RESEARCH

Initial Stability Measurements of Implants Using a New Magnetic Resonance Frequency Analyzer With Titanium Transducers: An Ex Vivo Study

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The establishment of dental implant stability is mandatory for successful osseointegration. Resonance frequency analysis (RFA) is the most frequently used method for the clinical measurement of implant stability. The purpose of the present study was to evaluate the reliability of the recently developed RF analyzer Penguin RFA and to compare it with the traditional RF analyzer Osstell ISQ. Sixty implants were inserted into fresh steer vertebrae and pelvis. Implant stability was measured using Penguin RFA by its transducers (multipegs) and Osstell ISQ by its transducers (smartpegs). Additionally, stability was measured by multipegs with Osstell ISQ and by smartpegs with Penguin RFA. The intraobserver and interobserver reliability of Penguin RFA were estimated by the intraclass coefficient (ICC). Mean implant stability quotients (ISQs) measured with Osstell ISQ were higher than the ISQs measured with Penguin RFA ($P < .05$). The intra- and interobserver reliability of Penguin RFA were considered as excellent (ICC > 0.7). For Osstell ISQ, no significance in ISQs was detected between the readings by smartpegs and multipegs ($P > .05$), while for Penguin RFA ISQs by smartpegs were significantly higher than the ISQs by multipegs ($P < .05$). The recently developed Penguin RFA is reliable and can be used in clinical practice for the measurement of dental implant stability regardless of the bone type. The multipegs originally manufactured for the Penguin RFA is also compatible with Osstell ISQ.

Key Words: osseointegration, implantology, experimental design, implant stability, resonance frequency, dental implant

INTRODUCTION

Stability of an implant is considered as a prerequisite for the development of successful osseointegration.[1] Implant stability can be monitored in two different stages: primary stability, which is the stability immediately after implant surgery; and secondary stability, which is the stability afterward in the next phase.[1,2] Establishment and preservation of stability have been reported as key factors in the success and survival of dental implants.[1–3] Therefore, stability of an implant should be monitored right after the surgery, as well as at the loading time and at the follow up periods. A simple, reliable, and noninvasive method should be preferred for the measurement of implant stability. Resonance frequency analysis (RFA) is a commonly used method for the clinical measurement of stability.[4–9]

RFA was initially designated by Meredith.[1] In the beginning, an electronic device was manufactured that used a direct connection between an L-shaped transducer with a vertical beam with two attached piezo-ceramic elements and the resonance frequency analyzer.[1,10] The transducer was used by fastening it with a screw to the implant body or abutment. The working principle of the system was transmission of a sinusoidal signal over the range of 5–15 kHz in steps of 25 Hz by one of the piezo-ceramic elements and analyses of the response of the transducer to the vibration by the other piezo-ceramic element.[1,5,10] Initially, the manufactured RFA device was capable of measuring the stability in Hertz; but with the improvement of the device, the values were later transformed to implant stability quotient (ISQ) units which are much easier to record and analyze. ISQ units range from 1 to 100, where 1 indicates the lowest and 100 indicates the highest stability.[7,11] This cabled device was branded with the name of the manufacturer as the Osstell device and has been used successfully for many years. However, some shortcomings (e.g., difficulty in mounting on the implants with the cable and availability for only a few implant systems[10]) forced the manufacturing company to fabricate a more user-friendly wireless device, which was named as Osstell Mentor. In this new system, the L-shaped transducer is instead a magnetic aluminum transducer (measurement peg) and called a "smartpeg." After screwing a smartpeg into an implant, the probe of the Osstell Mentor is held perpendicular to the smartpeg. When the probe identifies and stimulates the magnetic part of the smartpeg, the smartpeg starts to vibrate and resonance frequency is output electromagnetically as ISQ and the stability value can be read in the digital screen of the RFA device.[12,13]

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More recently, the same company introduced Osstell ISQ as the latest version, which uses the same magnetic technology as the Osstell Mentor. In this latest version of Osstell, the company claims that it is less reactive to electromagnetic noise, more efficient and user-friendly, and faster measurements can be achieved.[12] Nevertheless, reliable results have been shown in the measurement of primary stability in many in vitro and clinical studies with the new and old versions of Osstell, which has over 20 years of history.[4–9,14] However, it is very important to compare and analyze both versions in order to make real judgements of the stability values of implants in the scientific literature.

It has been shown that ISQ measurements of the Osstell Mentor are 8–12 higher than the original cabled Osstell device in a clinical study.[15] However, ISQs of the Osstell Mentor and the newest Osstell ISQ did not differ in an ex vivo study.[12] Therefore, ISQs of the two magnetic devices may be compared with each other longitudinally, but the ISQs of the cabled and the magnetic devices cannot be compared directly.

More recently, another RF analyzer working with the same electromagnetic technology has been developed by a different company and commercialized with the name of Penguin RFA. The measurement pegs of the Penguin RFA are called "multipegs" and they are made of titanium, which is the most noticeable difference from smartpegs that are made of aluminum. Smartpegs can only be used once because they cannot be sterilized. The main advantage of the Penguin system is that the titanium multipegs can be sterilized and used multiple times (up to 20 measurements). Currently, scientific data with the Penguin are very limited, and only a few studies have evaluated the reliability and consistency of this device.[16–18]

In an ex vivo study, Yao et al[16] reported no significant differences and a strong correlation between the the Osstell Mentor and the Penguin RFA, but a better consistency of readings from the Penguin RFA. However, the main subject of their study was the detection of narrow marginal bone defects around dental implants. Comparison of the Osstell and the Penguin was accessory data of the study and only the correlation in the values provided by the two devices were detected.

The reliability of the Osstell ISQ and the Penguin RFA were compared in a recent in vitro study.[17] The results showed both devices were reliable only when the implants were embedded in stiff materials, but the intraclass correlation coefficient (ICC) value of the Osstell ISQ was higher than the Penguin RFA. This investigation has been performed in a completely in vitro nature and only the intraobserver reliability of Penguin RFA was evaluated.

In a clinical set-up, Becker et al[18] compared the Osstell and the Penguin RFA in 38 implants and indicated that RF evaluation were similar for both instruments. However, the reliability of the devices was not measured and the version of the Osstell instrument was not mentioned.

It is not possible to make clear decisions on the reliability or consistency of the ISQs measured with the new Penguin RFA system based on the above-mentioned few studies. Moreover, since the Osstell is widely used in the market, it is unknown whether it can read the ISQs when multipegs are used instead of smartpegs.

Therefore, the present study was conducted in order to combine the above-mentioned evaluations[16–18] in an ex vivo environment and 1) to compare ISQs obtained by the Osstell and the Penguin RFA in two types of bones, 2) to evaluate both the intraobserver and interobserver reliability of the Penguin RFA, and 3) to compare the ISQs obtained when the pegs of the Osstell ISQ and the Penguin RFA are changed.

The null hypothesis was that there would be no difference in ISQ readings between the Penguin RFA and the Ostell ISQ systems.

Materials and Methods

Specimen preparation

Fresh vertebrae and pelvis belonging to a steer that weighed 700–800 kg were collected from a butcher's shop for the experimental procedures. The bones were not frozen and directly used for the ex vivo experiment the same day after collecting. The soft tissues covering the bones were completely dissected with the use of lancets and periosteal elevators to expose the bones.

To evaluate as a model for soft and hard human jawbone, the pelvis and the vertebrae were used for implant placements. According to the Lekholm and Zarb classification,[19] the pelvis was similar to type I- and type II-quality bone and the vertebrae were similar to type III-quality bone.

Sixty implants with dimensions of 3.5 mm diameter $\times$ 11 mm length belonging to the same manufacturer (Neoss straight ProActive, Neoss System, Neoss Ltd, Harrogate, UK) were selected for the experimental procedures. Implant beds were prepared by a professional oral and maxillofacial surgeon blinded to the study protocol following the drilling protocols recommended by the manufacturer with a safe distance from each other. After preparing the implant beds, each implant was inserted until its rough area was completely inserted into the bone.

The sample size of 30 was selected with the outcome of power analysis. At least 15 implants for each bone type were required to detect the differences depending on the calculation with 5% alpha errors and 90% power of test ($d = .809$, standard deviation $= .90$). For each type of bone, 30 implants were placed and evaluated for stability measurements.

Implant stability measurements

The RFA measurements with the Penguin RFA device were carried out by 3 prosthodontists who were blinded to the study protocol. Multipegs (Multipeg; Penguin Integration Diagnostics, Gothenburg, Sweden) calibrated for Neoss implants were mounted on each implant and tightened with hand pressure (approximately 4–6 Ncm)[12] using the metallic screwdriver supplied by the manufacturer (Figure 1). The probe of the Penguin RFA was held 1 mm from the multipeg at a 90° angle and ISQ was registered on the digital screen of the instrument for each implant (Figure 2). Two consecutive measurements, one from the frontal and one from the lateral direction from

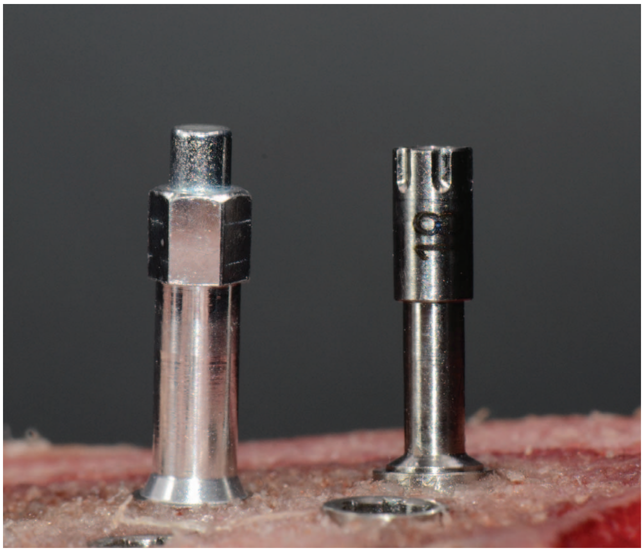

FIGURE 1. Implant stability quotients were measured after smartpegs were screwed to the implants with the Osstell ISQ (left), and multipegs were screwed to the implants with the Penguin RFA (right).

each implant, were recorded. The mean of the lateral and frontal ISQ values was considered the final ISQ of each implant. For detecting intraobserver reliability, the measurements were repeated three times[12,20] in both the frontal and the lateral directions for each implant at 2-hour intervals.

Additionally, one of the examiners made RFA measurements with the the Osstell ISQ device by using the smartpegs (Smartpeg, Integration Diagnostics, Savedalen, Sweden) calibrated for Neoss implants and using the plastic screwdriver supplied by the manufacturer (Figure 1).

After completing all of the RFA measurements, multipegs were mounted and hand screwed to all of the implants and two of the examiners measured the ISQs with the Osstell ISQ device. The same examiners also mounted the smartpegs; hand screwed to the implants and measured the ISQs with the Penguin RFA after unscrewing the multipegs.

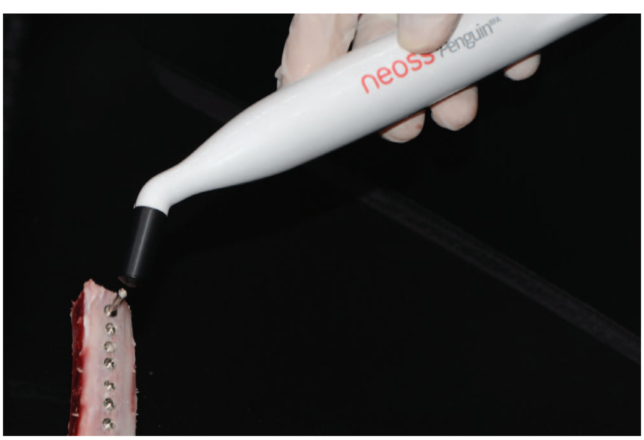

FIGURE 2. The probe of the Penguin RFA was held 1 mm from the multipeg at a 90° angle and the implant stability quotient was registered on the digital screen of the instrument for each implant.

Statistical analysis

The methodology was reviewed by an independent statistician. Statistical analysis was performed using SPSS (IBM SPSS Statistics for Windows, Version 22.0, IBM Corp, Armonk, NY). Descriptive statistics (mean and standard deviation for continuous variables, frequency for categorical variables) were calculated for all implant samples. The Shapiro–Wilk test was used to determine if the measured parameters met the assumptions of normal distribution. The results indicated that the data were not normally distributed. Wilcoxon signed-rank test was used for the comparison of ISQ values between and within the groups. The intra-observer and inter-observer reliability were estimated by the ICC. Following previous recommendations,[21–23] the two-way mixed model with measures of absolute agreement was used. The reliability was considered poor when ICC was < 0.4, fair-to-good when ICC $= 0.4$ to 0.7, and excellent when ICC was > 0.7.[23] Spearman's correlations (q) were calculated between the Penguin RFA and the Osstell data. The confidence interval was set at 95% and $P < .05$ was considered as statistically significant.

RESULTS

Results were reviewed by the independent statistician. ISQs measured by two RFA devices in two bone types are presented in Table 1. In both bone types, the mean of ISQs of frontal and lateral measurements by the Osstell ISQ were significantly higher than the mean ISQs measured by the Penguin RFA ($P < .05$). Additionally, when all the measurements were considered regardless of the bone type, frontal, lateral and mean ISQs measured by THE Osstell ISQ were significantly higher than the ISQs measured by the Penguin RFA ($P < .05$).

Mean ISQs measured with the Penguin RFA for each observer in Type I and Type III bones, and intra- and interobserver ICC values for each examiner in two bone types are presented in Table 2. For all observers, the ICC values for the intraobserver reliability were above 0.7 and therefore reliability was considered as excellent according to previous recommendations.[21–23] Additionally, the ICC values for interobserver reliability were above 0.7 and reliability were considered as excellent for both bone types.[21–23]

A statistically significant positive correlation was detected between the mean ISQs measured by the Osstell ISQ and the Penguin RFA devices ($r = 0.78$; $P < .01$). No statistically significant difference was detected between the ISQs measured with the Smartpeg-Osstell ISQ and the Multipeg-Osstell ISQ ($P > .05$), while the ISQs measured with the Smartpeg-Penguin RFA were significantly higher than the ISQs of the Multipeg-Penguin RFA ($P < .05$; Table 3). The intraobserver reliability of the observers was excellent (ICC > 0.7) for the ISQs measured with the Multipeg-Osstell; whereas it was poor for the ISQs of the Smartpeg-Penguin RFA (Table 4).

DISCUSSION

The null hypothesis that there would be no difference in ISQ readings between the Penguin RFA and the Osstell ISQ systems was rejected.

Table 1

The comparison of the implant stability quotients (ISQs) measured by two resonance frequency analysis (RFA) devices in type I and type III bones and the whole measurements

Bone Type	Measurement Direction	RFA Devices Mean ± SD (median) Osstell ISQ	Penguin ISQ	P*
Type I	Frontal	77.1 ± 4.2 (76.5)	74.72 ± 2.73 (75.16)	.001
	Lateral	78.9 ± 2.77 (77.5)	76.43 ± 2 (75.5)	.001
Type III	Frontal	72.2 ± 2.68 (72.5)	71.34 ± 2.14 (71.33)	.03
	Lateral	75.23 ± 3.54 (76)	73.55 ± 2.14 (73.83)	.002
Whole measurements	Frontal	74.65 ± 4.31 (75)	73.03 ± 2.16 (73)	.001
	Lateral	77.06 ± 3.65 (77.5)	74.99 ± 2.51 (75.33)	.001

*Wilcoxon signed-rank test.

Techniques to measure and monitor the stability of an implant give valuable benefits to clinicians with decision making both during and after the surgery.[24] More than just deciding the loading time of an implant, these techniques may lead the clinicians in taking precautions in case of increasing degree of micro-mobility both during healing time and after loading.[25] Therefore, the technique used for measuring implant stability is projected to be reliable, noninvasive, easy to use, and repeatable.[12,26]

This ex vivo study aimed to evaluate the effectiveness of a new RFA device by comparing it with the frequently used Osstell which has been used for over 20 years and has already been confirmed to be reliable, effective, and accurate previously.[5–9,11,27] Today, the literature does not provide strict evidence for the reliability of the new Penguin RFA device. Only a few studies[16–18] have reported limited information but still some significant points have to be clarified such as the repeatability of the measurements, reliability of the device, and the behavior of its transducers.

The steer vertebrae and pelvis were selected to mimic two different bone types in the present study. The vertebrae were comparable to type III-quality bone, and the pelvis was comparable to bones with type I or type II quality according to the Lekholm and Zarb classification[19] due to the macroscopic composition of the cortical and medullar bones.[5,12,27] The results showed that both devices are capable of differentiating the bone types in agreement with other studies.

According to the results of the present study, both devices measured the stability accurately and effectively with a strong positive correlation between the readings. These results are in accordance with the previous investigations.[16–18]

Reliability is a chief subject when considering the options for the appropriate stability-measuring device. In the present study, the reliability of the Osstell ISQ was not evaluated in order not to duplicate previously documented findings.[12]

According to the present findings, intraobserver and interobserver reliability of the Penguin RFA was excellent in both of the bone types. These findings indicate that it is possible to monitor the ISQs of an implant over time even if the same clinician did not perform the measurements. It has been shown that there may be variations between the Osstell ISQ measurements of different examiners.[12] Depending on the present findings, this outcome can be regarded as an advantage of this new device. The multipeg driver is made of stainless steel whereas the smartpeg driver is plastic.[12,24] The magnetic part of the peg is caught by the metallic driver facilitating insertion and tightening.[18,24] This may be the reason of excellent interobserver reliability of ISQs measured by the Penguin RFA.

In a similar ex vivo study, Yao et al[16] reported no significant difference between the readings of the Osstell and the Penguin RFA but detected slightly higher ISQ values by the Penguin RFA device in bone defects. An in vitro study[17] also reported higher ISQs in the Penguin RFA, but did not mention if this difference was significant or not because the main subject of the study was the comparison of the reliabilities of the Penguin RFA and the Osstell, but not the ISQs. Becker et al[18] reported slightly but significantly higher ISQs when measuring the primary stability

Table 2

Mean implant stability quotients measured with the Penguin RFA by each observer in type I and type III bones and intra- and interobserver intraclass correlation coefficient (ICC) values with confidence interval (CI)

	Mean ± SD (median)	ICC (CI) Intraobserver	ICC (CI) Interobserver
Bone Type I			
Observer 1	77.80 ± 2.70 (77.25)	0.954 (0.917–0.977)	0.789 (0.577–0.883)
Observer 2	75.57 ± 2.27 (75.5)	0.821 (0.673–0.909)	
Observer 3	76.25 ± 2.79 (76)	0.800 (0.632–0.898)	
Bone Type III			
Observer 1	75.42 ± 2.12 (75)	0.913 (0.840–0.956)	0.731 (0.552–0.833)
Observer 2	73.63 ± 2.47 (73.5)	0.649 (0.356–0.821)	
Observer 3	73.92 ± 2.59 (74)	0.843 (0.712–0.920)	

Table 3

Implant stability quotients measured by Ostell-Smartpeg, Ostell-Multipeg, Penguin RFA-Multipeg and Penguin RFA-Smartpeg combinations (Mean ± SD)*

Direction of Measurement	RFA Device and Transducer Type		
	Osstell-Smartpeg	Osstell-Multipeg	*P*†
Frontal	72.26 ± 2.68	72.96 ± 1.92	.219
Lateral	75.26 ± 3.82	75.53 ± 1.31	.573
	Penguin RFA-Multipeg	Penguin RFA-Smartpeg	
Frontal	71.86 ± 2.85	80.3 ± 2.71	.001
Lateral	74.93 ± 2.28	77.2 ± 2.52	.006

*RFA indicates resonance frequency analysis.
†Wilcoxon signed-rank test.

of implants with the Penguin RFA (2.2 units), but no significance between the ISQs measured by the two devices at preloading in a clinical study of 38 implants. However, according to the present findings, the Penguin RFA measures ISQ significantly lower than the Osstell (about 2.5–3 units), which is somewhat contradictory to the above-mentioned studies.[16–18] In the study of Becker et al,[18] measurements were made in one direction, whereas in the present study two-directional measurements were made because it has been stated that two-directional assessments are more sensitive than one-directional readings.[28] This variance and the clinical situations such as the wet environment due to saliva, blood, etc, or the patient difficulties when making measurements may be the reasons of our contrary findings than those of Becker et al.[18] It has been stated that some different characteristics of the studies with an in vitro behavior, such as bone kind like porcine, steer, bovine, or others or the artificial bones and the experimental conditions, such as humidity and temperature may influence the results.[29] These may be the reasons of present contradictory results to the previously published ex vivo and in vitro studies.[16,17] Although slight differences such as 2–3 units are not of high clinical importance, this issue should be clarified in future clinical, ex vivo or in vitro investigations.

One of the most important findings of the present study was the reading of the ISQs of both devices when the pegs were switched. Present findings indicated that the Osstell ISQ is capable of measuring the ISQs with multipegs, which are originally manufactured to be used with the Penguin RFA, whereas the Penguin RFA is not capable of measuring ISQs when smartpegs are screwed to the implants. The readings of the Osstell ISQ with multipegs showed excellent repeatability and reliability. Depending on both the reliability findings and inconsistent results, the use of smartpegs with Penguin RFA is not suggested. During the experiments, it was not always possible to catch the proper magnetic signal between the smartpegs and the Penguin RFA. This incompatibility can depend on the differences between materials used for manufacturing the transducers.

The magnetic Osstell devices have been used since 2004.[14] Smartpegs are disposable and it has been shown that cleaning and sterilizing the smartpegs are not recommended because of corrosion of aluminum that result in problematic measurements afterwards.[24] The recently commercialized titanium multipegs can be sterilized and used repeatedly. Depending on the present findings, the use of multipegs instead of smartpegs can be recommended when a clinic is equipped with a magnetic Osstell device. Further investigations are needed to confirm this result and to inspect the measuring capability of multipegs after repeated sterilization procedures.

The limitation of this study was the lack in experimental setting that simulates the saliva, blood, humidity, or mouth temperature, etc. ISQ measurements for all groups in the study were completed using only one type of implant connection and implant system. The authors suggest that the new Penguin RFA system and the multipegs should be investigated in future studies using different implant connections and implant systems. However, the strength of the present study was the handling of the RFA device both from frontal and lateral directions, which was always easy for each observer and also can be followed from the normal range in standard deviation findings. In a clinical set up, it may not be always easy to measure the stability using RFA devices due to conditions such as limited mouth opening, abnormal position of an adjacent tooth, etc.

Future research should be conducted to delineate which commercially available RFA device measures the dental implant stability most accurately.

Conclusion

In this ex vivo study the following conclusions were drawn: 1) The recently developed RF analyzer the Penguin RFA is reliable. 2) The titanium multipegs of the Penguin RFA, which can be sterilized and used multiple times, may be used with magnetic Osstell devices. These conclusions should be also confirmed in a clinical set-up.

Table 4

Mean implant stability quotients (ISQs) measured by Osstell ISQ-Multipeg and Penguin RFA-Smartpeg combinations and intraobserver and interobserver intraclass correlation coefficients (ICCs)

	Mean ± SD (median)	Intraobserver ICC (CI)	Interobserver ICC (CI)
Ostell-Multipeg			
Observer 1	73.58 ± 1.73 (74)	0.851 (0.639-0.930)	0.692 (0.353-0.853)
Observer 2	74.68 ± 1.67 (75)	0.920 (0.780-0.964)	
Penguin-Smartpeg			
Observer 1	76.68 ± 1.67 (77)	0.278 (0.084-0.586)	0.219 (0.050-0.497)
Observer 2	80.46 ± 3.04 (80)	0.335 (0.183-0.739)	

Abbreviations

ICC: intraclass correlation coefficient
ISQ: implant stability quotient
RFA: resonance frequency analysis

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Note

The authors declare that they have no conflicts of interest.

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