 6 evaluate the influence of loading timing on ISQ values,^{20,83–87} and 5 explore the relationship between implant stability and bone augmentation techniques.^{88–92}

DISCUSSION

In all studies discussed in this article, RFA measurements of ISQ were obtained using the Ostell Mentor device.

Dental Implant Design

Numerous studies have evaluated the relationship between implant designs and RFA-measured primary dental implant stability. The implant systems and designs reported are listed in Table 1.

In an RCT, Lang et al⁶² found no significant differences in primary stability between cylindrical and tapered designs when implants were placed immediately in fresh extraction sockets. Implant stability was measured by RFA at surgery and at 3 months. ISQ values for cylindrical and tapered implants were 55.8 and 56.7 immediately post-surgery and 59.4 and 61.1 at 3 months, respectively. The authors found no differences in the primary or secondary implant stability between the implant designs. Ho et al⁶⁹ compared stability

values between implants with a “highly retentive” design (NobelActive) and conventional-matched Brånemark implants (control group). Surprisingly, higher mean ISQ values were obtained with the control versus test implants at all time points although the difference was only significant at 2 months after implant placement ($P = 0.027$). Gultekin et al⁷⁰ compared the marginal bone loss and stability obtained using implants with internal conical connection and back-tapered collar-carrying platform-switched (PS) abutment (test group) versus those carrying a matched-platform abutment (control group). Although the primary stability (mean ISQ value) was significantly higher in the test group than in the control group (72.86 ± 5.94 vs 69.24 ± 5.06 ISQ) at implant placement

($P < 0.01$), this difference had disappeared at 3-month postsurgery (74.06 ± 5.17 vs 72.58 ± 4.24 ISQ). In a clinical study, Dursun et al¹⁹ compared bone level and stability at 6 months between PS and standard platform implants (SP) using a nonsubmerged protocol for their placement. Mean ISQ values were significantly ($P < 0.05$) higher for SP versus PS implants at baseline (76.4 ± 3.37 vs 71.81 ± 5.34 ISQ) and at 6 months (77 ± 2.75 vs 73.38 ± 5.27 ISQ). A large number of geometric designs and shapes of implant thread are currently available. Although some have obtained higher ISQ values (greater primary stability), studies have not been conclusive, and further RCTs with well-defined inclusion/exclusion criteria are required to elucidate the influence of the macrostructure of an implant on its stability.

Nienkemper et al⁶⁸ studied the impact of implant length on primary stability, comparing between 11-mm long (test group) and 9-mm long (control group) implants during the healing period. Although ISQ values in the test group was significantly lower ($P < 0.05$) at implant placement (36.14 ± 6.08 vs 33.35 ± 5.34 ISQ), this difference had disappeared at 4-week postsurgery.

Regarding their microscopic structure, a major increase in ISQ values has been observed for implants with roughness-enhancing surface treatments, with a consequent improvement in secondary stability, osseointegration, and biological response. Schätzle et al⁶³ compared a chemically modified sandblasted/acid-etched titanium surface (modSLA) with a standard SLA surface, finding significantly ($P < 0.05$) higher ISQ values at 12 weeks for the implants with modSLA (77.8 ± 1.9 ISQ) versus SLA surfaces (74.5 ± 3.9 ISQ). Likewise, Karabuda et al⁶⁴ obtained higher ISQ values at loading stage (8 weeks in mandible and 12 weeks in maxillae) for implants with modSLA versus standard SLA surface ($P < 0.05$). In contrast, Oates et al⁶⁵ observed no significant differences in ISQ values between active modSLA and SLA surfaces at 6 weeks despite recording a greater degree of primary stability in the former at 2 and 4 weeks

($P < 0.001$). Similar results were obtained by Khandelwal et al⁷¹ in their comparison of implant stability between conventional SLA and chemically modified SLA implants in patients with poorly controlled type 2 diabetes mellitus. No significant difference in implant stability was observed between conventional SLA implants and modSLA implants at any time point. Geckili et al⁶⁶ used RFA to compare the stability of titanium dioxide grit-blasted dental implants with and without fluoride treatment over the first 24-week post-implantation (at baseline and 1, 2, 3, 4, 5, 6, 12, and 24 weeks); the implants with fluoride did not exhibit the early decreases in RFA values observed in those without fluoride ($P < 0.05$). This suggests that fluoride-modified implant surfaces improve osseointegration during early healing, thereby avoiding the usual reduction in implant stability with the change from primary to secondary stability.

Finally, the results of an RCT by Abtahi et al⁶⁷ demonstrated that a thin bisphosphonate-eluting fibrinogen coating improves the fixation of dental implants, which showed a greater increase in ISQ values ($P < 0.0001$) from baseline to 6 months versus uncoated implants (72.6 vs 65.0 ISQ), increasing the secondary implant stability.

Besides good primary stability, it is important to achieve secondary stability as rapidly as possible to ensure the success and long-term survival of the implant. There is evidence that treatment to roughen the implant surface accelerates bone-implant integration and therefore secondary stability (higher ISQ values).

Surgical Techniques

Some authors have found that primary dental implant stability is influenced by the application of surgery (Table 2). Thus, given that primary stability is more readily achieved in high-density bone, bone-condensing surgery is performed in cases of low-density bone^{1,76} or the implant site is underprepared by using thinner drills,¹⁷ preserving the maximum bone volume possible and increasing its density to optimize primary stability.

Turkyilmaz et al¹⁷ compared ISQ values in 2 control groups with those in 4 corresponding test groups, using thinner drills to enhance primary implant stability. They found a significant enhancement in primary implant stability in test versus control groups (59.5 ± 5 vs 64.4 ± 3 ISQ, $P < 0.05$) for implants placed in the maxillary posterior region, where the bone quality is poor improving their survival rate. These authors also found that bone density (voxel values [gray scale]) and insertion torque values were strongly correlated with RFA values at implant placement ($P < 0.001$).

Błaszczyszyn et al⁷² observed no significant difference in primary stability between implants in beds prepared with conventional burs versus ultrasonic devices at implant placement (70 ± 4 vs 71 ± 4 ISQ) or at 6 months (ISQ = 70 ± 2 vs 72 ± 3). Similar results were obtained by Stacchi et al (2013),⁷⁷ who observed no significant difference in primary stability at implant placement between implants in beds prepared with twist drills versus ultrasonic devices (72.2 ± 5.8 vs 70.5 ± 5.8 ISQ). However, other authors reported significantly increased ($P = 0.04$) ISQ values at implant placement and at 90 and 150 days for implants placed in beds prepared with ultrasonic devices than for those placed in beds prepared with conventional burs.⁷⁵ García-Morales et al (2012)⁷³ found no increase in primary or secondary stability in implants treated with low-level laser versus nonirradiated implants at implant placement (77.4 vs 75.7 ISQ), 10 days (78.9 vs 76.2 ISQ), 3 weeks (76.8 vs 76.9 ISQ), 6 weeks (75.5 vs 76.3 ISQ), 9 weeks (76.2 vs 77.7 ISQ), or 12-week postimplantation (76.3 vs 78.4 ISQ).

Markovic et al¹ obtained significantly higher ($P = 0.001$) implant stability values using lateral bone-condensing versus conventional bone-drilling techniques both immediately postsurgery (74.03 ± 3.53 vs 61.20 ± 1.63 ISQ) and at 6 weeks (70.33 ± 1.21 vs 65.23 ± 0.43 ISQ). The improved primary stability obtained with the condensation technique can therefore increase periimplant bone density and bone-implant contact, improving the

primary stability. Shayesteh et al (2013)⁷⁶ also reported significantly higher ISQ values ($P = 0.026$) for implants placed in beds prepared with osteotomes (test group) than for those prepared with conventional burs (control group) at the time of implant placement (70.9 vs 64.7 ISQ), but this difference had disappeared at 3 months postsurgery (72.71 vs 71.37 ISQ).

In contrast, Tallarico et al⁷⁴ found no significant difference in ISQ values between 1- and 2-stage Nobel Biocare TiUnite implants in premolar or molar areas at any postimplantation time point.

In patients with compromised bone density, it may be useful to apply complementary surgical techniques or modify the implant bed preparation to obtain an acceptable primary stability. Additional well-designed RCTs are warranted to compare the ISQ values obtained with these methods.

Relationship Between CBCT Bone Density and RFA Values

In a clinical study on the relationship of primary stability with implant and bone variables, Merheb et al⁷⁸ found a significant ($P < 0.05$) linear relationship between ISQ and CBCT bone density voxel values (gray scale) at implant placement and loading. Song et al (2009)⁷⁹ also reported a strong correlation ($P < 0.025$) between voxel values (gray scale) and ISQ values, and Turkyilmaz et al,⁸⁰ in a study of 142 implants, observed a significant correlation ($P < 0.001$) between mean voxel values (gray scale) (751 ± 257) and ISQ (70.5 ± 7 ISQ) values at implant placement. Likewise, Aksoy et al,⁸¹ in a study of 23 dental implants, found a significant correlation ($P = 0.015$) between mean voxel values (gray scale) (554.87) and ISQ values (72 ISQ). Fuster-Torres et al⁸² also found a significant relationship ($P < 0.05$) between mean voxel values (gray scale) (623 ± 209) and ISQ values (62.4 ± 8).

There is convincing evidence of a direct correlation between CBCT bone density (voxel values [gray scale]) and primary ISQ values, supporting the value of CBCT bone density data for managing implant treatment (Table 3).

Methods Used to Measure Dental Implant Stability

Rabel et al¹⁶ quantified the primary stability of 602 self-tapping and non-self-tapping implants using both RFA and insertion torque techniques. They found no correlation between the mean insertion torque (28.8 Ncm) and the mean ISQ value immediately postimplantation (66.6 ISQ) or at 3 months (66.8 ISQ) with either implant system ($r = 0.305$). Simunek et al,⁶ in a study of 940 dental implants, also observed no significant relationship at implant placement between mean ISQ (72.2 ± 5.0 ISQ) and insertion torque (60.2 ± 12 Ncm) values.

However, Oh and Kim,¹⁸ found a significant negative correlation between ISQ and Periotest values ($P < 0.01$) and concluded that both appear useful to predict primary implant stability and determine loading protocols.

Contradictory data have been published on the comparative performance of the different methods available to measure implant stability (Table 3). RFA analysis is the most widely accepted technique, but additional studies are required to confirm that it offers the greatest accuracy and reliability for implant stability measurements.

Influence of Loading Time on ISQ Values

Jackson et al⁸³ observed significantly lower ISQ values in immediately loaded (IL) versus conventionally loaded (CL) orthodontic palatal implants at 8 weeks (38.4 vs 47.3 ISQ, $P < 0.05$), suggesting that an unloaded healing period results in greater stability. However, this difference may be attributable to their application of an excessive rather than a conventional occlusal load on the IL implants with unfavorable lateral forces. In contrast, Güncü et al²⁰ found no significant difference in mean ISQ values over a 12-month follow-up between IL (74.18 ± 5.72 ISQ) and CL (75.18 ± 3.51 ISQ) implants in mandibular sites ($P > 0.05$). In the same line, an RCT with 60 patients reported by Cannizzaro et al⁸⁴ found no significant differences in ISQ values between IL and early loaded implants (supporting bar-retained mandibular overdentures placed with

flapless technique) at 6 weeks after implant placement (71.95 vs 71.42 ISQ, respectively, $P = 0.311$) or at 1-year postloading (70.22 vs 70.43 ISQ, respectively, $P = 0.519$). The same group found significantly higher ISQ values ($P = 0.033$) at baseline in IL (69.15 ± 3.16 ISQ) versus CL (66.6 ± 4.09 ISQ) implants placed in partially edentulous patients but observed no difference in ISQ values between them at 1 ($P = 0.8$), 2 ($P = 0.66$) or 3 ($P = 0.52$) years postimplantation.⁸⁵ Similar findings were reported by Kokovic et al (2014),⁸⁶ who compared immediate versus early loaded SLA implants in the posterior mandible and found no statistically significant differences in ISQ values between the control and the test group at any measurement time point (implant placement, 6, 12 weeks, and 1 year).

Lee et al⁸⁷ found no significant differences in mean ISQ values at placement or 8-month postsurgery between implants loaded with a hybrid prosthesis with a conventional rigid bar splinting the implants (group 1) and those loaded with a semirigid cantilever extension system with titanium bars placed in the 2 distal abutment cylinders (group 2).

Authors have concluded that ISQ values are not influenced by the loading protocol (Table 4) although these findings should be interpreted with caution, given the differences in study eligibility criteria between groups receiving immediate and conventional loading.

Augmentation Techniques

The relationship between implant stability and bone augmentation techniques is shown in Table 4. Cannizzaro et al⁸⁸ observed no significant difference at implant placement or at 3 months or 1 year postloading in the ISQ values of early loaded implants between those in maxillary sinus augmented with a lateral approach using 50% particulated autogenous bone/50% Bio-Oss and those in crestally augmented sinus using autogenous bone. In another study, Borges et al⁸⁹ performed simultaneous sinus membrane elevation and dental implant placement bilaterally in 15 patients, using a split-mouth design and found no difference in ISQ values between

implants placed with and without intraoral autogenous bone graft at implant placement or at 6 months.

Rasmusson et al⁹⁰ compared 5 different groups of implants in 35 patients with severe maxillary atrophy treated with TiO₂-blasted implants: 25 of them were treated with iliac bone grafts at 5 to 6 months preimplantation and 19 of these received 76 dental implants in a 2-stage protocol (38 implants on one side after lateral onlay block graft [group 1] and 38 implants on the other side after particulate bone graft [group 2]); these 19 patients also underwent bilateral sinus floor augmentation with particulate bone (76 implants [group 3]); the 6 remaining patients treated with iliac bone graft had an unfavorable sagittal relationship between the jaws and underwent LeFort I surgery with interpositional bone blocks grafted to the nasal and sinus floors (48 implants [group 4]); finally, 10 patients were able to receive implants without bone augmentation (60 implants, group 5). The only significant difference in ISQ values among these groups at implant placement and at 6 months was a significantly lower mean value in the patients treated with LeFort I surgery in comparison with the other groups. Likewise, Al-Khaldi et al⁹¹ observed no significant difference in mean ISQ values between dental implants placed in grafted versus nongrafted anterior maxillae at implant placement or at abutment connection. Degidi et al⁹² also found no significant difference in ISQ values between 80 implants placed in grafted or nongrafted areas.

Regenerative techniques are frequently applied in dental implantation and may affect the stability of the implant. Further well-designed RCTs are required to compare the influence on primary implant stability of different types of graft material placed at the implant site as a guide for clinicians in making an appropriate choice of material for their patients.

CONCLUSIONS

- Primary implant stability can be influenced by the macrodesign of dental implants, and roughness-enhancing surface treatments can

increase ISQ values in later osseointegration phases, improving secondary implant stability.

- Primary implant stability is lesser with lower bone density and may be enhanced by the utilization of thinner drills (underpreparation) or osteotomes when the bone density is inadequate.
- There is a significant direct correlation between CBCT-measured voxel values (gray scale) and RFA ISQ values, indicating that CBCT bone density data are useful for managing implant treatments.
- Authors have concluded that ISQ values are not influenced by the loading protocol although their findings should be interpreted with caution given the differences in study eligibility criteria between the groups receiving immediate and conventional loading.
- No study has detected significant differences in dental implant stability as a function of bone augmentation technique.
- Further well-designed RCTs are required to provide high-quality evidence on the factors that affect dental implant stability as a support to the clinician in selecting the optimum implant type, prosthetic loading protocol, and, when appropriate, surgical and regenerative approach.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

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