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The effect of shape, length and diameter of implants on primary stability based on resonance frequency analysis

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ABSTRACT

Background: The aim of this *in vitro* study was to evaluate the effect of shape, diameter and length of implants on their primary stability based on resonance frequency analysis.

Materials and Methods: Replace select tapered and Branemark MK III implants were selected. Each of these two selected groups was divided into nine subgroups based on the implant length (IL) (short, medium and long) and the implant diameter (ID) (narrow platform [NP], regular platform [RP] and wide platform [WP]). Five implants were assigned to each of the nine subgroups. Implants were placed in artificial bone blocks with bone quality similar to D3 bone. Immediately after the implant placement, its primary stability was measured using Osstell Mentor equipment. *T*-test and Tukey's honest significant difference *Post hoc* were performed for data analysis. Statistical significance was defined at $P < 0.05$.

Results: Replace select system showed significantly higher primary stability compared to the Branemark system, when using the short implants for all three diameters ($P \leq 0.004$). However, in medium length implants there were no significant differences between the two implant systems ($P \geq 0.31$). In long implants, only when the NP and RP implants were used, the Replace Select system showed significantly higher primary stability compared to the Branemark system ($P = 0.000$). In the replace select system, long implants had a significantly higher primary stability compared to medium and short length implants ($P \leq 0.003$). In the NP and RP Branemark implants, short implants showed significantly lower primary stability compared to medium and long implants ($P \leq 0.002$). However, in WP Branemark implants, primary stability increased significantly with increasing the IL from short to medium and from medium to long ($P = 0.000$). There were also significant differences between NP and the two other wider implants in both systems ($P = 0.000$).

Conclusion: The use of tapered implants is recommended, especially, when the use of short implants is necessary. The use of RP implants is also preferred to WP implants, because thicker bone wall will remain in place when applying RP implants. Furthermore, no significant difference was observed between RP and WP implants.

Key Words: Dental implants, implant geometry, osseointegration, primary stability, resonance frequency analysis

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INTRODUCTION

One of the factors involved in the success of osseointegration and the long-term success of implants is the implant primary stability, which is defined as the biometric stability of the implant immediately after its placement within the bone.[1] If the primary stability of an implant is not sufficient, the healing process will be disrupted due to micro-motions, because a fibrous tissue will form and osseointegration will not take place.[2] A non-invasive and reproducible test for primary stabilities, which is easy to carry out, is the use of Osstell Mentor test equipment based on resonance frequency analysis (RFA). In this system, the primary stability of the implant is defined in the range of 1-100 based on implant stability quotient (ISQ), i.e., higher ISQ values indicate higher primary stability.[3]

A key factor for the implant primary stability is the bone-implant contact[4] and thus, factors such as implant shape, length and diameter that cause an increase in the contact area between the implant and bone may increase the implant primary stability. Furthermore, the quality of bone bed plays an important role in shaping the bone-implant contact area.[5]

Based on the data available, an increase in bone quality causes the primary stability of the implant to increase.[4,6-8] Therefore, it is essential in soft bones to achieve sufficient primary stability through other determining factors.[2]

Reports published on the relationship between the implant primary stability and its shape (parallel or tapered), length and diameter are controversial.[5] Ostman *et al.*,[7] reported that an increase in implant length (IL) caused the ISQ to decrease; however, the ISQ increased with an increase in implant diameter (ID). They also found that tapered implants exhibited lower ISQ values compared to parallel implants. Bilhan *et al.*,[2] carried out a study on the effect of implant shape on the ISQ and reported results similar to those reported by Ostman *et al.*,[7] However, in Bilhan *et al.* study[2] differences in IL and diameter did not result in significant differences in implant primary stability. In a clinical trial by Rokn *et al.*,[9] IL was found to have no significant effect on the ISQ; however, an increase in ID improved the primary stability of the implant. Contrary to the results reported by Ostman *et al.,*[7] and Bilhan *et al.*,[2] Rokn *et al.*,[9] reported higher ISQ values in tapered implants in comparison with parallel implants.

In clinical trial studies, there is a tendency to apply short, wide and tapered implants in the cases of insufficient bone height or low bone quality. This tendency may cause errors to the results of studies on the effect of geometrical factors on the implant primary stability.[7,10] Therefore, it is essential to carry out *in vitro* studies to avoid the effect of bone condition on the choice of the implant to be applied for treatment.

The aim of this *in vitro* study was to evaluate the effect of implant shape (conical or cylindrical), length and platform diameter on implant primary stability based on RFA by using Osstell Mentor test equipment.

MATERIALS AND METHODS

In order to determine the primary stability of implants and to evaluate the effect of IL, ID and implant shape on its primary stability, two implant groups were selected:

Group 1: Replace select tapered implants (Nobel Biocare, Gothenburg, Sweden) (n = 45). In this group implants were of tapered screw type.

Group 2: MK III Branemark implants (Nobel Biocare, Gothenburg, Sweden) (n = 45). In this group implants were of cylindrical screw type.

The surfaces of both implants were similar to each other and were of TiUnite type. Each group was divided into three subgroups based on the IL of short (10 mm), medium (13 mm) and long (16 mm in replace select and 15 mm in Branemark). Each subgroup was also divided into 3 subgroups as narrow platform (NP), regular platform (RP) and wide platform (WP) of 3.4 mm, 4.3 mm and 5 mm in diameter, respectively. Therefore, each group consisted of 9 subgroups and 5 implants were tested in each subgroup.

Implants were placed in artificial bone blocks (Dentium Implant Institute, Seoul, Korea) with an osseous quality similar to D3 bone. In each case, the entire implants length was placed in the bony block. The surgical protocol was followed as recommended by the manufacturer. Immediately after the implants were placed in the bony blocks, their primary stabilities were measured based on RFA using the Osstell Mentor test equipment (Osstell™ mentor; Integration Diagnostics AB, Sweden) and the ISQ index was also recorded.

Statistical analysis

The statistical software package used for data analysis was SPSS/11.5 (SPSS, Chicago, Ill). *T*-test and a Tukey's honest significant difference (HSD) *Post hoc* were used to compare ISQ values. Statistical significance was defined at $P < 0.05$.

Univariant analysis of variance (ANOVA) was performed to examine if there existed any significant interaction between variables. Since the interaction tests were statistically significant, *T*-test and Tukey's HSD *Post hoc* were performed for further data analysis. *T*-test was used to evaluate the effect of implant shape on ISQ. Tukey's HSD *Post hoc* was used to compare the effects of the IL and ID.

RESULTS

Table 1 presents the mean values and standard deviations of the measured ISQ values in the study groups. The highest and the lowest mean values measured were 69.8 ± 1.48 and 39.2 ± 2.77, for the WP Branemark implants with a length of 15 mm and NP Branemark implants with a length of 10 mm, respectively.

Implant geometry and ISQ

For short implants (10 mm) and for all three different IDs (WP, RP and NP) tapered implants showed significantly higher ISQ values compared to cylindrical implants ($P \leq 0.004$).

In medium length implants (13 mm) with equal diameters there were no significant differences between the two implant systems (IS) under study ($P \geq 0.31$).

In long implants (15 mm in Branemark system and 16 mm in Replace select system) with RP and NP diameters, tapered implants had a significantly higher ISQ values compared to cylindrical implants ($P = 0.000$). However, with the WP diameters there were no significant differences between the two IS ($P = 0.54$).

IL and ISQ

In the tapered implants, in all three diameter, 16 mm implants had significantly higher ISQ values compared to 10 and 13 mm implants ($P \leq 0.003$); however, there were no significant differences in ISQ values between 10 mm and 13 mm implants ($P \geq 0.68$).

Table 1: Means and standard deviations of ISQ values in the groups under study

IS	ID IL	WP	RP	NP
Replace select	10	63.2±1.48	60.4±2.96	48.8±2.58
	13	62.4±2.07	60.2±0.83	49.8±1.09
	16	69.0±2.64	69.0±1.87	60.0±1.58
Branemark	10	53.4±3.87	51.4±3.97	39.2±2.77
	13	61.4±0.54	59.2±1.92	49.8±1.92
	15	69.8±1.4	61.2±1.92	50.6±2.40

ISQ: Implant stability quotient; RP: Regular platform; NP: Narrow platform; WP: Wide platform; IS: Implant system; ID: Implant diameter; IL: Implant length (mm)

In the cylindrical implants with WP, 15 mm implants had higher ISQ values compared to 13 mm implants and 13 mm implants had higher ISQ values compared to 10 mm implants ($P = 0.000$). In cases of cylindrical RP and NP implants, 15 mm implants had higher ISQ values compared to 10 mm implants ($P = 0.000$). This difference was also observed between 13 mm and 10 mm implants ($P \leq 0.002$). However, there were no significant differences between 13 mm and 15 mm implants ($P \geq 0.51$).

ID and ISQ

For the tapered implants, no significant difference was observed between WP and RP implants of the same length ($P \geq 0.77$); however, the ISQ was significantly higher compared to when NP implants were utilized ($P = 0.000$).

In the cylindrical implants, with 10 mm and 13 mm implants there were no significant differences in ISQ values between WP and RP implants ($P \geq 0.11$). However, there were significant differences between NP and two other wider implants ($P = 0.000$). With 15 mm implants, WP implants had significantly higher ISQ values compared to RP and NP implants ($P = 0.000$) and RP implants had significantly higher ISQ values compared to NP implants ($P = 0.000$).

DISCUSSION

Primary stability of implants, which is a factor of bone to implant contact,[4] is an important factor in the success of implant treatment, especially, when immediate loading is planned.[1] Higher rate of implant treatment failure has been reported in cases of implant placements in low-quality bone,[11] where the cortical bone is narrow and the density of bony trabeculae is low.[2]

In such cases, attempts are made to increase primary implant stability by changing other factors involved, such as geometrical features of implant.[7]

In the current study, the effect of implant shape, length and also implant platform diameter on implant primary stability was evaluated in D3-type artificial bone blocks. The results proved the influence of these three factors on the implant primary stability.

Based on the results of the current study, with the use of short implants, tapered implants exhibited a better primary stability compared to parallel implants. This is consistent with the result of García-Vives *et al.*,[8] who compared 10-mm conical and parallel implants in type IV bone and also with a study by O'Sullivan *et al*.,[12] on human cadaver, in which tapered implants exhibited a higher RFA compared to parallel implants in type IV bone type. Similarly, in a clinical trial by Friberg *et al*.,[13] conical implants exhibited higher primary stability compared to parallel implants in low-quality bone. This difference was attributed by Rokn *et al*.,[9] to the fact that tapered implants exert more lateral compressive force on the bony walls surrounding the implant during implant placement. Therefore, in areas with inadequate bone height, where a short implant should be applied, the use of tapered implants is recommended.

On the other hand, some studies have reported results contrary to the results of the current study. In a study by Bilhan *et al*.,[2] cylindrical implants exhibited a higher RFA compared to tapered implants. This difference was attributed to a lack of conformity of the apical end of the implant with the drilled cavity; however, in the current study the drill used for tapered implants was also tapered and therefore, such a problem did not exist in the current study. A clinical trial by Ostman *et al*.,[7] yielded results similar to the results of a study carried out by Bilhan *et al*.,[2] Ostman *et al*.,[7] stated that they had placed tapered implants only in type IV bone; therefore, the compromised bone might have had an effect on the stability of implants.

In the current study, when 13-mm implants with equal diameters were used, the implant shape did not show to have any effect on the primary stability of implant. Therefore, 13-mm implants can be considered as implants with the most appropriate lengths and this is confirmed by the fact that they are the most commonly used implants.

In the current study, there was an increase in implant stability with an increase in IL in parallel implants. However, the difference was not significant between implants of 15 mm and 13 mm long, neither in NP nor in RP implants. Long tapered implants exhibited higher primary stability compared to shorter implants with the same diameter. Winter *et al*.,[4] used a finite element model and reported that in bone with low stiffness a linear increase in IL was associated with a non-linear increase in ISQ. However, many studies have not suggested a relationship between an increase in IL and an increase in implant stability.[2,6,9,14,15] In a study by Merheb *et al*.,[16] IL and diameter, when considered as single parameters, did not exert any effect on stability; however, when stepwise multiple regression model was used both parameters were effective. Furthermore, the thickness of the vertical plate was reported by Merheb *et al*.,[16] as a possible confounding factor. González-García *et al*.,[17] reported that since more forces are concentrated in the coronal area, ID have greater influence on the support of the occlusal forces compared to its length.

In the current study, the ID was found to have an impact on implant primary stability. In this context, in both tapered and parallel implants of long, medium and short lengths, NP implants exhibited less primary stability compared to wider implants. The primary stability for RP and WP implants with identical lengths was the same as each other except for the WP parallel implants with a length of 15 mm which demonstrated significantly higher primary stability compared to RP implants with 15 mm length.

According to Ostman *et al.,*[7] since wider implants are more appropriately engaged with the buccal and lingual cortical plates, they exhibit more primary stability. In a study by Rokn *et al.,*[9] Nobel Biocare Replce™ implants exhibited an increase in implant stability with an increase in the platform width; however, in a study by Bilhan *et al*.,[2] no significant differences were observed in primary stability of implants of 3.8 mm and 4.6 mm in diameter.

Lachman *et al*.,[5] evaluated the effect of implant geometry on implant primary stability and reported that implants of more than 4 mm in diameter do not exhibit significant differences. This result is in accordance with the results of the current study. Therefore, RP implants are recommended because they do not exhibit any differences in primary stability from WP implants in most cases. Furthermore, more residual bone remains around RP compared to WP implants after drilling, which may have a positive effect on implant longevity.

Within the limitation of the current study, which is the difference between the required *in vitro* environment and the clinical conditions, such as the lack of blood supply to the bone under study it can be concluded that:

1. In cases, in which bone height is not adequate and short implants should be used, use of tapered implants is recommended.
2. The primary stability of tapered implants is higher than that of parallel implants regardless to the IL and diameter.

3. An increase in IL from medium to long in tapered implants results in a higher primary stability. However, in parallel implants this change does not increase primary stability except for WP implants.
4. Implants of 13 mm long with three different diameters can provide an appropriate primary stability regardless of implant shape.
5. Primary stability of WP implants was not different from that of RP implants and since less bone is removed with RP implants during the drilling for implant placement, thicker bone will be left in place and therefore, the use of RP implants may have a positive effect on implant longevity.

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