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Can resonance frequency analysis detect narrow marginal bone defects around dental implants? An *ex vivo* animal pilot study

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ABSTRACT

Background: Resonance frequency analysis (RFA) is applied to assess implant stability, as expressed by the implant stability quotient (ISQ). This study aimed to investigate the potential of RFA devices to identify narrow marginal bone defects around implants.

Methods: Twenty-eight Straumann bone level (BL) implants and 28 bone level tapered (BLT) implants were placed *ex vivo* in porcine ribs. Implants in the control group (A) were fully submerged in the bone. In three experimental groups, implants were placed with a 0.9-mm circumferential marginal bone defect extending 2 mm (B), 4 mm (C) and 6 mm (D) apically. Two RFA devices were used to measure implant stability.

Results: ISQ values decreased as the defects' depth increased, with the greatest reduction observed between full bone (A) and 2-mm defects (B) ($P < 0.001$). No significant differences were found in the ISQ values recorded from BL and BLT implants.

Conclusions: ISQ values can effectively detect narrow, intrabony marginal bone defects, in particular when involving the first coronal 2 mm. This finding could have implications for the early diagnosis of conditions affecting the marginal bone, such as peri-implantitis. Further research is required to investigate if such findings can be replicated after osseointegration is achieved.

Keywords: bone defect, peri-implantitis, resonance frequency analysis, stability, tapered implants.

Abbreviations and acronyms: BIC = bone–implant contact; BLT = bone level tapered; BT = bone level; ISQ = implant stability quotient; RFA = resonance frequency analysis; SD = standard deviation.

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INTRODUCTION

Plaque-induced peri-implantitis is today among the major threats to the long-term success of dental implant therapy and it is characterized among other signs by gradual loss of marginal bone.[1] Other possible causes of marginal bone loss around implants such as overloading or adverse loading have been reported in the literature, although this remains a controversial topic.[2] Regardless of the cause, the diagnosis of marginal bone loss around implants relies primarily in periapical radiography, an instrument with low sensitivity and limited ability to detect initiating marginal bone defects. Even with standardized radiographs, the potential to positively identify bone level changes of 1 mm with periapical radiographs remains low.[3] Consequently, narrow marginal bone defects may be overlooked until an advanced and most likely irreversible state of disease has been reached. Clinical peri-implant evaluation during the maintenance is necessary for detecting the early signs of disease and for staging the appropriate treatment intervention. Therefore, the parameters routinely used to monitor implant stability during maintenance care should be of high sensitivity and/or specificity, be easy to measure and yield reproducible data.[4]

Approximately 20 years ago, Meredith and co-workers developed Resonance frequency analysis (RFA) as a means to measure implant stability.[5] The commercial product Osstell™ and its transducer (Smartpeg™; Osstell, Gothenburg, Sweden) have been available since then. More recently, a new instrument was developed with the name Penguin™ and a transducer (Multipeg™; Penguin Integration Diagnostics, Gothenburg, Sweden) made of titanium. Through measuring the resonance frequency of the transducer, both instruments can generate the implant stability quotient (ISQ) expressing the stability of implants (stiffness of the bone–implant interface). The mechanical properties of a bone–implant interface have been indicated as the major factor in determining ISQ value.[6,7] This introduces the concept of stiffness, which is the rigidity of an object. It reflects the extent to which it resists deformation in response to an applied force.[5] In RFA, stiffness is a combination of bone–implant contact (BIC) and bone density around the implant.[8] Several studies have documented the use of RFA for the purpose of monitoring the progress of osseointegration;[9] there is, however, no research investigating the possible impact of disintegration, in particular initial marginal bone loss as it would occur in conditions such as peri-implantitis.

Another aspect that seems to influence resonance frequency is the implant design.[10] The Straumann (Basel, Switzerland) bone level tapered implant (BLT) has an apically tapered implant body with three cutting notches. This self-tapping effect is reported to deliver increased primary stability by actively engaging the apical bone, especially in soft bone and fresh extraction sockets.[11,12] In clinical settings, this is often strengthened by slight underpreparation of the osteotomy with the final drill. The underprepared osteotomy walls increase the friction and resistance to implant insertion, which is suggested to increase insertion torque.[13] However, as primary implant stability is influenced by multiple factors (local bone quality, bone quantity, implant design and surgical techniques) the overall benefit of the apical tapered design is yet to be further evaluated.[14,15]

The purpose of this pilot study was to investigate whether ISQ values are able to predict circumferential defects of approximately 0.9-mm jump gap with varying depths. Furthermore, the study aimed to compare the ISQ values produced by two different implant designs (bone level implant (BL) and BLT) and two different RFA devices.

METHODS

Fresh young porcine ribs with an axial diameter between 12 and 16 mm were obtained. Tissue was not frozen and directly used for the *ex vivo* experiment. Ribs were fixed into a solid metal base. The soft tissues were carefully dissected and the bone was exposed. The positions of implants were marked. An implant bed for a 3.3 mm × 12 mm implant was prepared in sequence according to manufactures' instructions (round bur, 2.2 and 2.8 full-length drill, profile drill) and efforts were made to keep each site preparation consistent. All osteotomies were prepared by one operator. The bone structure of the porcine rib in this dimension is similar to the architecture of type III–IV bone, with an outer layer of cortical bone (2–3 mm) and mainly spongious internal architecture (Fig. 1).[16] After completion of the osteotomy, marginal bone defects were created at different depths with a 4.2-mm drill. Depending on the defect, the following groups were identified (Fig. 2):

(1) Group A, implant placed in full bone: (i) BL implant of 3.3 mm × 12 mm, eight implants; or (ii) BLT implant of 3.3 mm × 12 mm, eight implants.

(2) Group B, circumferential defect of 0.9 mm for the first coronal 2 mm: (i) BL implant of 3.3 mm × 12 mm, seven implants; or (ii) BLT implant of 3.3 mm × 12 mm, seven implants.

(3) Group C, circumferential defect of 0.9 mm for the first coronal 4 mm: (i) BL implant of 3.3 mm × 12 mm, seven implants; or (ii) BLT implant of 3.3 mm × 12 mm, seven implants.

(4) Group D, circumferential defect of 0.9 mm for the first coronal 6 mm: (i) BL implant of 3.3 mm × 12 mm, six implants; or (ii) BLT implant of 3.3 mm × 12 mm, six implants.

Twenty-eight BL implants and 28 BLT implants (Straumann) were then placed in the respective osteotomies.

After the placement of the implants, six consecutive measurements with Osstell/Smartpeg and Penguin/Multipeg were taken, three from the buccal and three from the mesial direction (Fig. 3). Each consecutive value was recorded. The mean of the six values was calculated as the final ISQ of each implant.

All data were analysed with descriptive methods. To compare the mean differences in two groups, a two-sample *t*-test was used. When analysing non-parametric data, a Wilcoxon rank sum test and Kruskal–Wallis test were used. To compensate for multiple testing situations, the Mann–Whitney *U*-test was applied and the *P*-values were corrected by using the Bonferroni adjustment procedure and compared with the alpha level of 0.05. All statistical analyses were conducted by using SPSS version 21 software (SPSS, Chicago, IL, USA).

RESULTS

Bone defects and ISQ

There was a strong correlation between the ISQ values and the presence and depth of a circumferential defect (Table 1). However, a significant drop in the ISQ values was only detected for the loss of the first 2 mm, which increased (but not as dramatically) with 4 and 6 mm (Fig. 4).

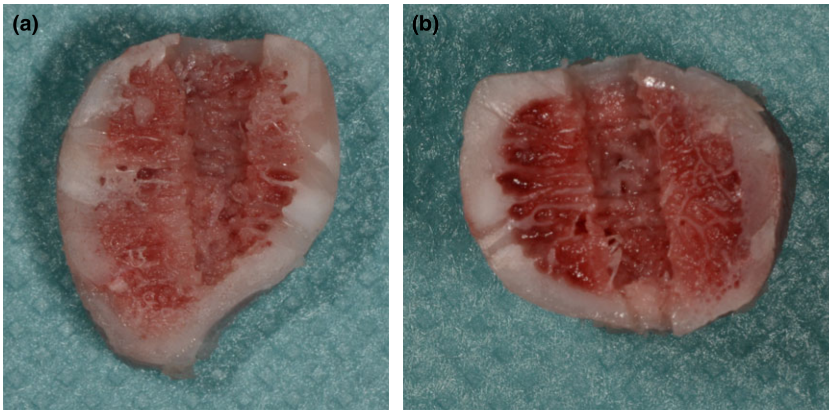

Fig. 1 Young porcine bone model in axial diameter, simulating type IV bone morphology. (a) Bone level tapered implant osteotomy. (b) Bone level implant osteotomy.

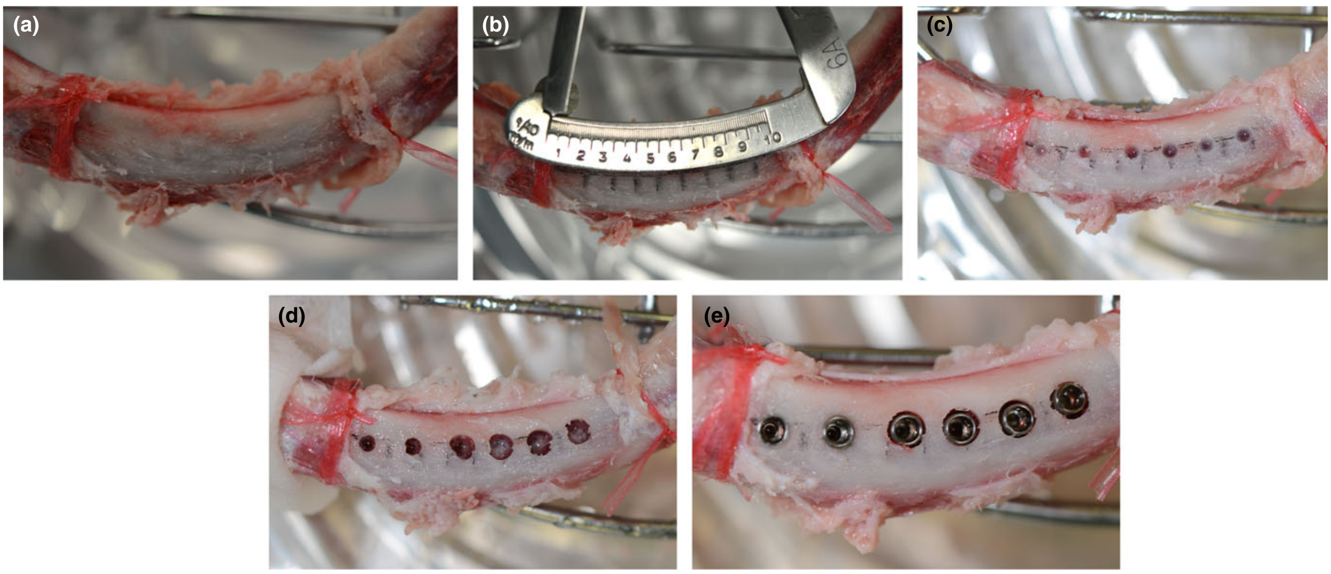

Fig. 2 Preparation of the osteotomy. (a) Fixation of the porcine ribs. (b) Marking of the sites. (c) Location of the osteotomies for six implants. (d) Final osteotomies with marginal bone defects. (e) Final implant placement.

BL and BLT implants

Generally, ISQ values decreased as the defect depth increased around both BL and BLT implants, but there was no significant difference between BLT and BL implants in all bone defect types (Table 2).

RFA devices

There was a strong correlation in the values provided by the two devices. Penguin appeared to give consistently slightly higher numerical values by 2–3 than Osstell (Tables 3,4).

DISCUSSION

Bone defect and implant stability

Bone–implant contact has been suggested as a critical determinant of implant stability.[8,17] Consequently, it is suggested that the amount of BIC impact is reflected in the ISQ values. However, the exact relation of BIC with the ISQ values, as well as the quality characteristics of this relation are not well understood. Some authors suggested that BIC does not have a linear correlation with ISQ,[7] as bone is a viscoelastic material and its response to mechanical stimuli is not easily predictable. Furthermore, the mineral density of the bone is not evenly distributed throughout the BIC surface. Typically, cortical bone appears at coronal BIC and reportedly forms a major contributor to implant stability.[6,18] In a simulation experiment, Ito *et al.* used three screws to stabilize an implant at four different levels. The resonance frequency decreased when unscrewing the most coronal screws but not with the loss of the more apical screws, which suggests that the marginal region is the most significant contribution to the outcome of RFA measurements.[8]

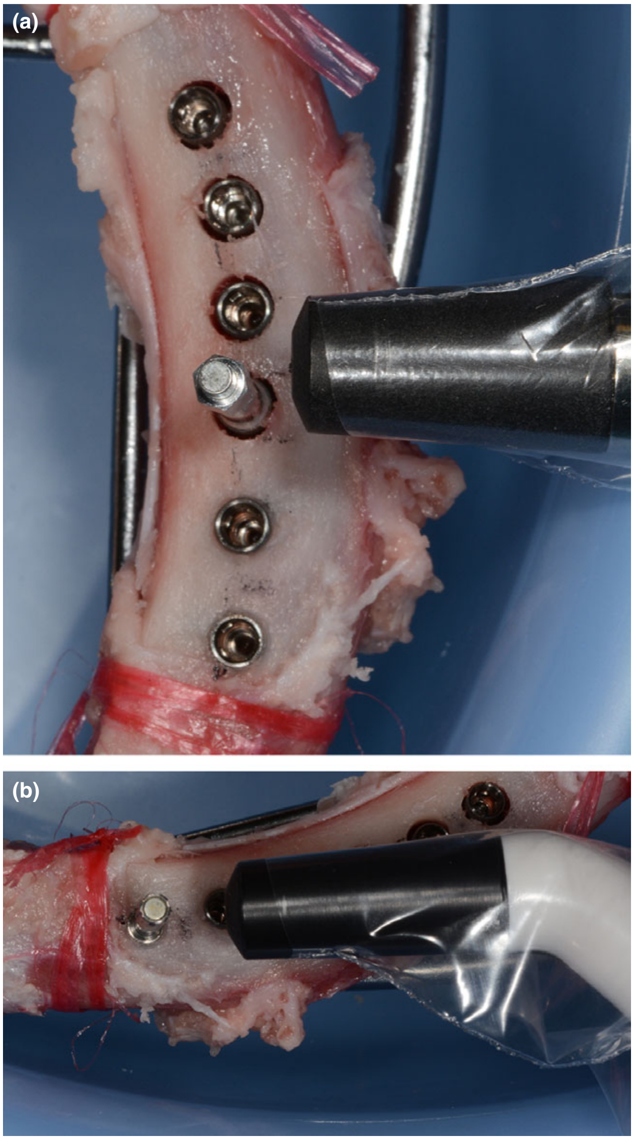

Fig. 3 Resonance frequency analysis measurement. (a) Osstell. (b) Penguin.

Table 1. ISQ values compared between different bone defects

	Bone condition	N	Mean (SD)	Multiple comparison*
Measurement	Full bone	16	78 (3.30)	Full bone >
	2-mm defect	14	60 (2.71)	2-mm defect =
	4-mm defect	14	57 (5.27)	4-mm defect =
	6-mm defect	12	52 (11.81)	6-mm defect
P†			<0.001	

*Mann–Whitney *U*-test, $P < 0.00833$.
†Kruskal–Wallis test.
ISQ = implant stability quotient; SD = standard deviation.

It is therefore reasonable to assume that even infrabony marginal defects with a small jump gap (e.g. <1 mm) could significantly influence the ISQ value. A recent study evaluated the defect type and depth on implant stability in an *ex vivo* bovine rib bone model.[19] The cortical bone thickness ranged 2.71–3.18 mm. Two-depth circumferential defects (2.5 mm and 5 mm) around the implant were prepared, which meant all cortical bone was removed when creating 5-mm defects. The ISQ value of the 2.5-mm defects were greater than those of the 5-mm defects. The author then concluded that loss of cortical bone reduced implant stability and ISQ values. In a cadaver mandible study, Turkyilmaz *et al.* demonstrated a negative linear correlation between peri-implant vertical bone defects and ISQ values.[20] All teeth in the cadaver were extracted and natural sockets were presented. The vertical defect depths from the implant shoulder to the first BIC at four sites (mesial, buccal, distal and lingual) were measured and five different vertical depths were recorded (1 mm, 2 mm, 3 mm, 4 mm and 5 mm). After RFA by Osstell, ISQ values presented a corresponding decrease of approximately 2.7 ISQ/mm. In our study,

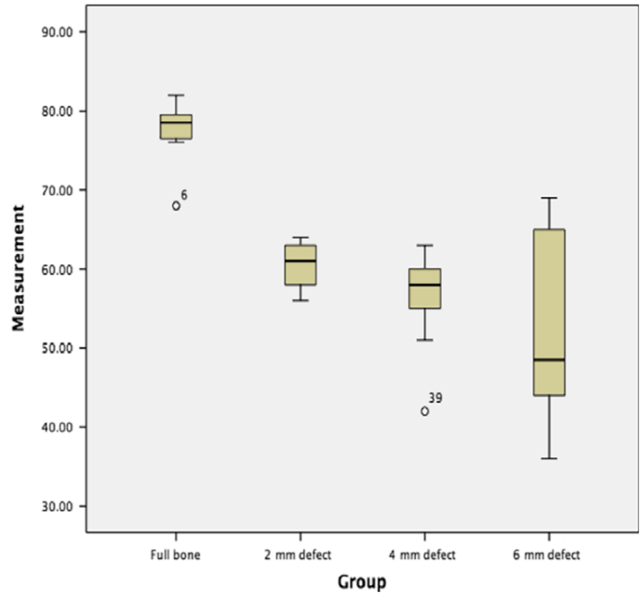

Fig. 4 Implant stability quotient values compared in four bone conditions.

Table 2. BLT and BL implant comparison in four bone conditions

	Mean (SD)			
Implant	Full bone	2-mm defect	4-mm defect	6-mm defect
BLT	78 (4.31)	61 (2.75)	59 (2.79)	47 (10.95)
BL	78 (2.12)	60 (2.85)	55 (6.35)	58 (10.37)
*P**	0.665	0.710	0.107	0.091

*Two-sample *t*-test.
BLT = bone level tapered; BT = bone level; SD = standard deviation.

Table 3. Penguin and Osstell comparison in four bone conditions

	Mean (SD)				
Device	Full bone	2-mm defect	4-mm defect	6-mm defect	*P**
Penguin	80 (3.93)	62 (2.76)	59 (3.92)	53 (10.32)	<0.001
Osstell	76 (3.36)	60 (2.71)	57 (3.02)	49 (11.99)	<0.001
P†	0.001	0.002	0.005	0.007	

*Kruskal–Wallis test.
†Wilcoxon rank sum test.
SD = standard deviation.

Table 4. ISQ values of BLT and BL implants generated by Penguin and Osstell

		Mean (SD)	
Implant	Device	BLT	BL
	Penguin	64 (12.42)	65 (11.19)
	Osstell	61 (12.32)	62 (10.43)
*P**		<0.001	<0.001

*Wilcoxon rank sum test.
BLT = bone level tapered; BT = bone level; ISQ = implant stability quotient; SD = standard deviation.

only the first 2-mm defects showed a significant ISQ value drop, which corresponds to the loss of the coronal cortical bone. When defects were 4 and 6 mm, the corresponding reduction in ISQ values was much less.

As the corono-apical length of the bone utilized varied between 12 and 16 mm and the implant length was 12 mm, it is anticipated that at times the implants would have achieved a bicortical stabilization, thus presenting with higher ISQ values. As this event would occur randomly between the different groups, and the test and control implants were placed very near, we would not expect any systemic influence in the outcomes of this study.

The implants placed in this experiment were not osseointegrated. The measured ISQ values correspond to primary stability and not the stability of an osseointegrated implant. Nevertheless, as BIC appears to be the common denominator between primary and secondary stability, it is not unreasonable to expect a similar pattern to apply for osseointegrated implants, when marginal bone loss is initiated due to peri-implantitis. If this finding is confirmed in osseointegrated implants with initial stages of peri-implantitis, it may allow for an early diagnosis of marginal bone breakdown through the detection of a significant drop in the ISQ value. Such a diagnostic tool may be a significant aid in the early diagnosis of peri-implantitis. This is further supported by the results of Sennerby *et al.* in experimental peri-implantitis, where the authors found the resonance frequency values to decrease correspondingly to the bone loss during the active phase.[21] Nevertheless, routine RFA examinations of osseointegrated implants will require removal of the prosthesis at regular intervals, which may not be possible or convenient and cannot be recommended in the absence of strong evidence for its efficacy. Further investigations in clinical settings will be required to confirm this hypothesis and reveal the further potential of RFA as an early detection method for marginal bone loss.

BL and BLT implants

The reduction pattern in the ISQ values was similar for BL and BLT implants, despite the difference in design. It appears that for both designs the major factor for stability reduction was the loss of the coronal cortical bone. At this point one has to note that the utilized model corresponded to type IV bone quality. Furthermore, the BLT implant was placed in osteotomies prepared at full length, while in clinical application clinicians will often underprepare the osteotomy by 1–2 mm in order to benefit from the implant's self-cutting tapered apex. Primary stability is the result of compression of the bone tissue in a lateral direction and clamping of bone between the threads and collar in an axial direction.[9] An increase in bone quality (e.g. from type 4 to 1) improves primary stability when the same surgical procedure is used.[22] However, when bone density is low, the clamper effect may not be so significant.[23] In a similar study, Senneby and co-workers compared two different types but the same coronal diameter implants with corresponding drill protocol.[24] In contrast to the present results, the authors concluded that placement of the marked tapered implants by using tapered drills resulted in higher primary stability than the subtle tapered implants when straight drills were used. Nevertheless, as different implant system and drilling protocols were used, the results may be not directly comparable.

Studies showing significant improvement in implant stability have typically compared tapered and parallel implants without specific diameter criteria.[13,25,26]

Overall, in the literature there appears to be a wider agreement of results showing the tapered implant design to be superior to parallel implants in terms of implant primary stability,[15,27] although exceptions do exist.[28]

Penguin and Osstell

At present, few studies have been reported regarding the efficacy of devices to conduct RFA.[29] RFA essentially applies a bending load, which mimics the clinical load and direction and provides information about the stiffness of the implant–bone junction.[9] The value produced by devices is a combination of BIC and bone density around the implants. To the best of our knowledge, this is the first study to explore the primary stability of BLT and BL implants with the RFA device Penguin. The Osstell and Penguin devices offer non-contact measurements and can generate ISQ directly without individual calibration, which allows for convenient clinical use. Smartpeg is the transducer of Osstell. It is made of alumina. According to Sennerby, one drawback of Smartpeg is that any attempt to clean and sterilize the peg could create corrosion and result in problematic measurements.[30] Penguin uses a Multipeg, which is made of titanium and can be sterilized and used repeatedly. In this study, both devices were shown to measure the ISQ value effectively, and there was a very high correlation between the readings. Penguin appeared to give a somewhat better consistency of readings, as there were fewer "outlying" results (i.e. single results in each set of three that appear to be more than 15 units different than the other two).

CONCLUSIONS

In this *ex vivo* experimental study, ISQ values around freshly placed implants were shown to significantly drop at the presence of a narrow circumferential bone defect of 2-mm depth. The ISQ values generated by two devices decreased as the circumferential defect depths increased, but to a much lesser extent. The measurements from both devices were highly correlated, while parallel and tapered implant design showed no significant differences in ISQ values.

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Dr Nikos Mattheos designed the study, developed the methodology, carried out the experimental implant placement and measurements, revised the manuscript and approved the final manuscript. Dr JY Coral participated in the design and methodology, was responsible for the data analysis/interpretation and compiling the manuscript. Dr L Ma contributed to the study design and execution and data collection.

DISCLOSURE

Implants for this study were donated by Straumann (Basel, Switzerland).

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