Medicon Medical Sciences
Volume 8 Issue 5 May 2025
Article Type: Case Report
ISSN: 2972-2721

Influence of Patient-related Factors, Implant Characteristics and Surgical Technique on the Stability of Dental Implants Measured by Resonance Frequency Analysis

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Received: April 08, 2025; **Published:** May 06, 2025

DOI: 10.55162/MCMS.08.288

Abstract

Objectives: To assess primary and secondary stability of titanium-zirconium alloy dental implants using resonance frequency analysis, and to identify factors influencing implant stability.

Materials and Methods: This was a longitudinal, prospective study utilizing the Straumann® implant system with either conventional or guided implant bed preparation techniques. Implant stability was measured using the Osstell ISQ® system (Integration Diagnostics AB, Gothenburg, Sweden) and analyzed in relation to patient-specific, implant-related, and surgical variables using multilevel modeling and multiple linear regression.

Results: A total of 274 implants were placed in 107 patients. Primary stability was positively correlated with bone density and insertion torque ($p < 0.05$). Higher primary stability was observed with 10 mm and 12 mm implants compared to 8 mm implants. Guided implant bed preparation resulted in higher and more consistent primary stability than conventional techniques. Patients with endocrine disorders demonstrated a reduction in ISQ values, with decreases of 5.63 units in the vestibular/palatal (ISQ Vb/PLv) and 6.07 units in the mesial/distal (ISQ M/Dv) directions. Greater increases in stability were observed in cases of caries-related tooth loss compared to periodontal disease, and with the use of longer and wider-diameter implants.

Conclusions: These findings underscore the value of standardized methods for assessing implant stability and highlight the relevance of patient-, implant-, and procedure-related factors in predicting implant success.

Keywords: implants; primary stability; secondary stability; resonance frequency analysis

Introduction

Stability is one of the main parameters that influence the long-term outcome of osseointegrated implants (Sim & Lang, 2010). Stability can be defined as primary (no implant movement after surgical insertion) or secondary (bone and soft tissue formation and remodelling around the implant during postoperative healing) (Raghavendra, Wood, & Taylor, 2005). Stability is known to be determined to a certain extent by biological properties, and there is evidence in the literature to show that it is also affected by factors such as the surgical technique used or the macroscopic and microscopic characteristics of the implant design. (Anchieta et al., 2014; Andrés-García et al., 2009; Bergamo et al., 2021; Chowdhary, Halldin, Jimbo, & Wennerberg, 2015; Daher, Abi-Aad, Dimassi, Baba, &

Majzoub, 2021; García-Moreno et al., 2018; He, Zhao, Deng, Shang, & Zhang, 2015; Lages, Douglas-de Oliveira, & Costa, 2018; Lioubavina-Hack, Lang, & Karring, 2006; Sim & Lang, 2010). Bone structure and bone density are among the biological factors that have been related to outcomes in oral implantology (Bergamo et al., 2021; Miguel-Sánchez, Vilaplana-Vivo, Vilaplana-Vivo, Vilaplana-Gómez, & Camacho-Alonso, 2015). In fact, bone density has been more closely correlated with shorter implant survival than location (mandible or maxilla) and position (Rozé et al., 2009), and plays a key role in surgical osteotomy (Higuchi, Folmer, & Kultje, 1995). For this reason, the effect of certain oral or even systemic conditions, such as osteoporosis, on bone density is currently of great concern in dentistry (Jeffcoat, Lewis, Reddy, Wang, & Redford, 2000; Merheb et al., 2016).

Several methods, both invasive and non-invasive, have been developed to measure implant stability. However, a particular non-invasive method has recently come to prominence due to its clinical utility and promising, scientifically proven outcomes, namely, resonance frequency analysis (RFA) using the Osstell® method (Meredith, Alleyne, & Cawley, 1996; Olivé & Aparicio, 1990). Whatever the method used, it is extremely important to determine both the primary and secondary stability of dental implants in order to predict treatment outcomes (Meredith, 1998).

In this context, we used RFA to determine primary and secondary stability after the placement of 274 titanium-zirconium alloy dental implants and evaluated the factors that can influence stability.

Material and Methods

Study design and variables

We designed a prospective, longitudinal, cohort study performed in a private dental clinic in Valencia (Spain). Consecutive patients undergoing dental implant therapy in the clinic who met the inclusion and exclusion criteria (Table S1) and gave their informed consent were selected using non-probability sampling techniques. The variables collected for analysis were: patient demographics and general clinical data, including edentulous space and implant design; surgical factors including bone density; and the primary and secondary stability of the implant.

This study conforms to the principles of the Declaration of Helsinki and was authorised by the CEU Cardenal Herrera University of Valencia Research Ethics Committee under decision no. CEI14/012.

Procedures and materials

A clinical history of the participants was collected before treatment, including general baseline data, presence of systemic pathologies, number of drugs taken in background therapy, and the reason for tooth loss. A computed tomography scan was then performed to plan the implant, and the bone density of the implant area was measured in Hounsfield units (HU). Surgery was always performed by the same surgeon and assistant, and the osteotomy bed was prepared using either conventional or guided surgery, as requested by the patient. The Straumann® implant system with titanium-zirconium implants was used, following the drilling protocol recommended by the manufacturer (Institut Straumann AG, Basel, Switzerland). All implants were inserted using the surgical motor, without irrigation, and with an initial torque of 20 Ncm, which was gradually increased up to 50 Ncm, depending on bone strength. The final insertion torque was recorded. When guided implant surgery was performed, the implants were inserted through the surgical template, which was then removed.

All primary stability measurements (4 measurements per implant and 2 variables for analysis: median ISQ of the vestibular and palatal/lingual surfaces, and median ISQ of the mesial and distal surfaces) were performed by resonance frequency analysis using the Osstell ISQ® system (Integration Diagnostics AB, Gothenburg, Sweden). At 12 weeks, the same measurements were performed to determine secondary implant stability.

Statistical analysis

First, descriptive statistics (mean, standard deviation, minimum, maximum and median) were used for continuous variables, and frequency and percentages were calculated for categorical variables. Multilevel models with multiple linear regression were used for inferential statistics in order to include different variables on different levels (patient and implant). In these models, which were constructed from the dependent variable (ISQ Vb/PL or ISQ M/D) and the independent variables, we calculated the β coefficients, the standard error, and the Student's *t* statistic with the corresponding *p*-value. The level of statistical significance used in all analyses was 0.05. Statistical analysis was performed on the statistical programme IBM SPSS Statistics 21.

The authors state compliance with the appropriate research reporting guidelines (STROBE checklist).

Results

Descriptive analysis of study variables

The study included a total of 107 patients who received 274 implants. Mean age was 54 years, with a range of 20 to 79 years. The baseline and clinical characteristics of the study patients and the corresponding distribution of the implants placed are shown in Table 1. An analysis of the distribution according to maxillary or mandibular location and position of the 274 implants showed 44 implants located in the anterior mandible, 78 in the posterior mandible, 60 in the anterior maxilla and 94 in the posterior maxilla. Mean bone density was 648.6 HU (range 216.2 - 1197.8).

Characteristics		***Patients (%)***	***Implants placed***
		N = 107	***N = 274***
Sex	Women	59 (56.1%)	142 (51.8%)
	Men	48 (44.9%)	132 (48.2%)
Age range	< 50 years	44 (41.1%)	89 (32.5%)
	51- 59 years	35 (32.7%)	104 (38%)
	> 59 years	28 (26.2%)	81 (29.6%)
Comorbidities	None	71 (66.3%)	162 (59.1%)
	Endocrine disease	13 (12.1%)	40 (14.6%)
	Cardiovascular disease	13 (12.1%)	41 (15%)
	Osteoporosis	5 (4.6%)	16 (5.8%)
	Clotting disorder	3 (2.8%)	7 (2.5%)
	Lung disease	2 (1.9%)	8 (2.9%)
Drugs	None	69 (64.5%)	162 (59.1%)
	1	9 (8.4%)	27 (9.8%)
	2	26 (24.2%)	72 (26.3%)
	≥3	3 (2.8%)	13 (4.74%)
Cause of tooth loss	Periodontal disease	54 (50.5%)	157 (57.3%)
	Dental caries	45 (42%)	107 (39%)
	Dental trauma or agenesis	8 (7.5%)	10 (3.6%)
Silness-Löe plaque index	0	57 (53.3%)	113 (41.2%)
	1	22 (20.6%)	36 (13.1%)
	Not evaluable	28 (26.2%)	125 (45.6%)

Table 1: Patient baseline and clinical characteristics and distribution of implants.

A total of 125 implants (45.6%) with a diameter of 4.1 mm and 149 implants (54.4%) with a diameter of 3.3 mm were placed. In terms of length, 65 implants (23.7%) were 8 mm, 107 (39.1%) were 10 mm, and 102 implants (37.2%) were 12 mm. Mean insertion torque was 38.49 Ncm (range 20 - 50). In terms of surgical technique, 87 patients underwent conventional surgery to place 170 implants, and 20 patients underwent guided surgery to place 104 dental implants.

Mean primary vestibular and palatal or lingual stability (Vb/PL) was 69.37 ISQ (range 40 - 83.5), while primary mesial and distal stability (M/D) was 70.69 ISQ (range 41 - 85.5). Secondary stability was also evaluated according to ISQ values 12 weeks after implant placement. A total of 4 implants failed, so secondary stability was measured in 270 implants. Mean ISQ Vb/PL_{12} was 74.30 (range 53 - 87) and mean ISQ M/D_{12} was 75.51 ISQ (range 53 - 88).

Factors influencing primary implant stability

The multivariate model showed a statistically significant correlation between primary ISQ Vb/PL and ISQ M/D values and HU; in other words, the higher the bone density, the higher the ISQ value. Greater primary stability was achieved with the 12 mm and 10 mm vs. 8 mm implants (Table 2). The higher the insertion torque, the greater the primary stability. Primary ISQ Vb/PL and ISQ M/D values were higher with guided vs. conventional surgery. A statistically significant correlation was also found between primary ISQ M/D and patient age; in other words, the younger the patient, the greater the primary stability. With regard to arch and position, we observed that stability was greater in implants placed in the mandible vs. the maxilla (Table 2) and in anterior vs. posterior implants (p <0.05).

		Implant length			***Arch***	
		8 mm	***10 mm***	***12 mm***	***Mandible***	***Maxilla***
Mean global ISQ	Valid N	65	107	102	120	154
	Mean	66.12	71.52	70.96	73.73	67.15
	Standard deviation	9.11	8.70	8.10	7.47	8.75
ISQ Vb/PL	Valid N	65	107	102	120	154
	Mean	65.45	70.91	70.25	72.94	66.59
	Standard deviation	9.02	8.70	8.04	7.47	8.75
ISQ M/D	Valid N	65	107	102	120	154
	Mean	66.78	72.13	71.67	74.52	67.71
	Standard deviation	9.34	8.77	8.27	7.62	8.82

ISQ, Osstell ISQ® System Stability Measurement Units; Vb/PL, vestibular/palatal or lingual; M/D, mesial/distal.

Table 2: Correlation between primary ISQ values and implant length or dental arch (p-value <0.05).

After applying the linear regression equations that combine all the factors that influence primary stability, the model showed that:

- ISQ M/D values decrease by 0.054 units for each 12-month increment in age.
- ISQ Vb/PL values increase by 1.219 units in mandible vs. maxilla implants.
- ISQ Vb/PL and ISQ M/D values increase by 0.022/0.024 units, respectively, for each Hounsfield unit increase in bone density.
- ISQ Vb/PL and ISQ M/D values increase by 2.473/2.508 units, respectively, in implants measuring 12 mm vs. 8 mm.
- ISQ Vb/PL and ISQ M/D values increase by 2.525/2.265 units, respectively, in implants measuring 10 mm vs. 8 mm.
- ISQ Vb/PL and ISQ M/D values increase by 4.536/4.691 units, respectively, in guided vs. conventional surgery.
- ISQ Vb/PL and ISQ M/D values increase by 0.829/0.752 units, respectively, for each unit increase in insertion torque.

When the potential influence of bone density on the different independent primary stability variables was analysed, a statistically significant correlation was observed between sex and bone density; i.e., bone density was higher in men vs. women. A statistically significant correlation was also observed between implant insertion torque and bone density; i.e., implant insertion torque increases by 0.02 units for each HU unit increment in bone density.

Factors influencing secondary implant stability

New ISQ Vb/PL and ISQ M/D measurements were performed 12 weeks after implant placement to determine secondary stability. We then calculated the variations between primary and secondary stability (ISQ Vb/PLv; ISQ M/Dv), and determined whether they were influenced by patient-related, surgery-related or implant design-related factors. A significantly lower increase in stability was observed in patients with endocrine disease vs. no disease, namely, ISQ Vb/PL_V and ISQ M/D_V decreased by 5.636/6.073 units, respectively, in patients with endocrine disease. In patients with a grade 1 vs. grade 0 Silness-Löe plaque index, ISQ Vb/PL_V and ISQ M/D_V variations decreased by 0.740/1.135 units, respectively. Furthermore, variations in ISQ Vb/PL and ISQ M/D values decreased by 0.176/0.174 units, respectively, for each unit increase in insertion torque. In contrast, stability increase was greater if the cause of tooth loss was caries (ISQ Vb/PL_V increased by 0.975 units) vs. periodontal disease, if the implant diameter was 4.1 mm (ISQVb/PL_V and ISQ M/D_V increased by 1.511/1.333 units, respectively) vs. 3.3 mm, and if the implant length was 12 mm (ISQ Vb/PL_V and ISQ M/D_V increased by 0.514/0.837 units, respectively) vs. 8 mm.

Significant differences were observed between the surgical method used and the variations in ISQV values. Primary stability values varied by 1.5 units when guided surgery was performed vs. conventional surgery; in other words, variations in stability were greater when conventional implant surgery was performed (Table 3). We also observed a statistically significant correlation between the number of drugs used in background therapy and variations in ISQ_V values; namely, variations in stability decreased by almost 3 units if the patient took more than 1 drug vs. no drugs.

		SURGICAL TECHNIQUE	
		Conventional	***Guided***
ISQ Vb/PL_V	Valid N	166	104
	Mean	5.18	4.00
	Standard deviation	2.50	2.95
ISQ M/D_V	Valid N	166	104
	Mean	5.08	3.87
	Standard deviation	2.81	3.32

ISQ, Osstell ISQ® System Stability Measurement Units; Vb/PL, variation in vestibular/palatal or lingual measurement; M/D, variation in mesial/distal measurement.

Table 3: Variations in primary stability (ISQ Vb/PLv, ISQ M/Dv) by surgical technique.

Discussion

The aim of implant therapy research is to predict and improve dental implant surgery outcomes. It is important to determine the status of the implant in relation to the surrounding bone, and this has prompted clinicians to search for methods to assess and monitor implant status and detect changes at an early stage (O'Sullivan, Sennerby, & Meredith, 2000).

In our study, we used the Osstell™ ISQ system to measure stability. The wireless technology makes it easy to use, although different values can be obtained depending on the horizontal positioning of the device, i.e., palatal/lingual, vestibular, distal or mesial. For this reason, we took 2 measurements from 2 different angles, and implant stability was defined as the mean ISQ value, as described elsewhere (Quesada-García et al., 2009).

The mean age of patients included in this study was 54 years, and the success rate of titanium and zirconium alloy implants at 12 weeks in this population was 98.5%. The mean primary ISQ value obtained was 70.03 ± 8.83 ISQ, a figure that indicates high primary stability. Altinci et al. also used titanium and zirconium alloy implants and obtained a mean primary ISQ value of 70.35 ± 7.01 ISQ (Altinci, Can, Gunes, Ozturk, & Eren, 2016), a result practically identical to that of our study. Our 12-week ISQ value (74.9 ± 7.9 ISQ), which indicates high secondary stability and sufficient healing to proceed with prosthetic loading, was very similar to that of Altinci et al. However, other studies in titanium implants report ISQ values in ranging from 66.9 to 75 (Degidi, Daprile, & Piattelli, 2012; Filho et al., 2014; Jayaprakash et al., 2020). This variability could be due to the fact that the type of implant and the surgical techniques and protocols used affect primary stability. We observed no significant differences in primary stability between male and female patients, a finding that is consistent with several previous studies (Boronat-López, Peñarrocha-Diago, Martínez-Cortissoz, & Mínguez-Martínez, 2006; Zhou et al., 2009), while in others, primary stability values were lower in women than in men (Kim, Kim, Joo, & Lee, 2017; Ostman, Hellman, Wendelhag, & Sennerby, 2006). This, however, may be due to the advanced age of these authors' study cohort and the fact that most women were postmenopausal. Therefore, this finding cannot be extrapolated to the remaining female population. In our study, 33.6% of patients presented some type of comorbidity. Endocrine disease was particularly important in this context, since a statistically significant correlation was observed between patients with controlled diabetes mellitus and variations in ISQ_V values. Some authors have studied implant survival in patients with endocrine disease, but not implant stability (Morris, Ochi, & Winkler, 2000). In contrast to other studies, no correlation was observed between the presence of osteoporosis and implant stability (Brügger et al., 2015). One possible explanation for this is the small number of patients with osteoporosis in our cohort. Two of our findings support those of other authors, namely, a significant correlation between evolution of stability and tooth loss due to periodontal disease, and the correlation between primary stability and mandible placement (Gehrke & Tavares da Silva Neto, 2014; Schou, Holmstrup, Worthington, & Esposito, 2006).

Our findings in respect of bone density are in line with other studies, insofar as bone quality significantly influences primary ISQ values. However, bone density does not appear to significantly affect the evolution of stability, and values tend to be similar once osseointegration has been achieved (Isoda et al., 2012; Turkyilmaz & McGlumphy, 2008).

Regarding the characteristics of the implant, our study shows that diameter does not seem to be related to primary stability, but does appear to influence its evolution. However, in our study, increasing the length of the implant improved primary stability, a finding echoed by other authors (Bedrossian, 2020; Farzad, Andersson, Gunnarsson, & Sharma, 2004). In our sample, primary stability increased by 7 ISQ units for every 5-unit increment in insertion torque. In contrast, ISQ variations decreased as insertion torque increased. This may be due to the fact that high primary ISQ values tend to be maintained, or can even decrease, during osseointegration of the implants, and these values correspond to the highest insertion torques.

Regarding surgical technique, implants placed using stereolithographic surgical guides showed less variation in stability than those placed using conventional techniques. This may be due to the fact that primary stability was higher in implants placed using guided surgery, so the ISQ values increased slightly or remained stable. The only previous paper analysing implant stability using resonance frequency analysis with stereolithographic surgical guides was the prospective study published by Altinci et al. (Altinci et al., 2016), in which primary stability values similar to ours were obtained, although the evolution of the stability of these implants was not evaluated.

It is important to highlight that the surgical technique or the number of drugs taken influenced outcomes at the individual level, but were not found to be influential in the multilevel analysis carried out to detect masked effects. In other words, in the presence of other factors, these variables do not appear to have an appreciable effect.

This study has some limitations, such as the follow-up time or the limitations of the Osstell™ ISQ method. However, Osstell™ ISQ has good intra- and interobserver reliability, and is currently the most widely used method for monitoring implant bone healing. Our study also has some advantages: the same implant brand was used in all patients, and the decision to use guided surgery was based on logistical and/or administrative issues and not on the clinical status of the patient. Furthermore, the surgical methods are protocolised and routinely used in clinical practice.

Conclusions

Our study has shown that primary and secondary stability can be affected by a series of patient-related (bone density, comorbidities, cause of tooth loss), implant design-related (length and diameter), and surgery-related (insertion torque and use of stereolithographic guides) factors. Bone density was found to be a key factor in primary stability, which was in turn related to the location of the implant (maxilla or mandible). Factors such as endocrine disease and tooth loss due to periodontal disease appear to determine the final stability of implants. In conclusion, evaluating implant stability using an objective instrument that can predict dental outcomes is extremely important in implantology, and will help standardise studies in dental implants. Further studies on this topic with larger sample sizes and longer follow-up are needed.

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