Influence of the Localization of Frontal Bone Defects on Primary Stability Values of 2 Different Implant Designs: An *In Vitro* Study

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Objectives: *The aim of this study was to determine the influence of different frontal bone defect localizations on primary stability values of 2 different implant designs.*

Materials and Methods: *Eight cow rib segments were prepared before implant installation, as 2 segments with coronal, 2 with middle, and 2 with apical defects and 2 with control. Thirty-two cylindrical and 32 tapered implants were placed in the remaining 4 segments. Implant stability measurements were performed using electronic percussive testing and resonance frequency analysis.*

Results: *No significance was detected between the stability values of the 2 implant designs except the implant stability quotient (ISQ) of control groups. The tapered implants control group showed significantly higher lateral ISQs compared with cylindrical implants ($P = 0.033$). For both implant types, stability values were significantly lower in coronal defects ($P < 0.01$). No significant differences were detected in other defect types.*

Conclusion: *Within the limitations of this study, it may be concluded that coronal defects may influence primary stability negatively, compared with middle and apical defects. Although statistically not significant, coronal defects caused lower primary stability values with the tapered design compared with parallel design. (Implant Dent 2017;26:87–94)*

Key Words: dental implant, electronic percussive testing, resonance frequency analysis, defect localization

The interaction between bone and implant plays an essential role in the osseointegration and long-term clinical success of dental implants.[1,2] This interaction has to be firm and stabile both after implant surgery, which is referred as primary stability, and during and after the healing process is named as the secondary stability.[3] Cortical bone is the main structure that provides the implant stability. Primary stability depends on the mechanical engagement with this cortical bone[4] and several other factors, such as the quality and quantity of the bone, the design and the material composition of the implant (shape, geometry, length, diameter, and surface) as well as the surgical technique.[5–7] There are various methods used for measuring primary implant stability as invasive research methods and noninvasive clinical methods. Among these, resonance frequency analysis (RFA) and electronic percussive testing (EPT) are preferred for their superior reliability, repeatability, and noninvasive features.[8–11] Different implant designs have been created to achieve good primary stability especially in bone types presenting reduced quality and quantity by altering surface characteristics and/or modifying the geometric design.[12] Tapered implants enhance primary stability by providing pressure on the coronal cortical bone regions, whereas cylindrical implants use middle and apical region of the bone for gaining stability.[13,14] Previous studies have shown that primary stability can be improved using a tapered implant design.[12,14] When bone quality is considered particularly poor, a tapered implant instead of a parallel implant is preferred because of the compression effect on denser cortical bone.[15] The

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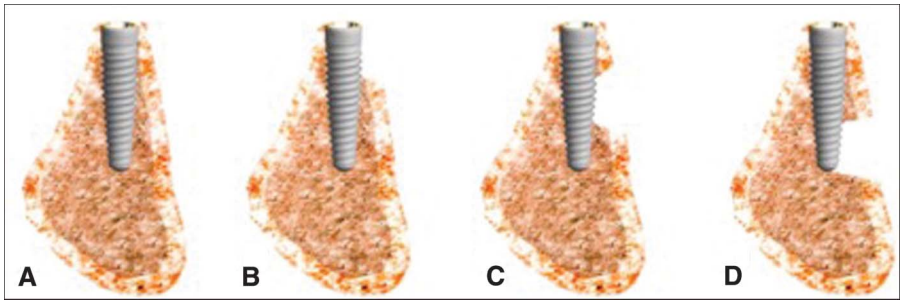

Fig. 1. Figure showing the 4 subgroups of both the implants. **A**, Control group; **B**, coronal defect group; **C**, middle defect group; **D**, apical defect group.

bone quantity is another important factor for primary stability and depends on many factors. In some cases, bony defects like dehiscence and fenestration may occur in cortical plates owing to the surgical techniques, anatomical features of the surgical site, or the differences of the bone resorption patterns.[16] It is not clear that the presence of periimplant bone defects affects implant stability by impairing bone quantity.[17–20] It has been considered that implant design and the location of the defects might also be important for primary stability. However, in the current literature, there is not enough evidence for the effect of localizations of frontal bone defects on primary stability and the implant design used.

This *in vitro* study was conducted to investigate the effect of tapered and cylindrical implant designs on primary stability in different frontal bone defects and to assess the influence of the localizations of these defects on primary stability using EPT and RFA.

Fig. 2. The defects which had a size of 4 mm vertically, 4 mm horizontally, and 2 mm sagittally were simulated. Defects were created only on the front side of the rib segment.

MATERIALS AND METHODS

Specimen Preparation

Fresh cow ribs with similar properties were selected from the butcher shop. The segments of cow ribs having thick cortical bone surrounded by wide trabecular bone were selected for specimen preparation. The selected 8 rib segments were divided into 2 main groups (group C and group D). Cylindrical implants (NobelParallel Conical Connection; Nobel Biocare, Gothenburg, Sweden) were placed in 4 segments and named as group C. Tapered implants (NobelReplace Conical Connection RP; Nobel Biocare) were placed in the remaining 4 segments and named as group T. All the implants placed were 13 mm long and 4.3 mm wide. For each implant design, implant beds were prepared following the drilling protocol recommended by the manufacturer.

Four subgroups were produced from each of these 2 main groups categorizing the prepared defected areas as follows: coronal, middle, apical, and a control group without any defect (Fig. 1). Defect sizes were determined to be approximately one third of the implant size. Rib segments were prepared to mimic alveolar bone contours and angulations to form each type of defect before implant placement. The crests of rib segments were tapered for coronal defects. An hourglass configuration was created on the rib segments for middle defects, and the bases of the segments were tapered for apical defects using a carbide round bur with a diameter of 2 mm. To prepare these defects, guide points were first marked on the rib segments after measuring with a caliper. The defects which had a size of 4 mm vertically, 4 mm horizontally, and 2 mm sagittally were simulated in the ribs using a round bur with a diameter of 2 mm (Fig. 2). These defects were created only on the front side of the rib segments to surround the implants with bony walls except the defect site.

For group C, 8 cylindrical implants were placed into each of the 3 prepared and 1 unprepared ribs with a distance of 10 mm between the center of 2 adjacent implants. Thus, a total number of 32 cylindrical implants were placed. Four subgroups were formed as follows: coronal C group, with a defect located in the coronal one third of the front side of the implant (n = 8); middle C group, with a defect located in the middle one third of the front side of the implant (n = 8); apical C group, with a defect located in the apical one third of the front side of the implant (n = 8); and control C group, without any defects

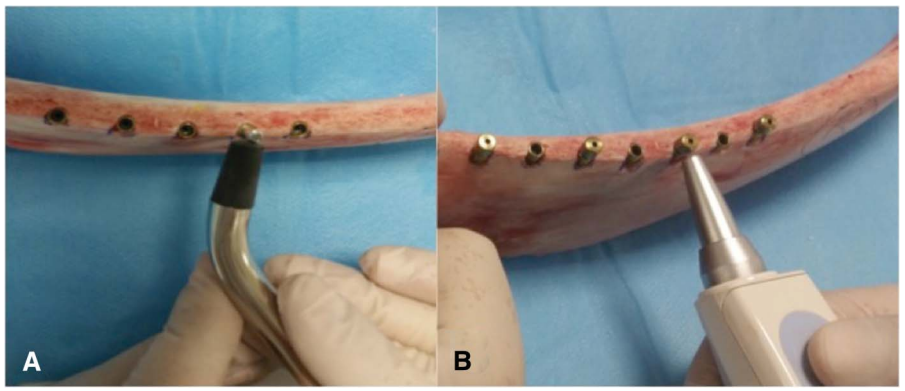

Fig. 3. **A**, Using Osstell ISQ device for coronal defect group; **B**, using a Periotest device for the coronal defect group.

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Table 1. Evaluation of Stability Values Measured by Osstell and Periotest Laterally and Frontally of Bone Defects Regarding Implant Types

	Implant Types		
	Group T, mean ± SD	Group C, mean ± SD	*P*
Osstell			
Control			
Lateral	88 ± 1.07	86 ± 2.14	0.033*
Frontal	83.88 ± 2.64	82.63 ± 3.7	0.450
Coronal			
Lateral	80 ± 0.76	83.5 ± 4.34	0.057
Frontal	75.63 ± 2	76.38 ± 6.74	0.770
Middle			
Lateral	85.88 ± 2.17	83.88 ± 2.36	0.099
Frontal	79.38 ± 5.55	74.63 ± 4.98	0.093
Apical			
Lateral	85.63 ± 1.92	84.63 ± 1.6	0.277
Frontal	81.38 ± 3.74	80.75 ± 3.58	0.738
Periotest			
Control			
Lateral	–7.03 ± 0.27	–6.96 ± 0.45	0.740
Frontal	–5.69 ± 0.69	–4.36 ± 4.03	0.375
Coronal			
Lateral	–4.65 ± 0.47	–5.28 ± 2.15	0.446
Frontal	–3.61 ± 0.59	–4.84 ± 2.22	0.153
Middle			
Lateral	–6.23 ± 0.88	–5.44 ± 0.89	0.098
Frontal	–4.63 ± 1.78	–4.55 ± 0.63	0.913
Apical			
Lateral	–6.78 ± 0.72	–6.51 ± 0.41	0.387
Frontal	–5.46 ± 1.35	–5.51 ± 0.7	0.928

No significant differences were detected between 2 of the implant designs ($P > 0.05$) except the ISQs of control groups.
*$P < 0.05$ (Student *t* test).

(n = 8). For group T, the remaining 4 subgroups were prepared in the same manner as subgroups coronal T group (n = 8), middle T group (n = 8), apical T group (n = 8), and control T group (n = 8).

Stability Measurements

Three different examiners measured the implant stability of the 64 implants 3 times (32 cylindrical and 32 tapered implants) using 2 different devices: Osstell ISQ (Osstell ISQ; Osstell, Goteborg, Sweden) was used for RFA, and Periotest (Periotest M; Medizintechnik, Gulden, Germany) was used for EPT. For the RFA measurements, Smartpegs calibrated for Nobel implants (Smartpeg Integration Diagnostics, Savedalen, Sweden) were screwed into the implants and hand tightened using a plastic screwdriver. The probe of the analyzer was held 1 mm away from the peg with a 90 degree angle, and the RFA values were read as implant stability quotients (ISQs) (Fig. 3). All the measurements were performed in buccal and lateral directions. After the RFA measurements, 4 mm healing abutments were screwed on to the implants, and EPT was performed using the cordless Periotest M (Periotest M; Medizintechnik) device. All the measurements were performed in buccal and lateral directions.

Statistical Analysis

The statistical analysis was performed by IBM SPSS Statistics 22 (IBM SPSS, Türkiye). Shapiro-Wilks test evaluated whether the parameters were normally distributed. In this

Table 2. Evaluation of Stability Values of Group T and Group C Measured by Osstell and Periotest Laterally and Frontally Regarding Bone Defects

	Control, mean ± SD	Coronal, mean ± SD	Middle, mean ± SD	Apical, mean ± SD	*P*
Group T					
Osstell					
Lateral	88 ± 1.07	80 ± 0.76	85.88 ± 2.17	85.63 ± 1.92	0.001*
Frontal	83.88 ± 2.64	75.63 ± 2	79.38 ± 5.55	81.38 ± 3.74	0.001*
Periotest					
Lateral	–7.03 ± 0.27	–4.65 ± 0.47	–6.23 ± 0.88	–6.78 ± 0.72	0.001*
Frontal	–5.69 ± 0.69	–3.61 ± 0.59	–4.63 ± 1.78	–5.46 ± 1.35	0.008*
Group C					
Osstell					
Lateral	86 ± 2.14	83.5 ± 4.34	83.88 ± 2.36	84.63 ± 1.6	0.315
Frontal	82.63 ± 3.7	76.38 ± 6.74	74.63 ± 4.98	80.75 ± 3.58	0.011†
Periotest					
Lateral	–6.96 ± 0.45	–5.28 ± 2.15	–5.44 ± 0.89	–6.51 ± 0.41	0.023†
Frontal	–4.36 ± 4.03	–4.84 ± 2.22	–4.55 ± 0.63	–5.51 ± 0.7	0.776

Considering the stability values related to defect locations, for both implant designs, the Tamhane T2 test revealed that coronal T and coronal C implants showed significantly lower stability values than the other groups ($P < 0.01$).
*$P < 0.01$ (1-way ANOVA test).
†$P < 0.05$ (1-way ANOVA test).

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study, the parameters were found to be normally distributed. One-way ANOVA test was used to compare the normally distributed parameters among the groups and to compare the quantitative data. Tukey HSD test and Tamhane T2 test were used for determining which groups in the sample differ significantly. To compare the parameters between 2 groups, Student *t* test was used. Pearson correlation analysis was used to determine the relationship between the measurements of Osstell and Periotest.

Intraclass correlation coefficient (ICC) was used to evaluate the intra-examiner/interexaminer reliability. The results were evaluated at a significance level of $P < 0.05$.

RESULTS

The Influence of the Implant Type and Defect Site on Primary Stability Values

No significant differences were detected between the 2 implant designs ($P > 0.05$; Table 1) except the ISQs of control groups. T implants in the control group showed significantly higher lateral ISQs compared with C implants in the control group ($P = 0.033$) (Table 1). Considering the stability values related to defect locations, both implant designs and Tamhane T2 test revealed that coronal T and coronal C implants showed significantly lower stability values than the other groups ($P < 0.01$) (Table 2). The comparison of the other groups showed no statistically significant differences ($P > 0.05$) (Table 2).

Intraobserver Reliability

The ISQ values obtained from Osstell ISQ (Table 3) and the Periotest values (PTVs) obtained from the Periotest M (Table 4) by the examiners showed a significant positive correlation ($P < 0.01$). For both implant types, indeed, excellent ICC values were detected according to the classification of Fleiss (1986).[21] All the ICC values were evaluated as excellent.

Interobserver Reliability

Very good interobserver reliability levels were obtained by the comparison of the measurements of each examiner by the Osstell ISQ (Table 5) and the Periotest M (Table 6) for both implant types ($P < 0.01$), as well.

The ICC values for the interobserver reliability ranged between 0.711 and 0.841 for the facial side, and between 0.728 and 0.919 for the proximal RFA measurements, and between 0.661 and 0.911 for the facial side, and 0.584 and 0.843 for the proximal PTV measurements, which can all be evaluated as "fair to good."

Table 3. ICC Values for the Intraobserver Reliability of the ISQs Measured Laterally and Frontally by the 3 Examiners

	Osstell	ICC	%95 Confidence Interval	*P*
Group T				
	First examiner			
	Lateral	0.978	0.960–0.988	0.001*
	Frontal	0.977	0.959–0.988	0.001*
	Second examiner			
	Lateral	0.962	0.933–0.980	0.001*
	Frontal	0.824	0.711–0.903	0.001*
	Third examiner			
	Lateral	0.843	0.739–0.914	0.001*
	Frontal	0.875	0.789–0.932	0.001*
Group C				
	First examiner			
	Lateral	0.932	0.881–0.964	0.001*
	Frontal	0.890	0.813–0.940	0.001*
	Second examiner			
	Lateral	0.883	0.801–0.936	0.001*
	Frontal	0.864	0.772–0.926	0.001*
	Third examiner			
	Lateral	0.833	0.725–0.908	0.001*
	Frontal	0.809	0.688–0.894	0.001*

*$P < 0.01$.

Table 4. ICC Values for the Intraobserver Reliability of the PTVs Measured Laterally and Frontally by the 3 Examiners

	Periotest	ICC	%95 Confidence Interval	*P*
Group T				
	First examiner			
	Lateral	0.908	0.842–0.951	0.001*
	Frontal	0.905	0.837–0.949	0.001*
	Second examiner			
	Lateral	0.942	0.898–0.969	0.001*
	Frontal	0.965	0.938–0.981	0.001*
	Third examiner			
	Lateral	0.962	0.933–0.980	0.001*
	Frontal	0.778	0.359–0.995	0.001*
Group C				
	First examiner			
	Lateral	0.954	0.919–0.976	0.001*
	Frontal	0.817	0.537–0.902	0.001*
	Second examiner			
	Lateral	0.968	0.944–0.983	0.001*
	Frontal	0.892	0.816–0.942	0.001*
	Third examiner			
	Lateral	0.799	0.638–0.895	0.001*
	Frontal	0.982	0.967–0.990	0.001*

*$P < 0.01$.

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Table 5. ICC Values for the Interobserver Reliability of the ISQs Measured Laterally and Frontally by the 3 Examiners

	Defect Subgroups	ICC	%95 Confidence Interval	*P*
Group T				
	Control T			
	Lateral	0.729	0.375–0.932	0.001*
	Frontal	0.741	0.332–0.932	0.001*
	Coronal T			
	Lateral	0.740	0.378–0.935	0.001*
	Frontal	0.711	0.331–0.926	0.001*
	Middle T			
	Lateral	0.919	0.759–0.982	0.001*
	Frontal	0.722	0.382–0.862	0.001*
	Apical T			
	Lateral	0.728	0.358–0.931	0.001*
	Frontal	0.735	0.332–0.937	0.001*
Group C				
	Control C			
	Lateral	0.747	0.390–0.937	0.001*
	Frontal	0.841	0.572–0.962	0.001*
	Coronal C			
	Lateral	0.746	0.388–0.936	0.001*
	Frontal	0.759	0.374–0.930	0.001*
	Middle C			
	Lateral	0.913	0.743–0.980	0.001*
	Frontal	0.732	0.364–0.932	0.001*
	Apical C			
	Lateral	0.882	0.665–0.973	0.001*
	Frontal	0.738	0.360–0.942	0.001*

*$P < 0.01$.

Concordance of Both Primary Stability Measurement Methods

Considering both implant types, measurements of 3 different examiners from 2 different sides with 2 different devices, the following results can be obtained (Table 7). The values of the stability measurements with 2 different devices in different situations and under different conditions revealed a statistically significant correlation.

DISCUSSION

Primary implant stability is a major consideration to achieve osseointegration and is also an important factor for implant survival and success.[3,4,22,23] In our study, RFA and EPT were used because they are the most frequently used stability measurement methods. These methods were chosen to measure the influence of defect localizations on primary stability. The reliability of these methods has been investigated in *in vitro* models in previous studies.[11,24,25] A positive correlation was found between the 2 methods as well, thus supporting the results of other studies.[19,26]

Good-excellent (fair-to-good reliability when ICC = 0.4–0.7, and excellent reliability when ICC >0.7)[21] results have been reported for the intraobserver and interobserver reliability values of EPT measurements[11,25] which are in congruence with our results. Good-excellent (fair-to-good reliability when ICC = 0.4–0.7, and excellent reliability when ICC >0.7)[21] intraobserver reliability and poor (poor reliability when ICC <0.4)[21] interobserver reliability have been reported for RFA.[24] However, our results did not show poor interobserver reliability for RFA. Both the interobserver and intraobserver reliability results were retrieved as good (fair-to-good reliability when ICC = 0.4–0.7)[21] in this study, which can be ascribed to similar hand-tightening forces exerted by the 3 examiners for Smartpeg tightening. The effect of the surrounding bone quality on primary stability has been investigated in many studies in the literature. Different types of materials such as cow ribs, goat femora and humeri, porcine ilia, steer vertebrae and pelvis, polyurethane blocks, human (cadaver) mandibles, and human femoral heads have been described for *in vitro* and *ex vivo* studies on dental implant primary stability.[25,27–32] Some studies preferred to use human cadavers for implant stability research,[18,19] but there are several studies reporting laboratory conditions such as storage and fixation with formaldehyde to influence the 3-dimensional structure of the protein, and thus, decreasing structural strength of alveolar bone.[33–35] Recently, Doi et al[36] have shown how 10% neutral formalin fixation influences RFA and EPT values. Primary stability is a result of the direct contact between bone and implant after insertion. The area of the implant body, which is in contact with bone, can define the level of primary stability. There are a few studies that have evaluated the influence of the implant-bone contact levels on RFA values, but according to the materials used and defects created, specifications of RFA values were not definitive. Kwak et al[20] evaluated the effect of different implant contact ratios and stiffness of surrounding materials on RFA values. They had used resin blocks and silicone putty blocks and made vertical and horizontal holes ø 6.5-9.0-12.0 mm or defect to decrease implant-resin contact. They concluded that RFA values do not differ between the groups with different resin implant contacts except when resin implant contact is less than 15% (ø 12.0 mm). However, acrylic resin was reported to be insufficient to simulate the effect of implant contact ratio on implant primary stability.[20] In light of these studies, cow ribs having a thick cortical bone surrounded by wide trabecular bone were selected for specimen preparation in this study.

Merheb et al[19] used the jaw of a human cadaver to evaluate the influence of bone defects on implant stability. Four different types of defects were created on the bone, one of them

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Table 6. ICC Values for the Interobserver Reliability of the PTVs Measured Laterally and Frontally by the 3 Examiners

Implant Design	Defect Type	ICC	%95 Confidence Interval	*P*
Group T				
	Control			
	Lateral	0.705	0.317–0.887	0.001*
	Frontal	0.729	0.360–0.931	0.001*
	Coronal			
	Lateral	0.730	0.371–0.828	0.001*
	Frontal	0.736	0.366–0.826	0.001*
	Middle			
	Lateral	0.584	0.153–0.885	0.001*
	Frontal	0.911	0.737–0.980	0.001*
	Apical			
	Lateral	0.732	0.365–0.932	0.001*
	Frontal	0.857	0.606–0.966	0.001*
Group C				
	Control			
	Lateral	0.629	0.211–0.900	0.001*
	Frontal	0.772	0.346–0.898	0.001*
	Coronal			
	Lateral	0.843	0.575–0.963	0.001*
	Frontal	0.661	0.254–0.910	0.001*
	Middle			
	Lateral	0.818	0.523–0.956	0.001*
	Frontal	0.787	0.461–0.948	0.001*
	Apical			
	Lateral	0.675	0.367–0.811	0.001*
	Frontal	0.778	0.446–0.945	0.001*

*$P < 0.01$.

Table 7. The Correlation of Stability Values Obtained From Osstell and Periotest of Group T and Group C Measured Laterally and Frontally by 3 Different Examiners

	Osstell-Periotest	
	r	*P*
Group T		
First examiner		
Lateral	–0.913	0.001*
Frontal	–0.783	0.001*
Second examiner		
Lateral	–0.916	0.001*
Frontal	–0.266	0.141
Third examiner		
Lateral	–0.687	0.001*
Frontal	–0.542	0.001*
Group C		
First examiner		
Lateral	–0.798	0.001*
Frontal	–0.179	0.327
Second examiner		
Lateral	–0.871	0.001*
Frontal	–0.583	0.001*
Third examiner		
Lateral	–0.436	0.013†
Frontal	–0.486	0.005*

The values of stability measurements with 2 different devices in different situations and under different conditions revealed, generally, a statistically significant correlation.
*$P < 0.01$ (Pearson correlation analysis).
†$P < 0.05$ (Pearson correlation analysis).

mimicking marginal bone loss. Diamond burs were used, and the bone around the implant was gradually removed in 1 mm increments. In the same study, periapical bone loss was achieved with the same protocol. They created buccal dehiscences which were 3 mm mesiodistal direction wide and with a 1 mm coronoapical direction long defect. After implant placement, the coronoapical-direction defect was extended by removing 1 mm gradually. In our study, the bone defects were created in the same manner but with 3 walls, and these defects were created before implant placement. We planned to evaluate the influence of perforation of the bone implant contact by creating defects with 3 walls.

Our results showed that all the defects, regardless of the localization, decreased stability, but this stability loss was only significant when the defects were in the coronal aspect. The stability of the implants inserted in the coronal defects was lower than the stability of the implants inserted in the defects of the other localizations. These results are in agreement with the results of previous studies.[19,37] The lower ISQs may be the reason for the effect of coronal bone reduction on the implants' primary stability.[37] During EPT, the upper part of the implants is tapped by the Periotest device. This may be the reason for higher PTVs detected in the cases of coronal defects. Additionally, it has been shown that EPT has the ability to detect marginal bone loss of more than 2 mm.[19,26] The results of this study show that detection of defects other than the coronal part of the implants is not possible with the use of EPT or RFA which is in agreement with the results of Merheb et al.[19] Therefore, these methods should be supported with additional radiographic methods or other stability measurement tools such as insertion torque.

For implant stability, one of the main factors is the mechanical property of bone. Cortical bone can be 10 times more rigid than cancellous bone in some cases, which explains why bone quality and quantity play an important role in implant stability.[38–40] Roze et al[41] showed the relevance of primary stability and cortical thickness around the implants and concluded that the implant stability was correlated with bone structure. In the same study, a special correlation had been found between ISQ values and the thickness of the cortical bone. In this study, the groups with the coronal bone defects showed significantly lower primary stability values than other groups, which is in accordance with other studies. In our study, it was planned to create similar size defects on different alveolar bone locations before implant placement. Previous studies have shown that primary stability is affected by the macrogeometry of the implant.[7,30,31] Therefore, we aimed to evaluate and compare the effects of bone defect localization on RFA and PTVs with 2 implants having different

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macrogeometries. NobelReplace implants with tapered implant body geometries and NobelParallel implants with a straightforward cylindrical design were compared for stability in this study, and a tendency of higher stability was observed in tapered implants. Nevertheless, this difference was not significant except for the lateral ISQs of the control group. It has been shown that tapered implants dispense forces to the surrounding bone more equally than cylindrical implants.[42] This may be the reason for higher stability tendency and the superior lateral ISQs of the control group of tapered implants.

CONCLUSIONS

Within the limits of the study, the following conclusions can be drawn:

1. Implants with coronal defects generally showed lower primary stability compared with implants with middle and apical defects, as well as the control group without any defects.
2. The primary stability of cylindrical (parallel walled) implants is less influenced by coronal defects compared with tapered implants.

DISCLOSURE

The authors declare that there is no conflict of interest associated with this study. The study was supported by Okan University, Dentistry School, Istanbul, Turkey.

APPROVAL

This *in vitro* study was performed at Okan University, Faculty of Dentistry. For this study, no animal was killed, and fresh cow ribs of the same animal with similar properties were selected from the butcher shop. Ethical protocol is not required for this research.

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