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# Influence of Peri-Implant Bone Defect Type on Insertion Torque and Resonance Frequency Analysis: An In Vitro Study

## Peri-İmplant Kemik Defekti Tipinin Yerleştirme Torku ve Rezonans Frekans Analizi Üzerine Etkisi: İn Vitro Çalışma

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**ABSTRACT Objective:** The aim of the present study is to investigate the effects of different peri-implant bone defects on primary stability and the correlation between insertion torque (IT) and resonance frequency analysis (RFA) measurements. **Material and Methods:** Fourty implant beds were prepared in artificial bone blocks using the 3D surgical guide. Implant osteotomies were divided into 5 groups (n=8) according to defect type: i) no peri-implant bone defect (control), ii) a dehiscence defect, iii) a fenestration defect on the middle part, iv) a fenestration defect on the apical part and v) a circumferential defect. Implants were inserted by using a surgical drilling unit with torque control and RFA measurement were done. **Results:** IT values for the control group were significantly higher than the other groups (p<0.001). The results of IT measurements for dehiscence defect group were significantly greater when compared to fenestration and circular defect groups (p<0.01). Implant stability quotient (ISQ) values for the control group were significantly higher than other groups (p<0.05). In addition, the ISQ values for the dehiscence defect group were significantly lower when compared to fenestration defect groups (p<0.001), and ISQ values for the circular defect group were significantly lower than any other groups (p<0.001). IT values and, ISQ values are moderately correlated (p=0.013, r=0.388). **Conclusion:** The location of peri-implant bone defect affects RFA measurements more than IT. However, IT seems to be correlated with bone implant contact. Therefore, in the case of peri-implant bone defect, IT measurement may be preferred for evaluation of primary stability.

**Keywords:** Resonance frequency analysis; dental implants

**ÖZET Amaç:** Bu çalışmanın amacı, farklı tipteki peri-implant kemik defektlerinin primer stabilite üzerindeki etkilerinin ve implantların yerleştirme torku (YT) ölçümleri ile rezonans frekans analizi (RFA) ölçümleri arasındaki korelasyonu incelemektir. **Gereç ve Yöntemler:** 3 boyutlu cerrahi kılavuz kullanılarak yapay kemik bloklarının içerisine 40 adet implant boşluğu hazırlandı. Farklı tipte peri-implant defektler oluşturulduktan sonra implant boşlukları defekt tipine göre 5 gruba (n=8) ayrıldı: i) implant çevresinde kemik defekti yok (kontrol), ii) dehisens defekti, iii) implantın orta kısımda fenestrasyon defekti, iv) implantın apikal kısmında fenestrasyon defekti ve v) sirküler kemik defekti. İmplantlar tork kontrollü cerrahi motor kullanılarak yerleştirildi ve RFA ölçümleri yapıldı. **Bulgular:** Kontrol grubunda ölçülen YT değerleri diğer gruplara göre istatistiksel anlamlı olarak daha yüksekti (p<0,001). Dehisens tipi defektleri olan grupların YT ölçümlerinin sonuçları, fenestrasyon ve sirküler kemik defekti grupları ile karşılaştırıldığında istatistiksel anlamlı olarak daha yüksekti (p<0,01). Kontrol grubu için implant stabilite katsayısı [implant stability quotient (ISQ)] değerleri diğer gruplara göre istatistiksel anlamlı olarak yüksekti (p<0,05). Ayrıca dehisens tipi defekt grubu için ISQ değerleri, fenestrasyon tipi defekti olan gruplar ile karşılaştırıldığında anlamlı derecede daha düşüktü (p<0,001). Bunun yanında sirküler kemik defekti grubu için ISQ değerleri diğer gruplara göre anlamlı derecede daha düşüktü (p<0,001). YT değerleri ile ISQ değerlerinin orta düzeyde korelasyon gösterdiği tespit edilmiştir (p=0,013, r=0,388). **Sonuç:** Peri-implant kemik defektinin lokalizasyonu, RFA ölçümlerini YT ölçümlerinden daha fazla etkilemektedir. Bununla birlikte YT'nin kemik implant teması ile daha güçlü bir ilişkisi olduğu görülmektedir. Bu nedenle peri-implant kemik defekti varlığında, primer stabilitenin değerlendirilmesi için YT ölçümü tercih edilebilir.

**Anahtar Kelimeler:** Rezonans frekans analizi; diş implantları

Dental implants are often preferred in the oral rehabilitation of patients with missing teeth due to their predictability and high success rate. Immediate loading of implant has gained popularity as a consequence of patients' increasing expectations in terms of shorter treatment period and aesthetic.[1] Primary implant stability is biomechanical stability that is affected by various factors such as surgical technique,

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bone quality and quantity, and implant macro design.[2] The primary stability is a key factor for implant success, especially in immediate loading protocol where the implant is exposed to functional load before osseointegration occurs. It has been reported that at micromotion over 150 µm, the wound may undergo fibrous repair instead of osseous regeneration.[3] Therefore, it is necessary to determine the primary stability of the implant, especially before immediate loading.

Bone quantity around a dental implant is one of the important factors for primary stability and peri-implant bone deficiency over a certain threshold may jeopardize primary stability.[4] The alveolar bone undergoes a progressive remodeling process resulting in three-dimensional resorption that alters the morphology of the residual alveolar ridge after dental extraction.[5] The bone quantity around dental implants is mostly affected by cortical bone defects like dehiscence and fenestration because of surgical techniques, the differences of the bone resorption pattern, and anatomical features of the surgical site.[6] Peri-implant dehiscence is defined as the absence of bone initiating from the cervical portion of the implant, while peri-implant fenestration is defined as a buccal or lingual window defect leaving marginal bone at the coronal portion.[7] Immediate implant placement also presents specific challenges for achieving proper primary stability because of the geometric discrepancy between the design of implant and extraction socket.[8] These kinds of defects necessitate guided bone regeneration procedures almost every time to achieve long term success.

Different methods such as periotest, dental mobility checker, insertion torque (IT), and resonance frequency analysis (RFA) allow the stability of the implant to be evaluated.[9,10] RFA is presented as a non-invasive and objective method of measuring primary stability.[11] RFA method is based on excitation of a magnetic device screwed into the implant with a vibration consisting of sinusoidal signals and measuring its response.[12] This method determines an implant stability quotient (ISQ) between 1 (the lowest degree of stability) and 100 (the highest degree of stability). The lowest ISQ value for immediate loading is considered 70.[13] On the other hand, IT is the measure of the moment of force (torque) necessary to insert an implant through a rotatory movement in its lodging place.[14] In clinical practice, it is considered that an IT of 45 N/cm is necessary for immediate loading so that this is the value considered the safest and most therapeutic.[15]

It is important to conclude how bone defects affect the primary stability of the implant. It has been considered that the location and type of defects might also be important for primary stability. The aim of the present study was to determine the effect of different types of peri-implant bone defects, that are encountered in daily clinical settings, on RFA and IT measurements. In addition, the correlation between ISQ and IT of dental implants with different peri-implant bone defects was also investigated.

## MATERIAL AND METHODS

### IMPLANT PLACEMENT AND DEFECT PREPARATION

A total of 40 implants (4 mm x 10 mm, Dentium Superline, Dentium Ltd., Seoul, Korea) were used for the present study. Artificial bone blocks (A-JT D3, Frasaco, Tettnang, Germany) mimicking Type 3 bone density according to the bone quality classification were used for implant placement.[12] The implant beds were prepared with 8 mm intervals using a 3D surgical guide to standardize of inter-implant distance and implant position (Figure 1). The preparation of implant bed was performed according to the instructions given in Dentium guided surgery manual using the

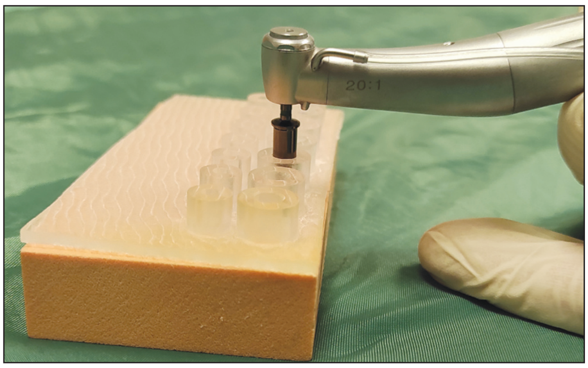


**FIGURE 1:** Preparation of implant beds using the 3D surgical guide. The implant beds were prepared with the inter-implant distance of 8 millimeters. Standardization of implant position and inter implant distance were ensured with the help of the 3D surgical guide.

complete sequence of drills finalized with counter sink drill. All of the osteotomies were prepared using a surgical drill at a rotational speed of 800 rpm and torque of 35 N/cm with external cooling. Implant beds were divided into 5 groups according to defect type: i) no peri-implant bone defect (control), ii) a dehiscence defect, iii) a fenestration defect on the middle part, iv) a fenestration defect on the apical part and v) a circular defect. Box-type peri-implant bone defects were made on one side of the implant beds using a high-speed diamond bur in dehiscence, fenestration on the apical part, and fenestration on the middle part groups. For all box-type defects (6 mm width and 5 mm height) implants were centered in mesio-distal direction. Depth of the dehiscence and fenestration type defects were designated to ensure that buccal half of the implants were located in the defect. In the circumferential bone defect group, sockets were first prepared by routine drilling sequences to a depth of 10 mm. Then, bone defects of 5 mm depth were created in the coronal part of the sockets using a trephine bur with an external diameter of 6 mm around the prepared implant bed. As a result, 25% bone implant contact (BIC) loss in the dehiscence and fenestration groups, and 50% BIC loss in the circumferential group were formed. All remaining bone between the implant bed and the line created with the trephine bur was removed using a high-speed diamond bur (Figure 2).

## STABILITY MEASUREMENTS

Implants were inserted in the prepared implant beds using a surgical drive unit (Implantmed, W&H, Bürmoos, Austria) that records torque values (N/cm) during implant insertion. Maximum torque values during implant insertions were noted as IT for each implant. Osstell Beacon (Osstell Beacon; Osstell, Goteborg, Sweden) was used for RFA measurement of placed implants. The SmartPeg (Integration Diagnostics, Savedalen, Sweden) was screwed into the implants in sequence by hand tightening with aid of a plastic mount. The probe was held 2 mm from the SmartPeg and perpendicular to the implant axis. The ISQ value of each implant was calculated by averaging the values measured three times in both directions (a total of 6 measurements for each implant).

## STATISTICAL ANALYSIS

The normality of distributions was examined by Shapiro-Wilk tests and the normality of the data was verified. The IT and ISQ values were analyzed with one-way ANOVA and Tukey's post-test. The correlation between the IT and ISQ values were evaluated by the Pearson's correlation test. All statistical data were analyzed using statistical software (PASW version 18.0, SPSS, USA) with a significance level set α=0.05. The statistical power of the present study was calculated by post hoc power analysis based on IT results. The calculated effect size was 2.68 and 8 implants in each group provided 99% power for the present study.

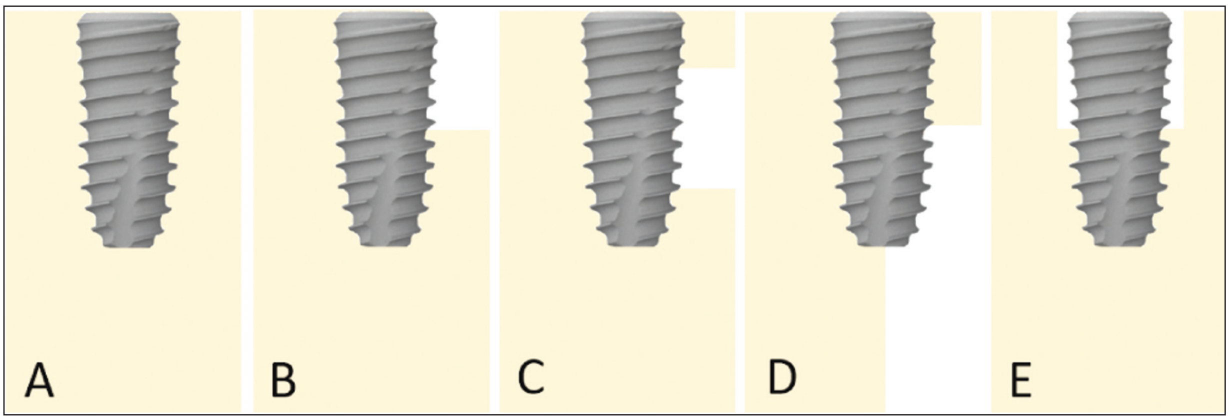


**FIGURE 2:** Experimental peri-implant bone defect configurations according to the study groups.
**A)** No peri-implant bone defect (control), **B)** Dehiscence defect, **C)** Fenestration defect on the middle part, **D)** Fenestration defect on the apical part and **E)** Circular defect. For all box-type defects (6 mm width and 5 mm height) implants were centered in mesio-distal direction. Depth of the dehiscence and fenestration type defects were designated to ensure that buccal half of the implants were located in the defect. For circular type defects, implants had 5 mm contact with artificial bone block and no circumferential contact for the first 5 mm.

## RESULTS

Descriptive statistics for IT and ISQ values were shown in Table 1.

### IT MEASUREMENTS

Statistical analysis of the IT measurements showed that any kind of peri-implant defect decreased IT values. IT values for the control group were significantly higher than the dehiscence defect group (p<0.001), fenestration defect on the apical part (p<0.001), fenestration defect on the middle part (p<0.001), and circular defect (p<0.001) groups. In addition, the results of IT measurements for the dehiscence defect group were significantly greater when compared to the fenestration defect on the middle part (p=0.009), fenestration defect on the apical part (p<0.001), and circular defect groups (p<0.001). However, the comparison of the other groups showed no statistically significant differences (p>0.05) (Figure 3).

The dehiscence, fenestration in the middle, and fenestration in the apical part defects cause loss of nearly 25% BIC. IT values for implants in the dehiscence, fenestration in the middle part, and fenestration in the apical part groups decreased 17.1%, 30.5%, and 39.3% respectively compared to control group. In the case of 50% loss of BIC, IT values reduced 40.3% in the circular defect group.

### RFA MEASUREMENTS

The ISQ values were highest in the control group while the ISQ values were lowest in the circular bone defect group. ISQ values for the control group were significantly higher than the dehiscence defect group (p<0.001), fenestration defect on the middle part (p=0.013), fenestration defect on the apical part (p=0.001), and circular defect (p<0.001) groups. In addition, the results of ISQ measurements for the dehiscence defect groups were significantly lower when compared to the fenestration defect on the middle part (p<0.001), fenestration defect on the apical part (p<0.001) however, the ISQ values for dehiscence defect groups was significantly greater than the circular defect group (p<0.001). Although the ISQ values for the fenestration defect on the apical part (p<0.001) and fenestration defect on the middle part groups (p<0.001) was significantly higher than the ISQ values for the circular defect group, the ISQ values of the fenestration defect on the middle part group were comparable with the ISQ values of the fenestration defect on the apical part group (p=0.812) (Figure 4).

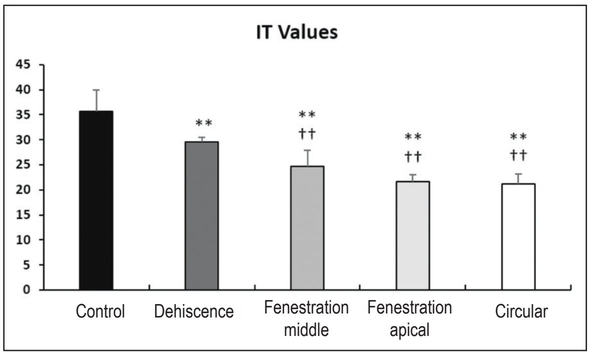


**FIGURE 3:** Results of IT measurements.
**p<0.01 compared with control group. ††p<0.01 compared with dehiscence group. Values are given as mean±standard deviation; IT: Insertion torque.

Losing 25% BIC in the dehiscence, fenestration in the middle and fenestration in the apical groups decreased ISQ values 21.3%, 4.58% and 6.5% respectively, compared to control group. Decrease in ISQ values become 30.2% in the circular defect group which 50% loss of BIC was simulated.

### CORRELATION BETWEEN IT AND RFA MEASUREMENTS

A total of 40 implants were inserted into artificial bone blocks. The mean 40 IT and ISQ values were 26.55±6.03 and 59.42±8.04 respectively, statistical

**TABLE 1:** Descriptive statistics for IT and ISQ values (mean±standard deviation).

| | Control | Dehiscence | Fenestration Middle | Fenestration Apical | Circular |
|---|---|---|---|---|---|
| IT values | 35.62±4.34 | 29.50±0.92 | 24.75±3.15 | 21.62±1.40 | 21.25±1.90 |
| ISQ values | 67.87±2.13 | 53.35±2.93 | 64.77±0.82 | 63.77±1.39 | 47.35±0.91 |

IT: Insertion torque, ISQ: Implant stability quotient.

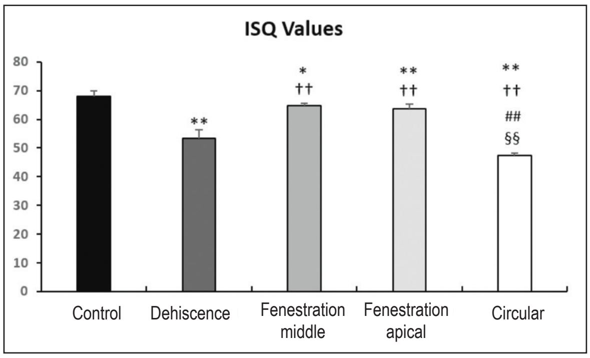


**FIGURE 4:** Results of RFA measurements.
*p<0.05/**p<0.01 compared with control group. ††p<0.01 compared with dehiscence group. ##p<0.01 compared with fenestration middle group. §§p<0.01 compared with fenestration apical group. Values are given as mean±standard deviation; ISQ: Implant stability quotient; RFA: Resonance frequency analysis.

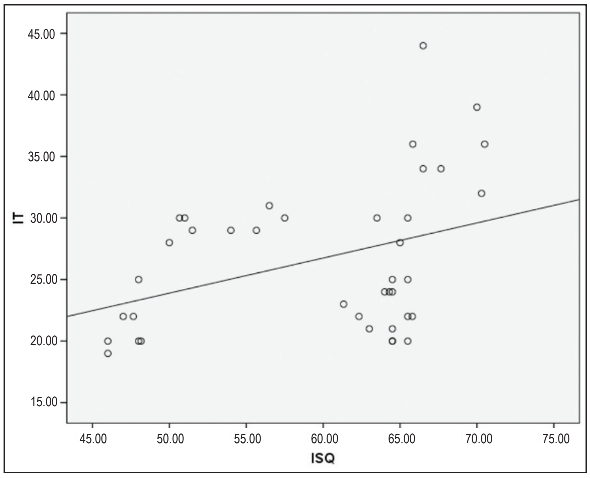


**FIGURE 5:** Results of IT and RFA measurement comparison.
There was a significant correlation between IT values and ISQ values and they are moderately correlated (p=0.013, r=0.388); IT: Insertion torque; ISQ: Implant stability quotient; RFA: Resonance frequency analysis.

analysis indicated that there was a significant correlation between IT and ISQ values and they are moderately correlated (p=0.013, r=0.388) (Figure 5).

## DISCUSSION

After a tooth extraction the alveolar ridge undergoes a significant amount of resorption in all directions. As a result, a dehiscence or a fenestration defect on the buccal side may occur. In addition to these, a circumferential defect is frequently seen during immediate implant placement due to the discrepancy between the extraction socket and the implant. No clear data are presented on the effect of bone defect morphology on the primary implant stability. In the present study, it was aimed to evaluate the effect of different types of bone defects on the ISQ and IT measurements. Moreover, it was investigated whether there was a correlation between IT and ISQ values.

Meredith et al. reported the use of RFA to evaluate implant stability in 1996.[16] This technique based on continual excitation of the implant through dynamic vibration analysis makes use of a transducer connected to an implant. The higher the resonance frequency, the more stable the implant.[17] Thus, RFA basically works with recording the longitudinal oscillation of implant and consequently, it is expected that the same dimensional peri-implant defect in different locations may affect the RFA values contrarily. The effects of different kinds of defects on RFA measurements were investigated in previous research. Mercan et al. created buccal bone defects on coronal, middle, and apical parts of the implants and determined the influence of these defects on ISQ values.[6] They reported that significantly lower ISQ values were noted in the coronal defect group than the other groups and the comparison of middle and apical defect groups showed no significant differences. Akça et al. compared RFA values of implants inserted in conventional surgical sockets with circular bone defects at the coronal half and stated that the bone defect group had significantly lower ISQ values than control group with the reduction rate of 38%, from 66.31 to 40.88.[18] Shin et al. investigated the effect of circular bone defects on RFA values of implants placed to bovine rib bone in 2 studies and showed that circular bone defects at the coronal half decreased ISQ values from 85.45 to 57.43 in the first study and from 84.70 to 56.07 in the second study which corresponds to a 33% reduction.[19,20] In addition to that in the second study of Shin et al. 1-wall defect at the coronal half of implants that is comparable to our dehiscence type defect, resulted in decreased ISQ values from 84.70 to 69.77.[20] In the present study, all kinds of simulated defects significantly decreased ISQ values of implants (Table 1). Fenestration in the middle and fenestration in the apical part decreased ISQ values 3.08 and 4.08 respectively however, in the dehiscence group due to losing the support of frontal bone in the coronal part ISQ values decreased 14.50. Despite decreasing nearly the same BIC area in the fenestration and dehiscence groups, the mean of ISQ values in the dehiscence group is significantly lower than both of the fenestration groups. Decrease in ISQ values become 20.50 in the circular defect group that has no circumferential bone support at the coronal half of implants. In the study of Akkocaoglu et al. implants were placed in fresh extraction sockets of a human cadaver and both the RFA values and depth of the dehiscence type defects were recorded.[21] According to the results of the study, it was suggested that bone contact at the coronal region has an important role during RFA measurements and an intimate bone-implant contact at the collar region increases the ISQ values. Extrapolating from the results of previous studies and current study RFA values seem to be most affected by peri-implant bone support in the coronal part. Reduction of bone support coronally may influence the oscillation during RFA recording and eventuate in decreased resonance frequency.[18]

IT is the amount of force required to advance the implant into the implant bed and caused by the friction generated between the implant and peri-implant bone.[22] BIC area theoretically affects IT with the structural stiffness being higher when a larger amount of bone is in contact with the implant.[23] Liu et al. investigated the correlation between the IT value of dental implants and BIC percentage and found that IT is strongly positively correlated with the 3D BIC percentage obtained from micro-CT images.[24] Akça et al. found that 50% loss of peri-implant bone support at the coronal half caused a 47% decrease in IT value.[18] They stated that because of the similarity in the amount of reduction, IT was very useful in detecting the primary mechanical anchorage of an implant. In the present study, controlled bone defects at the coronal half of dental implants were created in the circular bone defect group. Implants of the circular bone defect group had significantly lower IT values than implants of control group implants with the reduction rate of 40%, from 35.62 to 21.25. When compared with the results of the study of Akça et al. lower reduction rate was noted in the present study that may be explained by the designs of used implants.[18] Akça et al. used a cylindrical implant with an identical thread design over its entire length however Dentium Superline has a double threaded tapered body design with increased thread height and sharper threads in the apical part of the implant.[18] It has been suggested that high IT values could be achieved by providing close contact between the bone and the implant surface by using aggressive implants with increased thread depth.[15] Thus, with the design of Dentium Superline more IT preserved with peri-apical bone support in the present study when compared with the study of Akça et al.[18] In the present study dehiscence, fenestration in the middle, and fenestration in the apical part defects cause loss of nearly 25% BIC. IT values for implants in the dehiscence, fenestration in the middle part, and fenestration in the apical part groups were 29.50, 24.75, and 21.62 respectively. Even the bone loss around implants was nearly the same, IT values were significantly lower in the fenestration groups compared to the dehiscence group. Higher IT values in the dehiscence group may be explained with the preservation of peri-implant bone support in the apical part of Dentium Superline that has part more aggressive thread design in the apical part.

After improvements in the design of devices, RFA has become a simple, non-invasive, and widely used tool. The stability of implants can be assessed at different time intervals such as at the time of implant insertion, during the healing period, and with the prosthesis in function, while IT can only be measured at the time of surgery.[25] Although either the using ISQ or IT has been validated for the evaluation of primary stability, it is important to know whether the IT and ISQ values are comparable.[15] Park et al. and Turkyilmaz et al. found a linear correlation between ISQ value and the maximum IT in their clinical studies.[26,27] In addition to that, Kahraman et al. investigated the correlation between IT and ISQ with 42 self-tapping tapered endosseous implants and found a significant correlation between them.[28] The relationship between IT and RFA was evaluated in a systematic review and it was concluded that the studies had low evidence for identifying a relationship between IT and RFA measurements and most of these studies had a serious risk of bias.[15] In agreement with that systematic review, a nonsignificant correlation coefficient was found between IT and RFA measurements of implants in non-molar sites.[29] Moreover, Akkocaoglu et al. evaluated the IT and ISQ values of implants placed into freshly prepared extraction sockets of fresh frozen human cadavers and stated that a statistically significant correlation could not be determined between IT and ISQ values.[21] In the present study, a significant correlation was found between IT and ISQ values and they are moderately correlated. Further data collection is therefore required to verify all the methods for evaluating implant stability and determine if there is a correlation between ISQ and IT values.

IT and RFA work with different mechanisms, so it is expected that different variables influence the measurements differently. Akça et al. found that in the case of experimental 50% bone support loss ISQ values reduced 38% and IT values reduced 47%.[18] They suggested that the difference in reduction rates of both techniques was 9% and IT value measurements were more finely tuned than ISQ values. It is supported by the 2 recent histomorphometric studies which did not find a possible correlation between levels of BIC and ISQ values.[30,31] In contrast, Liu et al. found that IT was strongly positively correlated with 3D BIC% obtained from micro-CT records.[24] Moreover, Capparé et al. investigated the correlation between histologically investigated BIC% of retrieved implants and IT values during their placement and found a significant linear correlation.[32] Therefore, Akça et al. concluded that primary stability would be better analyzed by evaluating RFA measurements together with IT measurements.[18] Consisted with these findings in the case of 50% bone support loss ISQ values reduced 30% and IT values reduced 40% in the present study which supported the idea that correlation between BIC and IT is higher than RFA measurements.

The present study has several limitations such as inability to simulate clinical conditions and all properties of living bone since it is an in vitro study. In addition, the primary stability of one implant type was evaluated in artificial bone block with one type bone density. Parameters such as implant micro and macro design, implant length, implant diameter, and bone density may affect the primary stability, so further studies are needed to evaluate the impact of these parameters on the primary stability of implants with a peri-implant bone defect.

## CONCLUSION

The location of peri-implant bone defect did not similarly affect the RFA and IT measurements, especially the peri-implant bone at the coronal region had a decisive role in the RFA measurements. Although there was moderate correlation between IT and RFA measurements, the decrease in the IT values seemed to be more consistent with the decrease in BIC. Therefore, in the case of peri-implant bone defect, especially in the fenestration and circular type defects, IT measurement should be preferred for evaluation of primary stability or RFA measurements should be supported by IT measurements. More studies are required to prove a possible correlation between IT and ISQ values. In the absence of guidelines and consideration of the high number of implant surgery each year, further studies are needed to determine a proper algorithm for measuring implant stability in case of a peri-implant bone defect.

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*During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.*

### *Conflict of Interest*

*No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.*

### *Authorship Contributions*

***Idea/Concept:** Nurettin Diker, Burcu Diker; **Design:** Nurettin Diker, Burcu Diker; **Control/Supervision:** Nurettin Diker, Burcu Diker; **Data Collection and/or Processing:** Nurettin Diker, Burcu Diker; **Analysis and/or Interpretation:** Nurettin Diker; **Literature Review:** Nurettin Diker; **Writing the Article:** Nurettin Diker; **Critical Review:** Nurettin Diker, Burcu Diker; **References and Fundings:** Nurettin Diker, Burcu Diker; **Materials:**Nurettin Diker, Burcu Diker.*

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