

The Effects of Defect Type and Depth, and Measurement Direction on the Implant Stability Quotient Value

Seung-Yun Shin, DDS, MSD, PhD¹
 Seung-Il Shin, DMD, MSD, PhD¹
 Seung-Beom Kye, DDS, MSD, PhD²
 Jongrak Hong, DDS, MSD, PhD³
 Jun-Young Paeng, DDS, MSD, PhD⁴
 Seok-Woo Chang, DDS, MSD, PhD⁵
 Seung-Min Yang, DDS, MSD, PhD^{2*}

The purpose of this study was to evaluate the effect of defect type and depth as well as measurement direction on implant stability in an ex vivo peri-implant bovine rib bone model. Six kinds of defects (3-wall 2.5 mm, 3-wall 5 mm, 1-wall 2.5 mm, 1-wall 5 mm, circumferential 2.5 mm, circumferential 5 mm), and control (no defect) were prepared in 14 bovine rib bones. A total of 84 defects and 14 controls were created. The same type and size of implants (4 × 10 mm) were placed in each group. The thickness of cortical bone and the insertion torque were measured for each defect, and the implant stability quotient (ISQ) value was measured 3 times from 4 different directions. The thickness of cortical bone ranged from 2.71–3.18 mm. Insertion torque decreased as the defect size increased. As the defect size for the same defect depth increased, the ISQ value decreased ($P < .001$). There were significant differences between the ISQ values obtained with different measurement directions only between the control and 3-wall 5 mm defect ($P < .0001$). The ISQ value opposite to the defect direction was higher than that in the defect direction in all 3 directions of the 3-wall and 1-wall 5 mm defects. ISQ values were influenced by defect type and depth. Loss of cortical bone reduced the stability of implants and reduced the ISQ value. Measurement direction also influenced ISQ values.

Key Words: implant stability, implant stability quotient (ISQ), resonance frequency analysis, defect type, defect depth

INTRODUCTION

Implant stability can be defined as the absence of clinical mobility¹ and can be evaluated by percussion tests, insertion torque, mobility, resonance frequency analysis (RFA) values, radiographic interpretation, and sensations of the operator.^{1–5} Although operator sense is a very good tool for evaluating implant stability, it is not an objective method and requires extensive experience.

Resonance frequency analysis (RFA), first described by Meredith et al,⁶ is now widely used to evaluate implant stability because it is an objective method and does not damage the implant.² RFA results are expressed as implant stability quotients (ISQs), ranging in value from 1 to 100.² Resonance

frequency is determined by the stiffness of the bone-implant complex; this was demonstrated by Meredith et al, who performed repeated RFA measurements of implants placed in a self-curing resin.⁶ Various factors influence RFA, such as defect depth, implant stiffness, exposed fixture height, healing time, surface texture, implant shape, implant length, bone quality, and marginal bone loss.^{3,7–16}

The increase in the number of patients treated using dental implants seems to lead to a concomitant increase in the number of patients who suffer from peri-implant disease. Peri-implantitis includes alveolar bone loss around the implant. Bone defects around the implant can manifest in various forms and affect the stability of the implant.^{13,17} Bone defects in peri-implantitis lesions can be classified according to the criteria presented by Goldman and Cohen.¹⁸ One-wall intrabony defects are defects limited by 1 osseous wall and the implant surface. Three-wall intrabony defects are limited by 3 osseous walls and the implant surface. In peri-implantitis, circumferential defects are also common.¹⁹ The type of intrabony defect around the implant could affect the stability of implant to different extents. Although the effect of vertical bone loss on the stability of implants has been studied, the relationship between peri-implant bone defect type and the stability of implants has not yet been studied. Therefore, the purpose of this study was to evaluate the effect of defect type and depth as well as transducer

¹ Department of Periodontology, Institute of Oral Biology, School of Dentistry, Kyung Hee University, Seoul, Korea.

² Department of Periodontology, The Institute of Oral Health Science, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea.

³ Department of Oral Maxillofacial Surgery, The Institute of Oral Health Science, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea.

⁴ Department of Oral and Maxillofacial Surgery, Kyungpook National University, Daegu, Korea.

⁵ Department of Conservative Dentistry, Institute of Oral Biology, School of Dentistry, Kyung Hee University, Seoul, Korea.

* Corresponding author, e-mail: pkoyang@skku.edu

DOI: 10.1563/aaid-joi-D-13-0031

direction on implant stability in an ex vivo peri-implant model, namely, bovine rib bone.

MATERIALS AND METHODS

Drilling procedure and defect preparation

Fourteen frozen bovine rib bones were used in this study. Before the experiment, the frozen bovine rib bones were left for 3 hours at room temperature. The flat and wide side of the bovine rib bones—large enough to allow placement of 4-mm diameter implants—was used in this experiment. Seven implant beds were prepared in each rib bone, with the centers of the implant beds 15 mm apart from each other. The drilling sequence recommended by the manufacturer (Sola, Shinhung Co, Ltd, Seoul, Korea) was modified because of the thick cortical bone of the bovine rib as follows: 2.0 mm, 2.4/2.8 mm, and 3.2/3.6 mm using a 4.0 tap drill.

Six kinds of defects (3-wall 2.5 mm, 3-wall 5 mm, 1-wall 2.5 mm, 1-wall 5 mm, circumferential 2.5 mm, and circumferential 5 mm) and controls (no defect) were prepared. Three types of defect configurations were prepared (Figure 1). A 3-wall defect was prepared by removing the distal side of the prepared implant placement hole using a 4-mm trephine bur (Figure 1a). One-wall defects were prepared by removing bone 4 mm distal of the prepared implant hole using a #770 bur (Figure 1b). Circumferential defects were made using a trephine bur with an external diameter of 8 mm around the prepared hole. After drilling with the trephine bur, all remaining bone inside the trephine bur was removed using a #770 bur (Figure 1c). Each defect model was prepared at 2 different depths (2.5 mm and 5 mm). In the control, 1 drilling hole was left without creating a defect. The thickness of the cortical bone was measured using a UNC-15 probe. Outside the rib arch was considered the buccal side, and inside the rib arch was considered the lingual side. One-wall and 3-wall defects were made on the same side (distal side) in each bovine rib bone. The side opposite the defect was considered to be the mesial side (Figure 1d).

Implant placement and ISQ measurement

A total of 14 bovine rib bones were used for this study. Seven external connection type implants were placed in each rib bone. Implants with a 4-mm diameter and 10-mm length (Sola, Shinhung Co, Ltd, Seoul, Korea) were placed in each prepared hole. Insertion torque was measured during placement. After implant placement, the primary stability of the implant was measured. The ISQ value was measured from 4 directions: mesial, distal, buccal, and lingual. Measurements were repeated 3 times in each direction to improve precision and assess reproducibility. The mean of the 3 measurements in each direction was regarded as the ISQ value representative of that direction. The mean of 12 measurements in 4 directions was considered representative of the ISQ value of that implant.

Statistical analyses

Statistical analyses were performed with the help of an affiliated biostatistician in the biostatistics unit of Samsung Biomedical Research Institute. The results were analysed using

statistical analyses software (SAS, SAS Institute Inc, Cary, NC). Cortical bone thickness, insertion torque, and ISQ values were analysed with a mixed model considering random effects between subjects using Tukey's method. *P*-values were corrected using Bonferroni's method to prevent inflated type I error. The significance level of these tests (*P*) was .05.

RESULTS

Cortical bone thickness, insertion torque, and ISQ values are shown in Table 1. The original thickness of cortical bone ranged from 2.71–3.18 mm. All cortical bone was removed when creating 5-mm deep defects. However, thin cortical bone remained in the 2.5-mm deep defects. Insertion torque differed according to defect type and depth. Insertion torque in the control (17.93 ± 11.64) was significantly higher than that in any of the defects ($P < .05$). Insertion torque in the 2.5-mm deep defects was higher than that in the 5-mm deep inserts.

ISQ values varied widely according to defect type and depth. The ISQ value of circumferential 5-mm defects was the lowest (56.07 ± 8.51), while that of the control was the highest (84.70 ± 5.52). As the defect size increased for the same defect depth, the ISQ value decreased ($P < .001$). For 1-wall and circumferential defects, the ISQ values of the 2.5-mm defects were greater than those of the 5-mm defects ($P < .0001$). In 3-wall defects, the mean ISQ value of the 5-mm defects (81.74 ± 3.32) was higher than that of the 2.5-mm defects (80.93 ± 4.88).

We measured ISQ values from 4 directions to evaluate the effect of the measurement direction on ISQ values (Table 2). Measurements were repeated 3 times in each direction. There were significant differences between the ISQ values obtained in different measurement directions only between the control and 3-wall 5-mm defect ($P < .0001$). In the control group, the ISQ values at the mesial and distal sides were higher than those at the buccal and lingual sides. However, the ISQ values at the buccal and lingual sides were higher than those at the mesial and distal sides in the 3-wall 5-mm defect. In addition, the ISQ value at the distal side (defect side) was lower than that at the mesial side (the opposite side of the defect) ($P < .001$). In 1-wall and circumferential defects, there was no significant differences among the 4 directions.

In 3-wall and 1-wall defects, ISQ values were divided into 3 directions: defect direction (distal side), opposite to the defect direction (mesial side), and perpendicular to the defect direction (buccal and lingual side). ISQ values were analysed according to these 3 directions (Table 3). The ISQ value opposite to the defect direction was higher than that in the defect direction. Only 2 5-mm defect depth groups showed statistically significant differences. In the circumferential defect and control groups, measurement direction orientation could be divided into 2 directions: parallel to the rib bone direction (mesial and distal direction) and perpendicular to the rib bone direction (buccal and lingual direction). ISQ values were evaluated in these 2 directions (Table 4). Although the ISQ values in the parallel direction were higher than those in the perpendicular direction, this difference was not significant ($P > .05$).

The reproducibility of all ISQ values measured 3 times was evaluated using a mixed effect model considering random

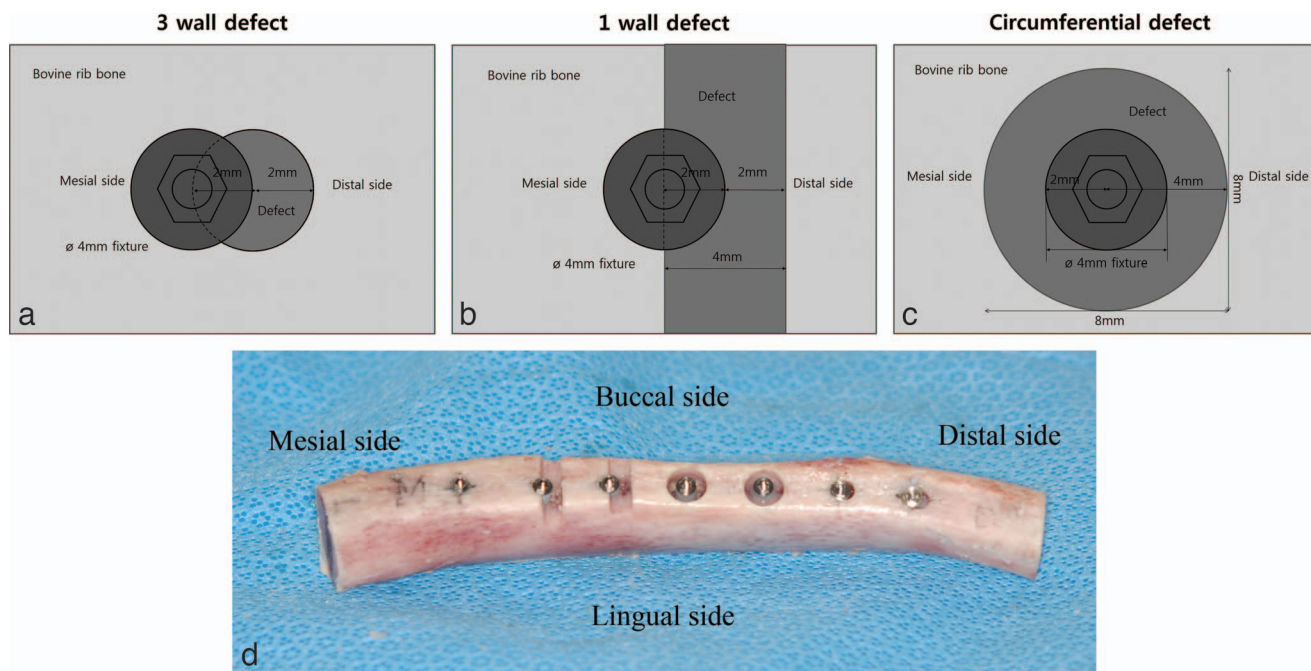


FIGURE 1. Schematic drawings of defect types (occlusal view) and photo of bovine rib bone after installation of seven implants. (a) 3-wall defects. (b) 1-wall defects. (c) Circumferential defects. (d) Control and 6 kinds of defects in bovine rib bone. From left side (mesial side, opposite side of the defect) no defect, 1-wall 5-mm defect, 1-wall 2.5-mm defect, circumferential 5-mm defect, circumferential 2.5-mm defect, 3-wall 5-mm defect, and 3-wall 2.5-mm defect. The defect side was considered the distal side.

effects to obtain the intraclass correlation coefficient (ICC). ICC was 0.993 (95% CI for ICC [0.991–0.995]).

Discussion

Implant stability is an important factor in evaluating implant success.²⁰ The ISQ value is widely used to monitor implant stability objectively. ISQ values are affected by many factors.^{3,7-15} When ISQ measurements are performed after implant installation, the effect of marginal bone loss after implant placement can be masked by the ongoing healing process in a clinical setting. In our previous study, we recorded bone levels and ISQ values during the early healing phase following implant placement;²¹ measurements were performed every week for 12 weeks. Mean marginal bone loss over 12 weeks was 1.28 ± 0.51 mm on the mesial side and 1.32 ± 0.57 mm on the

distal side of the implants. ISQ values were not significantly correlated with bone loss. Although this result could be due to bone loss lower than the threshold at which ISQ can discriminate,²² corticalisation of the surrounding bone during the healing process likely compensated for the loss of implant stability.

After initial marginal bone loss following implant placement, peri-implant defects can alter the ISQ value. We designed this study to evaluate the effect of defect type and depth on implant stability. The amount of cortical bone surrounding the implant fixture changes according to defect type and depth, and influences the stiffness of the implant-bone interface. Winter et al¹⁴ showed that implant stability increased as the thickness of cortical bone increased using finite element analysis. Tozum et al¹⁷ showed that an increase in peri-implant circular bone loss might decrease ISQ values using acrylic models. Hong et al³ also

TABLE 1

Cortical bone thickness (mm), insertion torque (Ncm), and implant stability quotient (ISQ) value of the 6 defect types and control.

Defect Type	Thickness of Cortical Bone (mm)	Insertion Torque (Ncm)	ISQ Value
Control	2.82 ± 0.72	17.93 ± 11.64	84.70 ± 5.52
3-wall 2.5 mm	2.79 ± 0.80	7.64 ± 3.34*†	80.93 ± 4.88*†
3-wall 5 mm	2.71 ± 0.75	5.86 ± 2.14*	81.74 ± 3.32
1-wall 2.5 mm	3.00 ± 0.83*†	8.00 ± 7.98*	73.36 ± 7.49*†
1-wall 5 mm	3.18 ± 1.12*	6.71 ± 4.84*	69.77 ± 8.93*
Circumferential 2.5 mm	2.89 ± 0.76†	3.79 ± 2.86*†	65.07 ± 7.31*†
Circumferential 5 mm	3.07 ± 0.65*	1.71 ± 1.20*	56.07 ± 8.51*

*Significant difference between the control and indicated defect type.

†Significant difference between 3 different depth defect types.

TABLE 2
Comparison of implant stability quotient (ISQ) values according to the measurement direction.

Defect Type	Buccal Side	Lingual Side	Mesial Side	Distal Side	P Value
Control	82.52 ± 6.71*†	82.60 ± 6.81‡§	86.57 ± 2.70	87.10 ± 2.57	<.0001
3-wall 2.5 mm	80.29 ± 5.94	81.36 ± 4.34	81.19 ± 4.81	80.90 ± 4.36	
3-wall 5 mm	83.31 ± 2.65*†	82.90 ± 3.09‡§	81.07 ± 3.02	79.69 ± 3.23	<.0001
1-wall 2.5 mm	73.05 ± 8.94	72.12 ± 9.06	74.55 ± 5.43	73.74 ± 5.81	
1-wall 5 mm	69.52 ± 8.22	69.71 ± 9.26	71.31 ± 9.15	68.52 ± 9.14	
Circumferential 2.5 mm	64.52 ± 7.31	65.14 ± 7.23	65.43 ± 7.23	65.17 ± 7.69	
Circumferential 5 mm	55.93 ± 7.11	55.10 ± 7.31	56.83 ± 9.94	56.40 ± 9.52	

*Buccal side vs mesial side.
†Buccal side vs distal side.
‡Lingual side vs mesial side.
§Lingual side vs distal side.
||Mesial side vs Distal side.

studied the influence of cortical bone on primary stability using 2 different types of polyurethane bone models. Cortical bone 1.5-mm thick increased the ISQ value significantly. In our study, defect type and depth affected the amount of cortical bone remaining, as well as the ISQ values. As defect size increased and loss of cortical bone increased, ISQ values decreased. Although bovine rib bone is thicker than human alveolar bone, all cortical bone was removed when creating 5-mm defects. However, a thin cortical bone layer remained in the 2.5-mm defect groups. This difference was responsible for the significant ISQ value difference between 2.5-mm defect and 5-mm defect group in the 1-wall and circumferential defects. This difference was also found in all 4 measurement directions. However, there was no significant difference in the ISQ values in the 3-wall defects. Loss of cortical bone in the 3-wall defects might not have been sufficient to influence the stability of the implant.

Rodrigo et al²³ reported that no Straumann implant with ISQ ≥60 failed, while 19% of implants with ISQ ≤60 failed before the placement of the prosthetic restoration. The ISQ values of all groups (except the circumferential 5-mm group) was over 60 in this study. Because of thick cortical bone, the ISQ values was over 80 in the control and 3-wall defect type. However, the ISQ value in circumferential 5-mm defect type was less than 60. In a clinical situation, additional treatment to improve primary stability should be considered to reduce the possibility of implant failure.

Valderrama et al²⁴ suggested that the specific orientation of measurement could affect the resonance frequency analysis reading, based on their observations that ISQ values were

significantly different whether the transducer was parallel or perpendicular to the alveolar crest. Veltri et al²⁵ and Fischer et al²⁶ showed that buccal-palatal measurements were lower than mesial-distal measurements in totally edentulous maxilla. When they measured the ISQ value perpendicular to the bony crest, they found that the ISQ values were 8 to 10 units lower than those measured in the parallel orientation. In the current study, we found that in addition to the ISQ measurement direction, the defect type and direction of the defect also influenced ISQ values. ISQ values in the perpendicular orientation were 4 units lower than those in the parallel orientation in the control, and this difference was significant (*P* < .0001). The orientation of the transducer also influenced the ISQ values in the 3-wall 5-mm defects. The ISQ values of the distal side of 3-wall 5-mm defects were 1–4 units lower than those of the other sides (*P* < .0001).

In this study, defect depths of 2.5 mm and 5 mm resulted in significant difference in ISQ values for all defect types except 3-wall 5-mm defects. Lachmann et al,²² using an ISQ measuring device, reported a threshold of 2 mm (range: 1–3 mm) for RFA discrimination of bone loss. They recommended that because many factors—such as implant length and implant diameter—can influence the threshold, the threshold should be applied to follow-up on the same implant. Turkyilmaz et al¹³ demonstrated a negative correlation between peri-implant vertical bone defects and ISQ values in a cadaver model. The average ISQ values were calculated for 4 bone defect sites, and it was found that ISQ values decreased at a rate of 2.7 ISQ/mm.

TABLE 3
Paired comparison of implant stability quotient (ISQ) values according to the measurement direction in 3- and 1-wall defects

Defect Type	Buccal & Lingual (Perpendicular to the Defect Direction)	Mesial side (Opposite to the Defect Direction)	Distal Side (Defect Direction)	P Value
3-wall 2.5 mm	80.82 ± 5.20	81.19 ± 4.81	80.90 ± 4.36	
3-wall 5 mm	83.11 ± 2.87*†	81.07 ± 3.02‡	79.69 ± 3.23	<.0001
1-wall 2.5 mm	72.58 ± 8.96	74.55 ± 5.43	73.74 ± 5.81	
1-wall 5 mm	69.62 ± 8.70	71.31 ± 9.15‡	68.52 ± 9.14	.0154

*Buccal and lingual vs mesial.
†Buccal and lingual vs lingual.
‡Mesial vs distal.

TABLE 4

Paired comparison of implant stability quotient (ISQ) values according to the measurement direction in control and circumferential defects.			
Defect Type	Buccal and Lingual Side (Perpendicular to the Rib Direction)	Mesial & Distal Side (Parallel to the Rib Direction)	P Value
Control	82.56 ± 6.72*	86.83 ± 2.63	<.0001
Circumferential 2.5 mm	64.83 ± 7.23	65.30 ± 7.42	
Circumferential 5 mm	55.51 ± 7.18	56.62 ± 9.68	

*Perpendicular to the rib direction vs parallel to the rib direction.

CONCLUSION

RFA is a nondestructive method used extensively in clinical research to monitor implant stability due to its high reproducibility.² Repeated measurement of ISQ values during this study confirmed the high reproducibility of ISQ values.

The limitations of this study include the small number of samples and variation among rib bone samples. Despite these limitations, however, we demonstrated that ISQ values of 1-wall and circumferential defects were influenced by defect type and depth. Loss of cortical bone reduced implant stability and ISQ values. Measurement direction also influenced ISQ values.

ABBREVIATIONS

ISQ: implant stability quotient

RFA: resonance frequency analysis

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