

## CLINICAL EVALUATION OF THE STABILITY OF IMPLANTS PLACED AT DIFFERENT SUPRACRESTAL LEVELS

### Farklı Kret Üzeri Seviyelerde Yerleştirilen İmplantların Stabilitésinin Klinik Olarak Değerlendirilmesi

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#### ABSTRACT

**Purpose:** The aim of this study was to evaluate the stability during healing and before loading of implants placed at two different supracrestal levels according to their collar texture.

**Materials and Methods:** This retrospective study included patients who received posterior implants with the same macro design. Implants with a machined collar were placed 0.3 mm above the crestal bone (M group), while those with a laser-microtextured collar were placed 1 mm above the crestal bone (L group). All implants healed in a single stage with healing abutments. Implant stability quotient (ISQ) values were determined using resonance frequency analysis immediately after implant placement during surgery and after 1, 4, 8, and 12 weeks after surgery. Other evaluated factors for stability included the implant diameter and length and the site of placement (maxilla or mandible).

**Results:** In total, 103 implants (47 L, 56 M) were evaluated. The median ISQ values at baseline and 1 week after placement were significantly higher for the M group than for the L group ( $p=0.006$  and  $p=0.031$ , respectively). There were no differences at the subsequent observation points. The ISQ value was higher for wide-diameter than regular diameter ( $p=0.001$ ) and mandibular implants than maxillary implants ( $p=0.001$  at 0-8. weeks;  $p=0.012$  at 12 weeks) at all observation points. When diameter data were neglected, the implant length did not influence the ISQ value at all observation points.

**Conclusion:** Our results suggest that submerging implant more inside bone may only influence primary stability. Moreover, the implant diameter and site of placement influence primary and secondary stability before loading, whereas the implant length does not when its diameter is not accounted for.

#### ÖZ

**Amaç:** Bu çalışmanın amacı boyun yüzeylerine göre iki farklı kret üzeri seviyede yerleştirilen implantların iyileşme sırasında ve yükleme öncesi stabilitelerinin değerlendirilmesidir.

**Gereç ve Yöntem:** Bu retrospektif çalışmaya posterior bölgede aynı makro tasarıma sahip implantlar yerleştirilen hastalar dahil edilmiştir. Lazer-mikroyüzey boyuna sahip implantlar kret seviyesinin 1 mm üzerinde yerleştirilirken (L grubu), cilalı boyuna sahip implantlar kret seviyesinin 0.3 mm üzerinde yerleştirilmiştir (M grubu). Tüm implantlar iyileşme başlığı ile tek aşamada iyileştirilmiştir. İmplant stabilite değerleri (ISQ) cerrahi işlem sırasında ve cerrahi işlem sonrasında 1., 4., 8., ve 12. haftalarda rezonans frekans analizi yardımıyla ölçülmüştür. Stabilite için değerlendirilen diğer olası etkenler implant çapı, boyu ve yerleşim bölgesidir (maksilla veya mandibula).

**Bulgular:** Çalışmada toplam 103 implant (47 L, 56 M) değerlendirilmiştir. Başlangıç ve cerrahi sonrası 1. haftadaki median ISQ değerleri M grubu için L grubuna kıyasla anlamlı derecede yüksek bulunurken ( $p=0.006$  ve  $p=0.031$ , sırasıyla) ilerleyen haftalarda anlamlı bir fark görülmemiştir. Tüm gözlem dönemlerinde, geniş çaplı implantların dar çaplı implantlara göre ( $p=0.001$ ) ve alt çeneye yerleştirilen implantların üst çeneye yerleştirilen implantlara göre ISQ değerleri daha yüksek bulunmuştur (0-8. haftada  $p=0.001$ ; 12. haftada  $p=0.012$ ). İmplant çapı gözardı edildiğinde, herhangi bir gözlem döneminde implant boyu ISQ değerlerini etkilememiştir ( $p>0.05$ ).

**Sonuç:** İmplantın yerleştirme sırasında kemik içine daha fazla gömülmesi primer stabiliteyi etkileyebilmektedir. Bununla birlikte, implantın boyu, çap gözardı edildiğinde, stabilite üzerine etkili değilken çapı ve yerleştirildiği bölge yükleme öncesi primer ve sekonder stabiliteyi etkilemektedir.

**Keywords:** Dental implant; implant stability quotient; supracrestal level; bone-implant interface; osseointegration

**Anahtar kelimeler:** Dental implant; implant stabilite katsayısı; alveolar kemik seviyesi; osseointegrasyon; kemik implant arayüzeyi

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## **Introduction**

Dental implantation is a successful treatment alternative for missing teeth. Several factors affect the healing of dental implants; including the amount of residual bone, bone quality, and implant stability. Implant stability is fundamental to achieve and maintain the osseointegration (1). Various techniques or devices have been used to measure implant stability such as insertion torque measurement, the Periotest, implant tapping, and removal torque analysis (2). However, the sensitivities of these methods are poor, their results are not objective, and most of them are not repeatable (3). In 1996, Meredith *et al.* (4) developed a noninvasive, nondestructive, and easy method known as resonance frequency analysis (RFA) for the evaluation of the stiffness of the bone–implant interface. Quantitative evaluation of implant stability using RFA is a reliable and predictable technique for the assessment of success (4). In this technique, a transducer is attached to the inserted implant and is subjected to vibrations through another device. The resistance of the implant to bending forces transmitted through the transducer to the surrounding bone is then determined; the obtained values are determined on a scale from 1 to 100 and are known as implant stability quotient (ISQ) values (3, 4). Higher ISQ values are reportedly associated with greater implant stability and osseointegration (5).

Primary and secondary stability play an important role in successful healing. While macro retention or resistance to friction immediately after implant placement is related to the primary stability, bone–implant contact after tissue integration is associated with secondary stability (biological stability) (6–8). The implant shoulder can be placed at different levels relative to the crestal bone, depending on the surface properties of the collar. Consecutive repetitive measurements during the healing period may provide valuable information regarding the influence of the implant design and position of the implant collar on stability. This also aids clinicians to determine the optimal time for the loading of implants placed at different levels with varied bone densities, consequently decreasing the rate of failure which would be caused by poor stability. To the best of our knowledge, no clinical study has evaluated the stability of implants during the healing period with respect to the level of placement in bone. The aim of this retrospective study was to evaluate the stability using RFA during the healing period of implants which

were placed at two different levels above the crestal bone according to their collar texture. In addition, the influences of the implant diameter and length and site of placement (maxillary or mandibular) on stability during the healing period were also assessed. The null hypothesis was that the implant stability during healing is not influenced by the level of placement relative to the crestal bone.

## **Materials and Methods**

### *Patient selection*

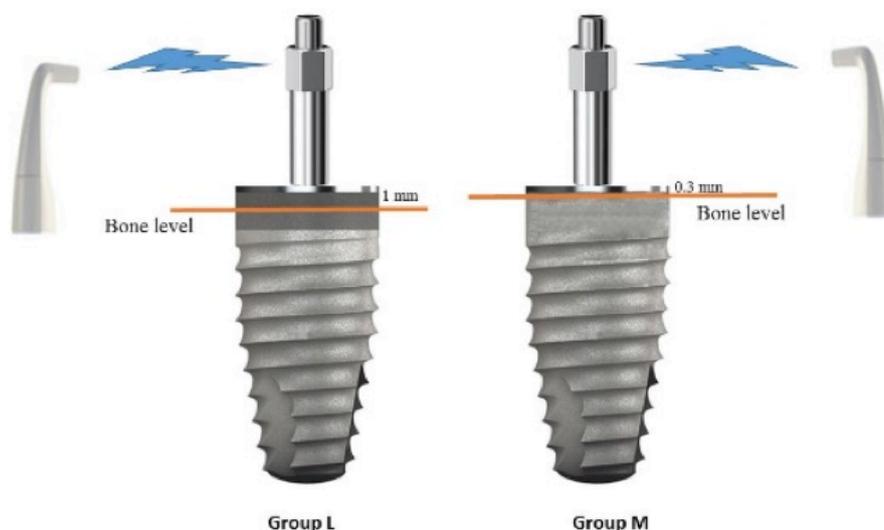
Patients referred to the Department of Oral Implantology at Istanbul University Faculty of Dentistry between December 2010 and December 2011 for the replacement of posterior missing teeth by implant treatment (received one of two types of implants; Tapered Internal Laser-Lok TLX and TRX; Biohorizons, Birmingham, AL) were included in this retrospective study. All patients were systemically healthy. The inclusion criteria were as follows: absence of at least one or more teeth in the posterior maxilla or mandible, the presence of adequate natural bone height and width for the placement of implants measuring at least 3.8 mm in diameter and 10.5 mm in length, and the presence of adequate follow-up during the study. The exclusion criteria were as follows: presence of systemic conditions that may complicate surgery, presence of uncontrolled periodontal disease, poor oral hygiene or the lack of willingness to maintain good oral hygiene, and the lack of primary stability. This study has been conducted in accordance with the Declaration of Helsinki and has been reviewed and approved by the Ethical Committee (Approval no: 2015/71306642-050). Written informed consents regarding surgical operation were obtained from all participants.

### *Implant design*

The macro designs of both implant types were identical (screw-shaped), with the same healing abutment connection and the same surface properties (Resorbable Blast Textured body and a surface roughness of 0.72–1.34  $\mu\text{m}$ ). The only difference was the presence of a machined collar in one type (0.3-mm machined, turned surface for epithelial tissue attachment for TRX) and a laser-microtextured collar in the other (0.3-mm machined, turned surface; a 0.7-mm section of 8- $\mu\text{m}$  microgrooves for connective

tissue attachment; and a 0.8-mm section of 12- $\mu$ m microgrooves for bone attachment for TLX). According to the manufacturers' recommendations, the implants with machined collar were placed 0.3

mm above the crestal bone (M group), while those with laser-microtextured collar (L group) were placed 1 mm above the crestal bone (Figure 1).

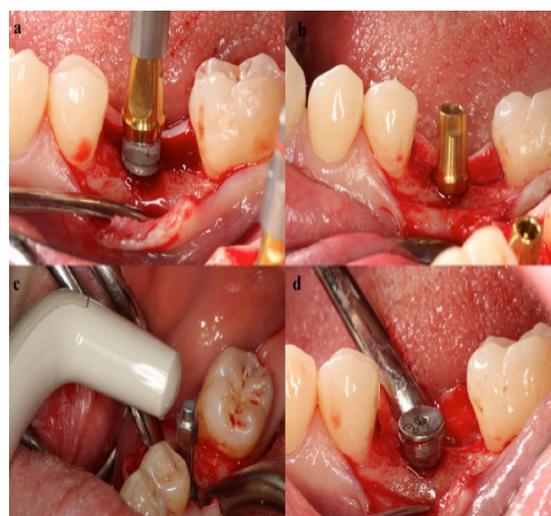


**Figure 1.** Representative images of the laser-microtextured group (group L) and machined collar group (group M) implants used in this study. The L group implant was placed 1 mm above the crestal bone, while the M group implant was placed 0.3 mm above the crestal bone. The implant stability was measured from the buccal and mesial sections of the transducer in the resonance frequency analysis system.

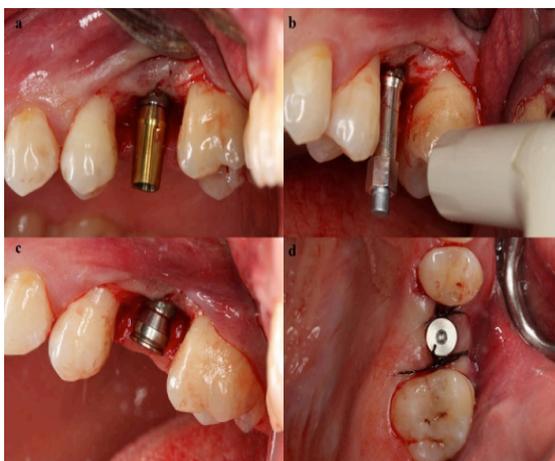
#### *Surgical procedure*

All surgeries were performed under local anesthesia (Ultracain DS Forte, Sanofi Aventis, Istanbul, Turkey). Following the placement of a midcrestal incision, full-thickness flaps were raised. Implants were placed using a customized surgical guide according to standard surgical protocols; the same surgical kit was used for both groups. All implants were placed according to the manufacturers' instructions. The mesial–distal aspect of the alveolar ridge was used as a reference. Healing abutments were attached to the implants for transmucosal healing (Figures 2 and 3).

The mucoperiosteal flaps were sutured with silk sutures (Dogsan Medical Supplies Industry, Trabzon, Turkey) after implant placement. Postoperative prescriptions included antibiotics (1000 mg amoxicillin and clavulanic acid, twice daily for 7 days, starting from the day of surgery), analgesics (600 mg ibuprofen as required, every 6 h), and 0.2% chlorhexidine mouthwash (twice daily for 2 weeks, starting from the day after surgery). Sutures were removed 7 days after surgery.



**Figure 2.** (a and b) Placement of an implant with a machined collar (M group) 0.3 mm above the crestal bone (c) Implant stability is measured using resonance frequency analysis (d) Healing abutment was attached to the implant for transmucosal healing.



**Figure 3.** (a and b) Placement of an implant with laser-microtextured collar (L group) 1 mm above the supracrestal bone and measurement of implant stability using resonance frequency analysis (c and d) Healing abutment was attached to the implant for transmucosal healing.

#### Study variables

Implant stability was determined using RFA (Osstell Mentor; Integration Diagnostics AB, Göteborg, Germany) immediately after implant placement during surgery (R-0) and at 1, 4, 8, and 12 weeks after surgery (R-1, R-4, R-8, and R-12, respectively). An implant-specific smartpeg was screwed into the implants. This instrument provided ISQ readings from the buccal and mesial sections of the transducer. All measurements were obtained three times by the same examiner (PG), and the average of all measurements for each implant was recorded as the final value. If an ISQ interval was measured instead of a specific value, the mean value was used. In addition to the level of placement, the implant diameter and length and site of placement were analyzed with regard to their influence on stability during healing. RFA measurements were restricted to a single clinician for increased reliability ( $R = 0.964$ ). All implant placement sites were imaged using with a digital radiography system using the long-cone parallel technique (Kodak DS, Rochester, NY, USA) at baseline and at 3 months after implant placement to evaluate vertical bone levels. The known implant length was used as a reference to increase the measurement accuracy and to eliminate the magnification factor in periapical radiographs. The distance between the mesial and distal edges of the implant shoulder and the most coronal level of the bone in contact with the implant body was

calculated using a software program (Kodak DS, Rochester, NY, USA). For each implant, the mean of the mesial and distal measurements was used. The baseline measurement was used as a reference point for comparisons.

#### Statistical analysis

The primary endpoint of the study was the change in implant stability (ISQ) over time during the healing period. The implant was used as the statistical unit and analyzed. Using G\*Power (version 3.1.9.2, Heinrich-Heine-Universität, Düsseldorf, Germany) and by consulting a previous study (8), a required sample size of minimum 32 implants was calculated to detect comparisons between the two groups. Statistical power of 80% (effect size  $d = 0.713$ ;  $\alpha = 0.05$ ) were accounted (with an estimated drop-out) and approximate total of at least 45 implants were deemed necessary for the study. The Number Cruncher Statistical System 2007 software (NCSS; Kaysville, Utah, USA) was used for statistical analysis. The standard descriptive methods such as median, frequency, minimum and maximum were applied to determine the characteristics of the sample. The Shapiro-Wilk test was used to assess the normality of the data distribution. Because the distribution of the data did not meet the requirements for normality and homogeneity of variances assumptions, the nonparametric quantitative data were compared between groups using Mann-Whitney U tests and within groups using Friedman tests and Wilcoxon signed-rank tests for pairwise comparisons. The confidence interval was set to 95% and  $p < 0.05$  was considered statistically significant.

#### Results

Initially, 66 patients were considered eligible for the study. Four with inappropriate measurements were excluded. Eventually, 62 patients were included in the study (34 women and 28 men; mean age  $52.24 \pm 13.38$  years). A total of 103 implants, including 47 in the L group and 56 in the M group, were placed. 65 (63.1%) were placed in the mandible and 38 (36.9%) in the maxilla. Implants measuring 10.5 and 12 mm in length and 3.8 (regular) and 4.6 (wide) mm in diameter were used; 72 (69.9%) measured 10.5 mm in length and 77 (74.7%) measured 3.8 mm in diameter. All implants exhibited clinical osseointegration, leading to a 100% survival rate. The ISQ values at baseline and R-1 were significantly higher for the M group

than for the L group (Mann–Whitney U test;  $p < 0.05$ ; Table 1). There was no significant difference in ISQ values at the subsequent observation points (R-4, R-8, and R-12) between the two groups (Mann–Whitney U test;  $p > 0.05$ ; Table 1, Figure. 4).

**Table 1.** Comparison of stability between L and M groups according to implant stability quotient (ISQ) values from baseline to 12 weeks after placement. L group: implants with laser-microtextured collar placed 1 mm above the crestal bone M group: implants with a machined collar placed 0.3 mm above the crestal bone.

	L group (n = 47)		M group (n = 56)		<sup>a</sup> p
	Median (Q1, Q3)		Median (Q1, Q3)		
Baseline (R-0)	70 (67, 73)		72 (70.5, 76)		<b>0.006**</b>
1 week (R-1)	70 (67, 73)		71.5 (70, 76)		<b>0.031*</b>
4 weeks (R-4)	68 (65, 72)		69.5 (67, 73)		<b>0.212</b>
8 weeks (R-8)	71 (68, 74)		72 (70, 75.5)		<b>0.434</b>
12 weeks (R-12)	73 (68, 76)		73 (70.5, 76.5)		<b>0.516</b>
	<sup>d</sup> 0.001**	<sup>d</sup> 0.001**			
	Median (Q1, Q3)	<sup>c</sup> p	Median (Q1, Q3)	<sup>c</sup> p	<sup>a</sup> p
0-1 weeks	0 (-1, 1)	0.538	0 (-1, 0)	0.001**	<b>0.028*</b>
0-4 weeks	-2 (-3, -1)	0.001**	-3 (-4, -2)	0.001**	<b>0.001**</b>
0-8 weeks	0 (-1, 2)	0.065	-1 (-2, 0)	0.001**	<b>0.001**</b>
0-12 weeks	2 (0, 4)	0.001**	0 (-1, 2)	0.480	<b>0.001**</b>
1-4 weeks	-2 (-3, -1)	0.001**	-3 (-4, -2)	0.001**	<b>0.003**</b>
1-8 weeks	0 (-1, 2)	0.153	-1 (-1.5, 0)	0.010*	<b>0.003**</b>
1-12 weeks	1 (0, 4)	0.001**	1 (-1, 2)	0.036*	<b>0.033*</b>
4-8 weeks	2 (1, 3)	0.001**	2 (1, 3)	0.001**	<b>0.544</b>
4-12 weeks	3 (2, 5)	0.001**	3 (2, 5)	0.001**	<b>0.635</b>
8-12 weeks	1 (0, 3)	0.001**	1 (0, 2)	0.001**	<b>0.918</b>

<sup>a</sup>Mann–Whitney U Test

<sup>c</sup>Wilcoxon Signed-Rank Test

<sup>a</sup>Friedman Test

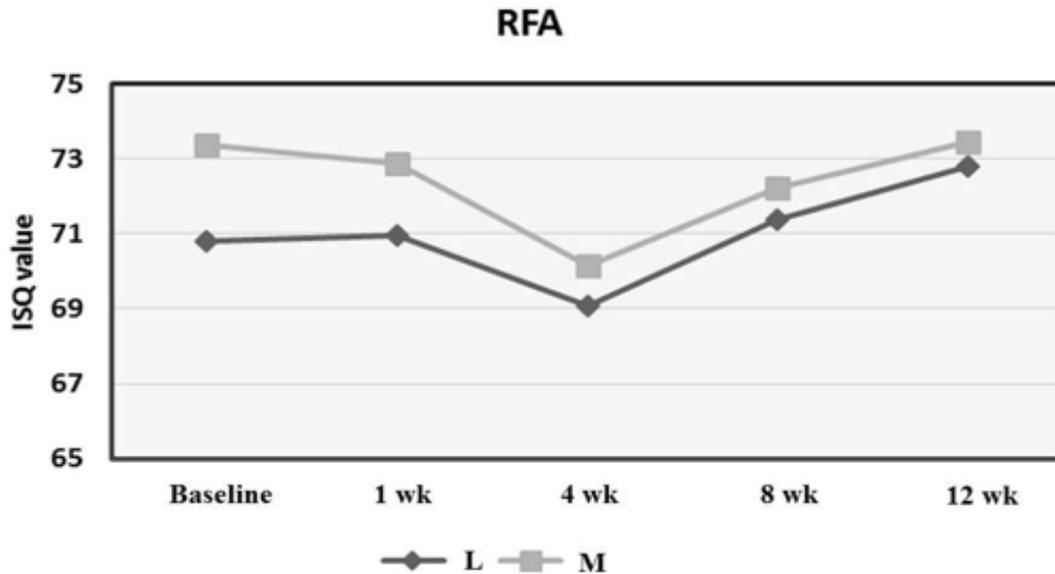
\* $p < 0.05$

\*\* $p < 0.01$

The M group implants demonstrated a statistically significant decrease in ISQ values at R-1, R-4, and R-8 relative to the baseline value (Wilcoxon signed-rank test;  $p < 0.01$ ; Figure 4) However, there was no significant difference between baseline and R-12 values (Wilcoxon signed-rank test;  $p > 0.05$ ; Table 1, Figure 4). The L group implants demonstrated a statistically significant decrease in the ISQ value at R-4 relative to the baseline value (Wilcoxon signed-rank test;  $p < 0.01$ ; Table 1). However, there was no significant difference at R-1 and R-8 (Wilcoxon signed-rank test;  $p > 0.05$ ; Table 1). In addition, a significant increase in the ISQ value was observed at R-12 (Wilcoxon signed-rank test;  $p < 0.01$ ; Table 1, Figure 4). When the ISQ data was analyzed according to the site of placement, regardless of the level of placement, we have found higher values for

mandibular implants than for maxillary implants at all observation points (Mann–Whitney U test;  $p < 0.05$ ; Table 2)

With regard to the diameter, ISQ values were significantly lower for regular-diameter implants (3.8 mm) than for wide-diameter implants (4.6 mm) at all observation points (Mann–Whitney U test;  $p < 0.01$ ; Table 3). With regard to 10.5-mm length, ISQ values were significantly lower for regular-diameter implants (3.8 mm) than for wide-diameter implants (4.6 mm) at all observation points (Mann–Whitney U test;  $p < 0.01$ ; Table 3).



**Figure 4.** Comparison of stability between L group and M group implants according to implant stability quotient (ISQ) values from baseline to 12 weeks after placement. L group: implants with laser-microtextured collar placed 1 mm above the crestal bone M group: implants with a machined collar placed 0.3 mm above the crestal bone.

**Table 2.** Relationship between implant stability quotient (ISQ) values and the site of placement.

	Mandible (n = 65)	Maxilla (n = 38)	
	Median (Q1, Q3)	Median (Q1, Q3)	<i>p</i>
Baseline (R-0)	73 (71,76)	68 (67,72)	<b>0.001**</b>
1 week (R-1)	72 (70,76)	69 (67,71)	<b>0.001**</b>
4 weeks (R-4)	71 (68,74)	66 (63,69)	<b>0.001**</b>
8 weeks (R-8)	73 (70,76)	69 (65,72)	<b>0.001**</b>
12 weeks (R-12)	73 (71,77)	71.5 (66,75)	<b>0.012*</b>

<sup>a</sup>Mann–Whitney U Test

\**p*<0.05

\*\**p*<0.01

With regard to length, no significant differences were observed between those measuring 10.5 mm and those measuring 12 mm length of implants at all observation points (Mann–Whitney U test; *p*>0.05; Table 4). With regard to a 3.8-mm diameter, no significant differences were observed between implants measuring 10.5 mm in length and those measuring 12 mm in length at R-0, R-1, R-4, and R-8

(Mann–Whitney U test; *p*>0.05; Table 4). However, ISQ values were significantly lower for 10.5-mm implants than for 12-mm implants at R-12 (Mann–Whitney U test; *p*=0.047; Table 4).

Marginal bone loss was lower in the L group than in the M group (Mann–Whitney U test, *p*<0.01); it was 0.27 (0.25, 0.29) mm in the former and 0.68 (0.65, 0.72) mm in the latter at 3 months (median; Q1, Q3).

**Table 3.** Relationship between implant stability quotient (ISQ) values and implant diameter.

		Diameter		
		3.8 mm (n= 77)	4.6 mm (n = 26)	<sup>a</sup> p
		Median (Q1, Q3)	Median (Q1, Q3)	
	<b>Baseline (R-0)</b>	72 (68, 72)	79 (75, 82)	<b>0.001**</b>
	<b>1 week (R-1)</b>	71 (67, 72)	79 (75, 82)	<b>0.001**</b>
	<b>4 weeks (R-4)</b>	69 (65, 70)	75.5 (73, 79)	<b>0.001**</b>
	<b>8 weeks (R-8)</b>	71 (67, 73)	79.5 (75, 82)	<b>0.001**</b>
	<b>12 weeks (R-12)</b>	72 (68, 74)	79.5 (75, 82)	<b>0.001**</b>
		3.8 mm (n= 50)	4.6 mm (n = 22)	
Length		Median (Q1, Q3)	Median (Q1, Q3)	<sup>a</sup> p
<b>10.5 mm</b>	<b>Baseline (R-0)</b>	71 (68, 72)	79 (76, 82)	<b>0.001**</b>
	<b>1 week (R-1)</b>	70 (67, 72)	80 (75, 82)	<b>0.001**</b>
	<b>4 weeks (R-4)</b>	68 (64, 70)	77 (73, 79)	<b>0.001**</b>
	<b>8 weeks (R-8)</b>	70 (66, 73)	79.5 (75, 81)	<b>0.001**</b>
	<b>12 weeks (R-12)</b>	71 (68, 73)	79.5 (75, 82)	<b>0.001**</b>

<sup>a</sup>Mann–Whitney U Test

\*\*p&lt;0.01

**Table 4.** Relationship between implant stability quotient (ISQ) values and implant length

		Length		
		10.5 mm (n= 72)	12 mm (n = 31)	
		Median (Q1, Q3)	Median (Q1, Q3)	<sup>a</sup> p
	<b>Baseline (R-0)</b>	72 (69,76)	70 (68,73)	<b>0.109*</b>
	<b>1 week (R-1)</b>	72 (69,75.5)	70 (69,73)	<b>0.192*</b>
	<b>4 weeks (R-4)</b>	69 (66.5,73.5)	68 (66,71)	<b>0.256*</b>
	<b>8 weeks (R-8)</b>	72 (68.5,75)	71 (68,74)	<b>0.542*</b>
	<b>12 weeks (R-12)</b>	73 (69.5,76)	74 (70,76)	<b>0.719*</b>
		10.5 mm (n= 50)	12 mm (n = 27)	
Diameter		Median (Q1, Q3)	Median (Q1, Q3)	<sup>a</sup> p
<b>3.8 mm</b>	<b>Baseline (R-0)</b>	71 (68, 72)	70 (68, 72)	<b>0.859*</b>
	<b>1 week (R-1)</b>	70 (67, 72)	70 (68, 72)	<b>0.629*</b>
	<b>4 weeks (R-4)</b>	68 (64, 70)	68 (66, 70)	<b>0.476*</b>
	<b>8 weeks (R-8)</b>	70 (66, 73)	71 (68, 74)	<b>0.264*</b>
	<b>12 weeks (R-12)</b>	71 (68, 73)	73 (70, 75)	<b>0.047**</b>

<sup>a</sup>Mann–Whitney U Test

\*p&gt;0.05 \*\*p&lt;0.01

## Discussion

In the present study, we have evaluated the stability of posterior implants with the same macro design placed at two different supracrestal levels according to their collar texture. Implant stability is a prerequisite for successful long-term outcome (7, 8). A deeper understanding of implant stability during the healing period helps clinicians to determine appropriate loading protocols, thus decreasing the risk of failure caused by poor stability. The present study provides a reference for implant stability with regard to 1 mm and 0.3 mm supracrestal placement according to the collar design. We have found equivalent stability for both groups after the initial healing period.

RFA is an objective, noninvasive, reliable, predictable modality for the measurement of implant stability (9). Huwiler et al. (10) found that the ISQ values of successfully placed implants during healing period were between 57 and 70. Sennerby and Meredith (11) observed that implants with an ISQ values higher than 65 could be loaded immediately or early and were less prone to failure. In the present study, both groups showed a median ISQ value higher than 65 during healing, and all implants maintained stability and did not fail during follow-up. Although stability was satisfactory in both groups, the ISQ values at baseline and 1 week after placement were higher for the M group than for the L group. However, this difference disappeared at subsequent time points. Therefore, part of the null hypothesis of the present study was rejected. One explanation for the difference in the initial healing period is the distance between the implant platform and the crestal bone at the time of placement, which was smaller in the M group than in the L group. In other words, the supracrestal collar length was smaller for the M group implants than for the L group implants. An increase in the resistance to lateral movement during initial healing may have increased the stability in the M group. The increased marginal bone loss in the M group may have been responsible for the lack of differences in stability after healing. The healing pattern may also be another explanation. After bone maturation, RFA may not be sensitive to stability differences between groups. It has been shown that ISQ values are directly related to the extent of osseointegration (5). Therefore, monitoring ISQ values also provides valuable information regarding osseointegration. In both groups, the ISQ values were lowest in the fourth week of healing, during which implants are most

vulnerable to failure. Bone resorption and woven bone formation decrease primary stability at 3 and 4 weeks after placement, during which the transition from primary stability to secondary stability occurs. Therefore, ISQ values decrease during this period (12). Nevertheless, no implants were lost during the study period. All implants were loaded 3 months after placement, and even the lowest mean ISQ values for both groups remained above 65. The maximum decrease in ISQ relative to the baseline value was 2–4 units. After 4 weeks, stability began to increase. In the present study, the third set of ISQ measurements was obtained in the fourth week after placement. If these measurements had been obtained in the third week, the decrease may have been slightly lower (5). One explanation for the lack of a wide range of changes in ISQ values is the high ISQ values observed in the initial period. When initial ISQ values are high, the extent of change during subsequent periods is generally low, as opposed to the change when initial ISQ values are low. Accordingly, high initial stability may not show a tendency to increase with time, while lower primary stability will increase and be replaced by developed biological (secondary) stability, a process known as osseointegration (13, 14). Another possible explanation is as follows. When implant surfaces are rough, secondary biological stability is very rapidly acquired; therefore, the lowest ISQ value is not very small, thus masking the actual decrease in mechanical stability (11).

Primary stability corresponds to the time point when resistance to friction between the implant body and the implant recipient site in the bone is achieved. In the present study, although both groups of implants were loaded as per conventional protocols, we can speculate that higher primary stability values fulfill the criteria for early or immediate loading of implants with this specific design (11). The macro design of implants may play an important role in primary stability. The root form of implants and the surgical protocol may result in high primary stability values (15). In the present study, stability during healing was higher for mandibular implants than for maxillary implants. This result is in accordance with the results of many previous articles (16, 17). The bone density in the mandible is greater than that in the maxilla, resulting in a stiffer interface between the bone and implant and, consequently, higher ISQ values (18–20). The reported effects of the implant diameter on ISQ values are inconsistent (21–24). In the present study, the implant diameter was found to

affect implant stability during the entire observation period; stability was lower with a regular diameter than with a large diameter. A greater surface area in wide-diameter implants increases the bone–implant contact surface area, resulting in increased ISQ values (23, 25).

The implant length did not influence the stability before loading when the diameter was neglected. This result is in accordance with the results of previous studies (20, 21, 25). The amount of cortical bone surrounding the implant collar may influence stability to a greater extent than the implant length does (20). Another possible reason is that a difference of 1.5 mm in length between implants may not be large enough to provide significant results. Therefore, we can speculate that the placement of 12 mm implants instead of 10.5 mm implants may not be beneficial for increasing primary and secondary stability. If only regular implants are evaluated, the stability of 10.5 mm regular-diameter implants may be lower than that of 12 mm regular-diameter implants after healing. The use of wide-diameter implants may mask this difference in implant stability during healing between two lengths. Therefore, it can be speculated that regular-diameter implants are more prone to stability changes compared with wide-diameter implants, regardless of the reason being marginal bone loss or the healing pattern. When clinicians are planning to use short implants, they must take precautions related to this expected decrease in stability after healing with the use of wide-diameter implants.

In the present study, we measured the dynamics of integration. Although ISQ values were high immediately after placement during surgery (primary stability), repetitive measurements were required to understand the dynamics of the biological process of osseointegration. Repetitive measurements have been recommended during healing after implant placement to accurately understand the dynamics of healing (26, 27). A single measurement during implant placement (primary stability) may lead to false conclusions. Thus, static measurements must be compared with subsequent measurements. Although RFA is reliable and predictable, four patients were excluded from the study because of a wide range of ISQ values during healing. If repetitive measurements were not performed, these incorrect values may have been overlooked. From these perspectives, we obtained measurements at five time points for all implants in the present study. One limitation of the present study is the lack of RFA measurements after loading. All

restorations were cement retained; therefore, ISQ values could not be measured after loading. Another limitation is the retrospective study design. Patients were not masked or randomized, and the diameter and length of implants were not equally distributed in both groups. The present study failed to address the differences in stability between wide-diameter implants measuring 12 mm in length ( $12 \times 4.6$  mm) and those measuring 10.5 mm in length ( $10.5 \times 4.6$  mm), because the sample size and distribution of these implants were not adequate from a statistical point of view, which could have led to bias. For the same reasons, differences between regular-diameter and wide-diameter implants measuring 12 mm in length ( $3.8 \times 12$  mm vs.  $4.6 \times 12$  mm) could not be addressed. Moreover, all implants were placed in optimal conditions, for example, none were placed at grafted sites. Furthermore, minimally invasive flaps were elevated during surgery.

## Conclusions

Within the study limitations, our results suggest that submerging implant more inside bone may only influence primary stability. Furthermore, the implant diameter and site of placement influence both primary and secondary stability, whereas the implant length does not when the diameter is neglected.

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## Conflict of interest

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