# Evaluating the effect of design and length of implants on primary stability using resonance frequency analysis: An *in vitro* study

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## ABSTRACT

**Evaluating the effect of design and length of implants on primary stability using resonance frequency analysis: An *in vitro* study**

**Background:** Primary stability (PS) is dependent on the length and diameter of the implant, micro-morphology of the implant surface, implant design, surgical procedure, bone quantity, and quality. This study aimed to compare short and standard dental implants according to primary stability in bone type IV using Resonance frequency analysis (RFA) test equipment.

**Methods:** Seventy two dental implants; sandblasting with large grit particles and acid etching (SLA) surface (Dentium®,SimpleLine II, Seoul, Korea), SLActive surface- (Straumann Roxolid®, Basel, Switzerland), Resorbable blast media (RBM) surface- (Implance®, Trabzon, Turkey) with very short (4-mm length), short (6-mm length) and standard dental implants (10-mm length) were placed in bovine cow ribs with bone quality similar to a type IV human bone. RFA was performed to evaluate the primary stability. One-way ANOVA test was used to compare the groups ve different groups were assessed with the post hoc Tukey test.

**Results:** Implant stability quotient (ISQ) measurements of 4-mm and 6-mm length implants were similar however, 10-mm-length implants showed statistically difference inter-groups. SLActive surface in 10-mm-length implant group showed highest ISQ value ($p<0.005$). When primary stability was compared in intra groups, SLA surface and RBM surface implants showed no significant difference, but 10-mm-length of SLActive surface implant showed higher ISQ value than 4-and 6-mm length ($p<0.005$).

**Conclusion:** Implant design and surface characteristics might be also effective in primary stability in very short and short implants and SLActive surface implants may show better primary stability in standard implants.

## KEYWORDS

**Dental implants, *in vitro*, resonance frequency analysis, short implants**

## ÖZ

**İmplant uzunluklarının ve tasarımının implant primer stabilite üzerine etkilerinin rezonans frekans analizi kullanılarak değerlendirilmesi: *İn vitro* bir çalışma**

**Amaç:** Primer stabilite (PS), implantın uzunluğuna ve çapına, implant yüzeyinin mikro morfolojisine, implant tasarımına, cerrahi prosedüre, kemik miktarına ve kalitesine bağlıdır. Bu çalışmanın amacı, çok kısa, kısa ve standard dental implantları Tip IV kemikte primer stabilitelerine göre Rezonans Frekans Analizi (RFA) test ekipmanı kullanarak karşılaştırmaktır.

**Gereç ve Yöntemler:** Yetmiş iki dental implant; Large grit kumlanmış ve asitlenmiş (sandblasting with large grit particles and acid etching, SLA) (Dentium®, SimpleLine II, Seul, Kore), SLActive yüzey- (Straumann Roxolid®, Basel, İsviçre), Resorbable blast media (RBM) yüzey- (Implance®, Trabzon, Türkiye) çok kısa (4 mm uzunluğunda), kısa (6 mm uzunluğunda) ve standard dental implantlar (10 mm uzunluğunda) insan tip IV kemiğine benzer kemik kalitesine sahip sığır türü kaburgaya yerleştirildi. Grupları karşılaştırmak için tek yönlü ANOVA testi kullanıldı ve farklı gruplar post hoc Tukey testi ile değerlendirildi.

**Bulgular:** Dört ve 6 mm uzunluktaki implantların İmplant Stabilite Katsayısı (Implant stability quotient, ISQ) ölçümleri benzerdi, ancak 10 mm uzunluktaki implantlarda gruplar arasında istatistiksel olarak anlamlı fark gözlendi. On mm uzunluğundaki implant grubunda SLActive yüzey en yüksek ISQ değerini gösterdi ($p<0.005$). Primer stabilite grup içinde karşılaştırıldığında, SLA yüzey ve RBM yüzey implantlarda önemli bir fark gözlenmezken 10 mm uzunluktaki SLActive yüzey implantı 4 ve 6 mm uzunluğundan daha yüksek ISQ değerine sahip bulundu ($p<0.005$).

**Sonuç:** İmplant tasarımı ve yüzey özellikleri de çok kısa ve kısa implantlarda primer stabilitede etkili olabilir ve SLActive yüzey implantları, standart implantlarda daha iyi primer stabilite gösterebilir.

## ANAHTAR KELİMELER

**Dental implantlar, *in vitro*, kısa implantlar, rezonans frekans analizi**

The use of implant rehabilitation of partially or fully edentulous patients provides an acceptable prosthetic treatment option with high survival and success rates.[1] The success of the implant procedures depends on many different factors including patient characteristics, surgical technique, implant design, implant primary stability and osseointegration.[2,3] Primary stability (PS), essential for osseointegration defined as the absence of mobility in the bone bed after implant placement that induces proliferation and differentiation of the

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osteoblast cells, and inhibits fibrous tissue invasion and encapsulation.[4] It is mainly dependent on the length and diameter of the implant, micro-morphology of the implant surface, implant design, surgical procedure and primarily functions to inhibit micromotion of the implant, bone quantity, and quality.[5-8]

The relation between the length of the dental implant and dental implant PS has been discussed for a long time. Different lengths of a dental implant are between 4 mm and 15 mm. Implant lengths commonly used are between 8 mm to 15 mm, which is similar to the natural root lengths.[9] Implants that are 4.0 mm in diameter and 9.0 mm or more in length are accepted the optimal implant to be selected in type IV bone for reducing stress.[10]

The macro-geometry of the implant may directly effected PS, as diameter, length, shapes, thread depth, thread helix angle and thread pitch established the primary bone/implant interaction and are essential for regulating the osseointegration process.[11,12]

Actually, thread pitch plays a specific role in achieving PS and optimum stress production. Using an implant with deeper threads, and decreased thread pitch enhance primer bone-implant anchorage.[12] Tapered implants are inserted routinely with drills that span a range of different diameters to form a hole in the bone that is of suitable depth and diameter to place an implant. The essential degree of compressive force is associated with following factors: the degree of taper of the implant, the relationship of the final drill diameter to the maximum diameter of the implant, and the mechanical properties of the bone itself.[14] In a randomized controlled clinical trial, Markovic et al[15] explained that the self-tapping implants caused higher PS values than non-self-tapping implants after drilling. Sennerby et al[16] concluded that tapered implants had higher PS using different drilling protocols in soft bone compared with parallel implants.

Some surgical procedures, including maxillary sinus lift, the use of onlay graft blocks, transposition of the inferior alveolar nerve, may increase patient distress, the possibility of injuries of gentle structures and the time of the prosthetic procedures beginning. Therefore, in recent years short dental implants have been preferred as a suitable alternative to the rehabilitation of regions with insufficient bone height.[17, 18] Studies have demonstrated that the success rate of short implants is similar to that of standard conventional implants and dependent on obtaining PS.[19, 20]

Resonance frequency analysis (RFA) is a non-invasive, easily feasible approach of measuring PS that can be used repeatedly in the intra-operative and post-operative settings.[21,22] The measured resonance frequency (RF) of a magnetic peg which is attached to the implant is transformed to a numeric value, the so-called implant stability quotient (ISQ) which ranges from 1 (low stability) to 100 (high stability).[23] The purpose of the present *in vitro* study was to compare the very short, short and standard dental implants according to the PS in bone type IV based on resonance frequency analysis using RFA test equipment.

## MATERİAL AND METHODS

### Implants

Three different implant lengths were used; 4 mm, 6 mm and 10 mm; all implants had the same diameter (4.8 mm). There were seventy-two dental implants; SLA (sandblasting with large grit particles and acid etching) surface- Dentium® (SimpleLine II, Seoul, Korea), SLActive surface- Straumann Roxolid® SLActive® (Basel, Switzerland), RBM (Resorbable blast media) surface- Implance® (Trabzon, Turkey) with very short (4-mm-length), short (6-mm-length) and standard dental implants (10-mm-length) (Figure 1).

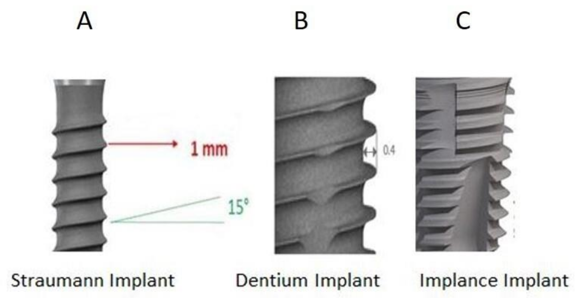


**Figure 1.**

Characteristics of thread design used in this study
**A)** SLActive surface- Straumann Roxolid® SLActive® (Basel, Switzerland)
**B)** SLA (sandblasting with large grit particles and acid etching) surface- Dentium® (SimpleLine II, Seoul, Korea)
**C)** RBM (Resorbable blast media) surface- Implance® (Trabzon, TURKEY)

### Experimental procedures

Eight fresh cow ribs originated from the same animal were chosen from a butcher's shop for the experimental protocols. Computer tomography (CT) was used to assess bone quality (GE Medical Systems, LLC; Waukesha, WI, USA). Bone quality from each cow ribs was classified in HU according to Misch and Kircos.[24] The ribs served as a model of type IV human jaw bone because of their macroscopic combination of cortical and medullary bone.

The implants were inserted into the working area by a single operator following the sequence of surgical drills recommended by the manufacturer. After finishing the implant site drilling, all implants were inserted with a torque of 35 Ncm. The implant placement was nearly symmetrical in all implant preparation. During the drilling procedures, care was taken to avoid the potential for overheating, the sharp bone drills were used and were not used in a manner where excessive drill speed or pressure was involved. Saline was used for irrigation of the implant site constantly to decrease the amount of heat generated.

For the RFA measurements, suitable transducer (Smartpeg) was vertically connected to the longitudinal axis of the cow rib block. The probe of a magnetic resonance frequency analyzer (Penguin®, Penguin Integration Diagnostics, Sweden) was held 1 mm from the peg at a 90° angle (Figure 2). Three measurements were taken for each of the implants from four different sites (buccal, lingual, mesial, and distal sides) and the mean of ISQ was recorded as one value. The ISQ is saved as a number between 1 and 100, the highest degree of stability is represented with 100.

**Figure 2.**

Correct positioning of the probe of a magnetic resonance frequency analyzer (Penguin®, Penguin Integration Diagnostics, Sweden)

## Statistical analysis

Statistical analysis was applied using SPSS® 21.0 software (SPSS, Chicago, IL, USA). Shapiro-Wilk test was used to stated whether the data were normally distributed or not and all data showed normal distribution. Descriptive values of the measurements were summarized as mean±SD. One-way ANOVA test was used to compare the groups ve different groups were assessed with the post hoc Tukey test. The results were evaluated at 95 % confidence interval, at a significance level of 0.05.

## RESULTS

In the present study, for 4-mm-length (very short) implants, the mean ISQ value in SLA surface group was 72.62 ± 6.75, 73.75 ± 3.19 in RBM surface group and 77.50 ± 3.66 in the SLActive surface group. For 6-mm-length (short) implants, the mean ISQ values in RBM surface group was 75.12 ± 7.56, 76.87 ± 3.04 in the SLA surface group, and 78.25 ± 5.31 in SLActive surface group. However, for 10-mm-length (standard) implants, the mean ISQ value in RBM surface group was 76.25 ± 8.04, 78.12 ± 2.99 in SLA surface group and 86.00 ± 5.18 in the SLActive surface group. While no statistical difference was shown in ISQ measurements of 4-mm and 6-mm length implants, 10-mm-length implants showed statistical difference according to different implant system groups ($p = 0.018$, Table 1). Ten-mm-length implant in SLActive surface group (4.8/10 mm) showed the highest ISQ value ($p < 0.005$) (Table 1).

**Table 1.**

**The average ISQ values of studied implants having three different lengths (4, 6, 10- mm-long) between groups**

| Group | 4mm (very short) | | 6mm (short) | | 10mm (standard) | |
|---|---|---|---|---|---|---|
| | Mean + SD | P | Mean + SD | P | Mean + SD | *p* |
| SLA surface | 72,625 ± 6,75991 | 0.130 | 76,875 ± 3,04432 | 0.596 | 78,125 ± 2,99702 | 0.018* |
| SLActive surface | 77,5 ± 3,6645 | | 78,25 ± 5,31171 | | 86 ± 5,18239 | |
| RBM surface | 73,75 ± 3,19598 | | 75,125 ± 7,56755 | | 76,25 ± 8,04896 | |

*SLA surface: Dentium® (SimpleLine II, Seoul, Korea), RBM surface: Implance® (Trabzon, Turkey), SLActive surface: Straumann Roxolid® SLActive® (Basel, Switzerland), Min: Minimum, Max: Maximum, SD: Standard Deviation*
**: The mean difference is significant at the 0.05 level.*

When PS is compared in intra groups, RBM surface group and SLA surface group implants showed no significant difference according to their different lengths, but in SLActive surface group 10-mm-length implant showed higher ISQ value than 4- and 6-mm-length ($p < 0.005$) (Table 2).

**Table 2.**

**The average ISQ values of studied implants having three different lengths (4, 6, 10-mm-long) within groups**

| Group | Implant length (mm) | n | Mean ± SD | p |
|---|---|---|---|---|
| SLA surface | 4 | 8 | 72,625 ± 6,75991 | 0,065 |
| | 6 | 8 | 76,875 ± 3,04432 | |
| | 10 | 8 | 78,125 ± 2,99702 | |
| SLActive surface | 4 | 8 | 77,5 ± 3,6645 | 0,003* |
| | 6 | 8 | 78,25 ± 5,31171 | |
| | 10 | 8 | 86 ± 5,18239 | |
| RBM surface | 4 | 8 | 73,75 ± 3,19598 | 0,755 |
| | 6 | 8 | 75,125 ± 7,56755 | |
| | 10 | 8 | 76,25 ± 8,04896 | |

*SLA group: Dentium® (SimpleLine II, Seoul, Korea), RBM surface: Implance® (Trabzon, Turkey), S: Straumann Roxolid® SLActive® (Basel, Switzerland), SD: Standard Deviation, Min: Minimum, Max: Maximum, N: Number of implants*
**: The mean difference is significant at the 0.05 level.*

## DISCUSSION

While short implants are considered to be a good option for resorbed maxilla and mandible, there are various opinions in the literature. While it has been explained that the short implants exhibited a higher failure rate than standard implants[25], some investigators stated a survival rate for short implants ranging from 87.5 %-100 %.[26-28] Primary implant stability is the most critical clinical goal to be achieved at the time of implant insertion.

This study has assessed the effect of different design and surface characteristics of implants on PS by using both different implant length and same diameter implants with using RFA in *vitro* animal model.

In our study, no statistical difference was shown in ISQ measurements of 4-mm and 6-mm length implants, however, 10-mm-length implants showed statistical difference according to different implant system groups. The reasons for these results are thought to be the differences between thread design, thread pitch, and thread depth of the different implant system. SLA surface group implants have double-threaded tapered body design and have a thread pitch of 0.4 mm. For SLActive surface group implants, the thread pitch on the standard plus implant measures 1.0 mm and SLActive surface Bone Level implants have a cylindrical outer contour and a thread pitch of 0.8 mm that tapers off in the coronal part of the implant. RBM surface group implants have a hybrid design, which is a combination of straight and tapered implant designs and semi-aggressive groove design. In a systematic review, it is concluded that tapered, long implants with wide implant diameter and more threads provide good PS.[29] Also, Park et al[30], compared the PS in different taper body implants with various design by measuring the ISQ and the removal torque value. They found that without being engaged to the inferior cortical wall fixtures had PS affected by implant types and in poor quality bone, under-drilling enhanced PS.[30] In our study, according to the manufacturer's recommendation in the SLActive surface group implants, last step drill was not carried out and implant fixture was installed with self-tapping effect. This technique may increase the ISQ value and under-drilling could be helpful to achieve PS in the poor quality bone.

Recent studies have suggested that short implants have been as successful as conventional implants 10-mm-long or more.[31,32] Also, some studies reported that short implants gave an acceptable outcome and surgical success was not varied relative to implant length.[33,34] The 12 months followed up study that assessed the success rates of short and standard implants inserted in fully edentulous mandibles demonstrated similar success rates for these both types of implants and short implants were presented as an alternative for cases of severe bone resorption in both maxilla and mandible.[19] However, the previous study has suggested that the use of short implants with length less than 8 mm (4–7 mm) had a high failure rate compared to standard implants and reported that because of presenting greater risks for implant failures short implants should be used with caution when compared to standard implants.[25] According to our results, we did not find a significant difference in ISQ values in very short and short implant groups. One explanation may be that all implants were inserted in type 4 bone of bovine ribs specimen, but cortical bone seems to influence more remarkably on a difference of RFA values. Because of the high density, cortical bone has a higher elastic modulus than cancellous bone.[35,36]

A study reported that increased the implant length enhances the dental implant PS in the poor quality bone. In that study, for the implant length 15 mm, the mean ISQ value was 73.47, which was significantly different more than that implant length 8 mm and 13 mm.[37] Recent studies showed that in high-density bone the implant length did not show a significant difference in PS, whereas in low-density bone the long length implants caused an increased in PS.[38,39] Probably, these differences are because of the geometry of the implant body.[40,41] Thus, Möhlhenrich et al. demonstrated that implant length effects PS, but only for bone qualities D1–D3, no effects were occurred for implants in D4 type bone.[42] In our study, all implants in the groups were placed in the D4 type animal bone, and both in RBM and SLA surface implant system, standard implants had higher ISQ values than very short and short groups, but this was not statistically significant. Besides, in SLActive surface implants, ten mm length implants presented higher PS than 4 and 6-mm-length implants. This can be explained by the fact that the implant design and surface characteristics are effective in PS. Also, implant surface area in bone may be important in PS.

Resonance frequency analysis (RFA) was preferred because it is a noninvasive, clinically proper method that can be used repeatedly for quantitative assessment of implant stability during and after operation, and the ISQ values measured can be compared independently of the implant system used.[15] Studies found that both RFA and insertion torque measurements are important methods to determine implant stability and give precious knowledge about implant stability by evaluating positive correlation between them.[43,44] Primary stability, an essential for osseointegration resulting from the mechanical interaction between bone tissue and the implant during surgical placement, may be affected by the surface roughness.[7] Various techniques have been used to change the surface properties of dental implants. Recently, the SLA surface and the RBM surface are the two major subtractive surfaces in clinically used.[15] Dental implants used in this study have SLA surface (Dentium®), SLActive (Straumann®) and RBM surface (Implance®). SLA surface is created first by sandblasting with large grit particles then followed by acid etching to remove the remaining particles and further increase the roughness. The SLA surface has surface average roughness (Sa 1.78 µm).[45] RBM surface is constituted through propelling resorbable coarse bioceramics (calcium phosphate) particles on titanium metal substrate followed by passivation process aiming to increase the level of roughness and increased the osseointegration capability of the implant.[46] Some authors suggested that the SLA surface have a compensating influence in areas with poor bone quality through the enhanced bone-implant-contact which might increase the survival rate at such area compared to less rough RBM surface particularly during initial of osseointegration.[46] Recently SLActive(®) titanium surface has been designed to enhance bone apposition.[47] Rupp et al.,[48] explained that SLActive implant has a higher surface energy and is more hydrophilic than the SLA implant. These surface characteristics are vey important to facilitate a stronger cell reaction and bone tissue response in the early phase of bone healing.[49] The SLActive implant has a greater bone-to-implant contact (BIC) at 2 and 4 weeks compared to the SLA surface. [50] Elkhaweldi et al. have reported that geometrically same implants with whether RBM or SLA surface had as good as survival rates at least in the short term, and the SLA surface appeared to be superior in the posterior maxilla with poor bone density.[46] In this study, SLActive surface implant showed better ISQ value in PS for 10-mm-length implants with the same diameter when compared inter-groups. This can be explained as follows, the macro-geometry of the implant might increase the primary bone/implant interaction.

An experimental study involves some limitations, such as the quality of bone in an area other than the oral cavity, as well as lack in vascularization. However, an experimental study on which each parameter is controlled would make it possible to get a clear picture derived from the result. Also still, there is no evidence for a universally “critical” ISQ value, under which implants are not primarily stable. ISQ value should be defined for each implant system.

## CONCLUSION

Within the limitations of the present study, it has been demonstrated that higher ISQ values were reached using the SLActive implant system with 10-mm-length implants, a fact that indicates higher primary stability. However, primary stability as measured by RFA was similar for the 4-mm and 6-mm-length implants regardless of the tested implant system. Long term data with a larger number of implants and different experimental and clinical studies are necessary to confirm these *in vitro* results.

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