https://doi.org/10.4047/jap.2023.15.3.126

Reliability of implant stability measuring devices depending on various clinical conditions: an *in vitro* study

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Received March 9, 2023 /
Last Revision May 8, 2023 /
Accepted May 15, 2023

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This study was supported by the Korea Medical Device Development Fund grant funded by the Korean government (Ministry of Science and ICT; Ministry of Trade, Industry and Energy; Ministry of Health & Welfare; and Ministry of Food and Drug Safety) [grant number: RS-2020-KD000292].

PURPOSE. The aim of this study was to evaluate the reliability of implant stability measuring devices depending on the location of the implant and the position of the patient. **MATERIALS AND METHODS.** Six implants were installed in different dentate sextants of six artificial bone models. Implant stability was measured in three conditions of the bone model (without mounting on a phantom head, mounted on a phantom head in supine position, and mounted on a phantom head in upright position). A resonance frequency analysis device (Osstell) and two damping capacity analysis devices (Periotest and Anycheck) were used to measure implant stability. The values measured outside the phantom head were treated as controls, and the values inside the phantom head were compared using an independent *t*-test. **RESULTS.** Osstell showed different results in two of the six divisions in both the supine and upright positions compared to outside of the mouth ($P < .05$). Periotest showed different results in all six parts in the supine position and in five parts in the upright position compared to outside of the mouth ($P < .05$). While Anycheck showed different results in five areas in the supine position compared to outside of the mouth, it showed different results in only one area in the upright position ($P < .05$). **CONCLUSION.** In the difficult implant position for the operator to access, the implant stability measuring devices show less reliability. The accessibility of implant is greatly affected in the order of Osstell, Anycheck, and Periotest. [J Adv Prosthodont 2023;15:126-35]

KEYWORDS
Implant stability; Resonance frequency analysis; Damping capacity analysis; Osseointegration

INTRODUCTION

Osseointegration of dental implants is one of the most important parameters evaluated in long-term dental implant studies.[1,2] It has been defined as "a process whereby a clinically asymptomatic rigid fixation of alloplastic ma-

pISSN 2005-7806 • eISSN 2005-7814

terials is achieved and maintained in the bone during functional loading."[3] Osseointegration is also a measure of implant stability, which can occur at two stages: primary and secondary stability.[3] Primary stability at implant installation is achieved by the physical congruence between the surgically created bone bed and the implant, which is dependent on the macroscopic implant design, surgical technique, and bone density.[4] During the osseointegration healing period, the bone gradually forms inside the implant threads and, thus, the secondary stability is attained by an incremental degree of bone-to-implant contact.[4] This is translated clinically into a critical period, during which the primary stability decreases while the secondary stability is being established.[4] During this transition, the risk of micro movements and the potential for impairment of the osseointegration are enhanced.[4] Moreover, osseointegration is a patient dependent wound healing process affected by various factors.[5] Quantification of implant stability at various time points may provide significant information on the individualized "optimal healing" time.[5] Quantifying implant stability at various time points and determining the timing of loading are of utmost importance.[6,7]

To evaluate implant stability, two types of widely used non-invasive diagnostic methods have been developed and tested: resonance frequency analysis (RFA) and damping capacity analysis (DCA).[8] In RFA, a method used by Osstell, the stiffness of the bone/implant interface is calculated from a resonance frequency as a reaction to oscillations exerted on the implant/bone system.[9,10] The implant is excited with an oscillating transducer screwed onto the implant, and the resonance specific to the resonance system implant/bone is captured electronically over a range of 5 to 15 kHz.[10,11] The implant's oscillation under a given transducer frequency is mainly dependent on the fixation of the implant in the alveolar bone.[11-13] The unit of measurement in this approach is the implant stability quotient (ISQ), calculated from the resonance frequency, and ranges from 0 to 100 units with increasing stiffness of the interface.[11,13] One DCA system device, Periotest (Siemens AG, Bensheim, Germany), has been used to evaluate the mobility of natural teeth and is claimed to have the potential to reliably assess the stability of the bone-implant interface.[14] This instrument comprises a handpiece with a metal slug that is accelerated towards an implant by an electromagnet. The duration of contact between the slug and the implant is measured using an accelerometer.[15] The software in the instrument is designed to relate contact time as a function of implant mobility. The results are displayed digitally and audibly as Periotest values (PTVs) on a scale of -8 (low mobility) to 50 (high mobility) for implant mobility.[11]

Previous studies have reported a correlation between RFA and DCA device values, indicating the stability of the same implant.[16-20] *In vitro* studies showed a strong correlation (more than 0.7) between RFA and DCA devices.[16,19,20] Lee *et al*.[16] showed a correlation coefficient of 0.981 with statistical significance between the ISQ and implant stability tester (IST; Anycheck) values; Krafft *et al*.[19] also reported a correlation coefficient of 0.871 with statistical significance between ISQ and PTV. Contrastingly, *in vivo* studies showed moderate (between 0.3 and 0.7) or weak (less than 0.3) correlation between the results from RFA and DCA devices. Andreotti *et al*.[17] reported a correlation coefficient of 0.294 between ISQ value and PTV with statistical significance through a systematic review. Aal *et al*.[18] showed that when correlating ISQ value and PTV readings of the buccal surface during implant installation, there was a moderate negative statistically significant correlation (correlation coefficient: -0.466) between the two devices for all 80 patients in a clinical trial. The different results between the experimental and clinical conditions suggest that there are factors in clinical conditions that affect the reliability of implant stability measuring devices.[15] In an experimental condition, the examiner can examine implant stability without any obstacle and position the device to the implant in an ideal way. However, to examine the stability of the implant in the oral cavity, access to the implant may be difficult because of the cheek, tongue, and contralateral teeth.[15,21] These obstacles may have an unfavorable influence on the factors regarding the accurate measurement of implant stability, including the contact between the implant and the device, angle of the device with respect to the implant, and angle of the device against gravity.[15,22-26]

The aim of this study was to evaluate the reliability

https://doi.org/10.4047/jap.2023.15.3.126

of implant stability measuring devices under different clinical conditions. To achieve this, three conditions for the examination of implant stability were provided: 1) implant placed model without mounting on a phantom model, 2) implant placed model in a phantom model in the supine position, and 3) implant placed model in a phantom model in the upright position. One RFA device (Osstell) and two DCA devices (Periotest and Anycheck) were used to examine implants located in the 1) maxillary right posterior, 2) maxillary anterior, 3) maxillary left posterior, 4) mandibular right posterior, 5) mandibular anterior, and 6) mandibular left posterior regions. The null hypotheses were as follows: 1) the position of the patient as well as 2) the location of the implant in the oral cavity do not affect the reliability of implant stability measuring devices.

MATERIALS AND METHODS

The implant (CMI IS-II; Neobiotech, Seoul, Korea) (4.0 mm in diameter and 10.0 mm in length) was installed in six artificial bone models (SUMBL01; Osstem, Seoul, Korea). The implants were placed in the dentate sextants at the upper right first molar (upper right molar, URM), upper left central incisor (upper central incisor, UCI), upper left first molar (upper left molar, ULM), lower right first molar (lower right molar, LRM), lower right central incisal (left central incisal, LCI), and lower left first molar (lower left molar, LLM). The drilling process followed the manufacturers' instructions. The site was drilled using a point Lindemann drill and surgical drills, in the order of ∅2.2, 3.0, and 3.5 mm. To achieve similar insertion torque values among implants, a well-trained researcher carefully drilled each implant bed at regular depth and angle. All implants were inserted using only the hand piece of the implant engine (iCTmortor, WH-1; Dentium, Seoul, Korea).

Implant stability was measured under three conditions: 1) outside, 2) supine, and 3) upright (Fig. 1A). The outside condition refers to an implant placed in an artificial bone model without mounting on the phantom head. The supine condition refers to an implant placed in the model mounted on the phantom head in a supine position. The upright condition refers to an implant placed in the model mounted on the phantom head in an upright position. Outside results were used as references to evaluate the reliability of the results acquired from the upright and supine positions. A well-trained right-handed researcher measured the implant stability. For the outside group, the researcher measured implant stability following the manufacturer's instructions without any obstacles outside the phantom model. In the phantom model, the researcher measured implant stability while avoiding excessive retraction of the cheek.

Implant stability measurement with Osstell (Osstell AB, Gothenburg, Sweden) was performed prior to measurement with other devices to prevent the fixation force of the implant from changing during the process of installing and releasing the healing abutment. All the devices were used according to the manufacturers' instructions. For measurement with Osstell, Smartpeg (Osstell AB, Gothenburg, Sweden) was manually connected to the implant fixture. The manufacturer of Osstell recommends holding the instrument tip close (2 - 4 mm) to the top of the Smartpeg without touching it, at an angle of approximately 45°. To prevent the improvement in the accuracy of measurement as the same implant is measured repeatedly in succession, the implants in each area were measured in turn. After measurements with Osstell, healing abutments (Neobiotech, Seoul, Korea; Diameter × Cuff: 4.0 mm × 4.0 mm) were connected to the implants using a torque ratchet of 10 Ncm. After the healing abutment connection, implant stability was measured using Anycheck and Periotest. Percussion with Periotest was performed perpendicular to the longitudinal axis of the abutment, holding the handpiece parallel to the floor. The start button was placed on top, and the rod and healing abutment surface were maintained at 0.6 - 2.0 mm. The metal rod of Anycheck and the long axis of the implant were set perpendicular to each other. The tip of the tapping rod of Anycheck was in slight contact with the healing abutment, maintaining a contact angle between 0° and 30°. The measurement method for each instrument is illustrated in Figure 1B. All devices were measured in the buccal (or labial) direction and recorded by a single examiner. The measurements were conducted ten times for the inserted fixtures according

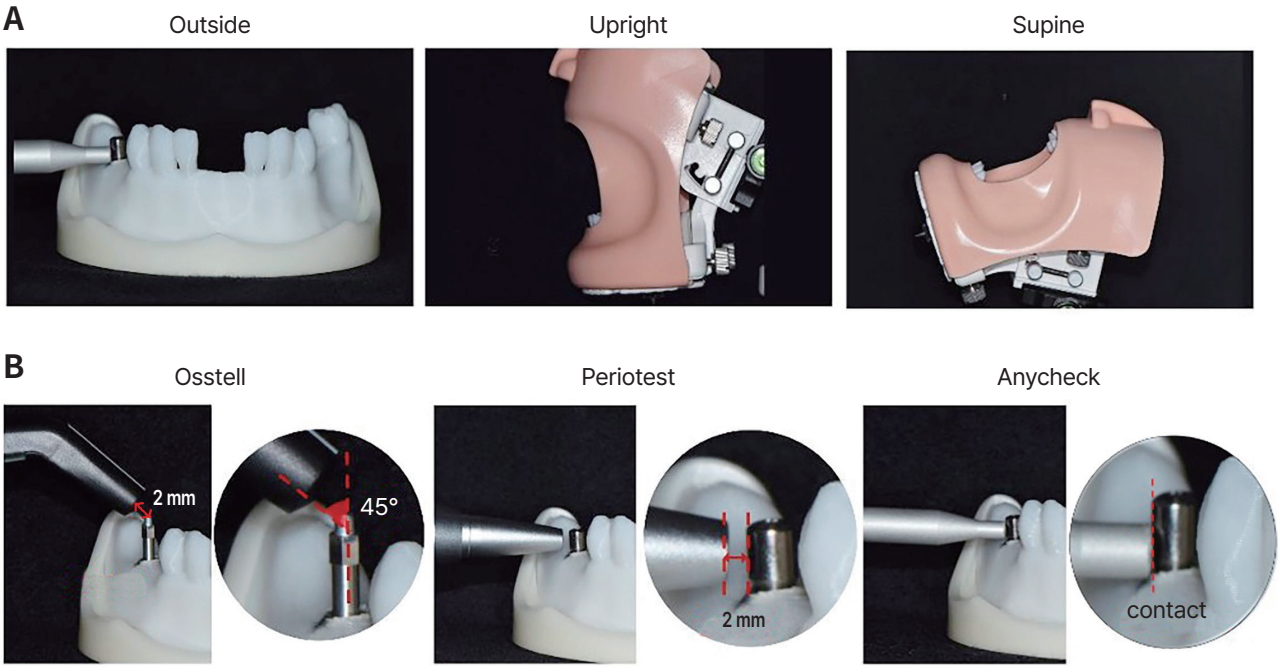

Fig. 1. (A) Position of the artificial bone model. (B) Measurement methods for each device, following the manufacturer's instruction.

to the groups (outside, supine, and upright). DCA devices evaluated the impact errors which represents how many invalid attempts are made during measurement. For Anycheck, the valid number of impacts was counted through a connection with a customized measuring device. When measuring using Periotest, the examiner counted the high sound generated by the device, indicating that an error had occurred. The angle between the long axis of Anycheck and the horizontal plane was perpendicular to the direction of gravity when measuring implant stability; the examiner recorded the angle between the device and horizontal plane using a customized measuring device.

SPSS version 21.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis. Previous studies evaluated the accuracy of devices through evaluating the correlation coefficient with ISQ. The hypothesis of the comparison was that ISQ is accurate and the similar results of experimental device with ISQ show high accuracy. However, in this study, the values of the outside group were treated as controls, and the values of the inside groups were compared using an independent *t*-test to evaluate the accuracy of measurement. Independent *t*-tests were conducted to evaluate the differences between the supine and upright positions in the number of impact errors in Periotest and Anycheck. An intergroup comparison of the locations in DCA impact error and the angle of Anycheck was conducted using a one-way analysis of variance (ANOVA). The impact errors and angles were separately analyzed using two-way ANOVA with positions and location of implants as the main factors, followed by Tukey's post-hoc comparisons. In all tests, $P < .05$ was considered statistically significant.

RESULTS

The means and standard deviations of the measured values of implant stability using the devices for the location of the inserted fixture are shown in Figure 2. Independent *t*-tests were used to determine whether there were differences in position (Fig. 2). It was assumed that the results from the outside represented the accurate implant stability, and that the results from inside the phantom model, which were statistically different from those from the outside, were con-

https://doi.org/10.4047/jap.2023.15.3.126

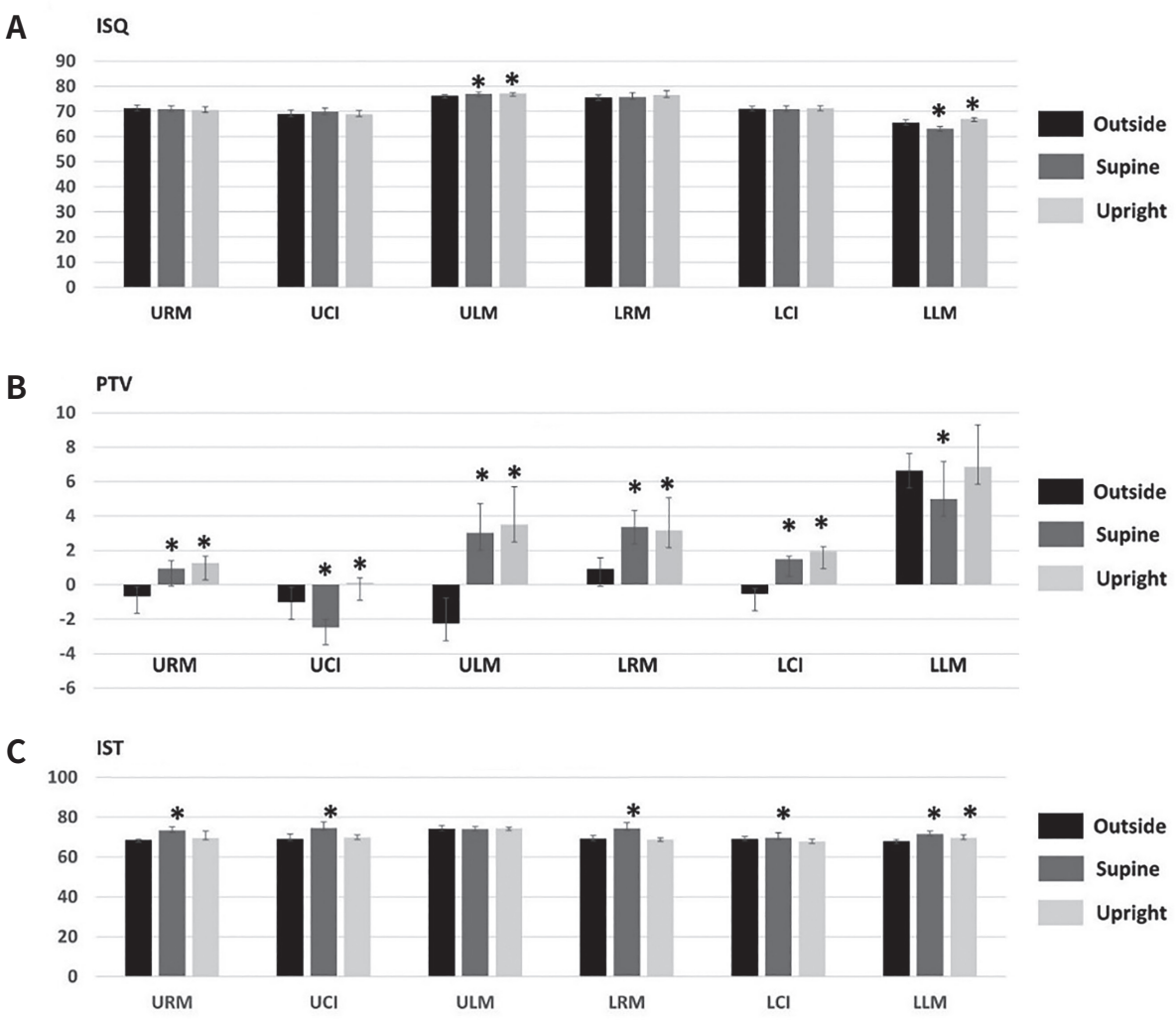

Fig. 2. The means and standard deviations of the measured values of implant stability using the devices and the statistical differences between outside and inside position (supine and upright). (A) Implant stability quotient (ISQ) using Osstell, (B) Periotest value (PTV) using Periotest, (C) Implant stability tester (IST) using Anycheck.
ISQ, implant stability quotient; PTV, periotest value; IST, implant stability tester (value); URM, upper right molar; UCI, upper central incisor; ULM, upper left molar; LRM, lower right molar; LCI, lower central incisor; LLM, lower left molar.
* indicates a statistically significant difference from the value measured outside ($P < .05$).

sidered inaccurate measurements. In the ISQ, there were statistically significant differences between the values of the outside and inside positions in the ULM and LLM ($P < .05$). In the PTV, there were statistically significant differences at all locations and positions, except for the LLM in the upright position ($P < .05$). In the supine position of the IST, there were statistically significant differences at all locations, except for the ULM ($P < .05$). In contrast, there was a significant difference only in LLM in the upright position ($P < .05$).

Table 1 shows the mean and standard deviation (SD) of the number of impact errors with Periotest and Anycheck, as well as the one-way ANOVA and independent *t*-test results. The impact errors in the PTV according to the position showed significant differences, except for the URM. Meanwhile, there were no significant differences in the IST, except for the ULM and LLM. Table 2 presents the statistically significant differences in the two-way ANOVA results.

The supine and upright positions showed a significant effect on the impact error values of Periotest ($P < .05$), although the location of the implants had no sta-

Table 1. Mean (Standard deviation) of impact error of Periotest and Anycheck

	Inside groups	URM	UCI	ULM	LRM	LCI	LLM
PTV	Supine	0.60 (0.52)^{Aa}	2.40 (2.12)^{Aab}	2.10 (2.42)^{Aab}	4.20 (3.29)^{Bb}	3.90 (3.11)^{Bab}	3.20 (2.70)^{Aab}
	Upright	1.20 (0.79)^{Aa}	2.60 (1.78)^{Ba}	3.00 (2.67)^{Ba}	2.10 (2.18)^{Aa}	1.80 (1.55)^{Aa}	3.50 (2.76)^{Ba}
IST	Supine	1.00 (0.00)^{Aab}	0.70 (0.48)^{Aab}	0.70 (0.48)^{Aab}	0.90 (0.57)^{Aab}	1.10 (0.32)^{Ab}	0.50 (0.53)^{Aa}
	Upright	0.70 (0.48)^{Aab}	0.70 (0.48)^{Ab}	1.10 (0.32)^{Bab}	0.40 (0.52)^{Aa}	0.80 (0.42)^{Aab}	0.90 (0.32)^{Bab}

PTV, periotest value; IST, implant stability tester (value); URM, upper right molar; UCI, upper central incisor; ULM, upper left molar; LRM, lower right molar; LCI, lower central incisor; LLM, lower left molar. Similar superscript letters (uppercase for columns and lowercase for rows) indicate homogenous subsets among the experimental groups ($P < .05$).

tistical effect ($P = .387$). In Anycheck, the positions ($P = .160$) and location of the implants ($P = .531$) did not significantly affect the number of impact errors.

The results of the Anycheck angle during measurement, including the means, SDs, and significant differences, are listed in Table 3. The supine position showed a significantly higher angle during measurement than the outside and upright position ($P < .05$). There were significant differences in the supine position (URM < ULM < LLM < UCI < LRM < LCI) and upright position (LRM = LCI < URM = UCI = ULM = LLM) according to the location of the implant. Two-way ANOVA revealed significant differences in the angle according to the position and location of the implant ($P < .05$) (Table 4).

DISCUSSION

Reliable information on when clinically sufficient osseointegration for bearing load is achieved helps clinicians determine the timing of providing prostheses on implants in a short treatment period without the risk of implant failure.[6,7] In contrast to a laboratory situation where it is favorable to measure implant stability under a constant condition, measuring it in the oral cavity is affected by factors that may reduce the accuracy of the measuring devices, including less accessibility, unfavorable sight of the clinician, and inclination of devices against gravity. In this study, the accuracy of implant stability measuring devices was evaluated under conditions simulating the oral cavi-

Table 2. Two-way ANOVA results showing the effect of the positions of the bone models and the locations of implants on the number of impact errors

	Position	Location
Periotest	.018*	.387
Anycheck	.531	.160

* indicates statistical significance ($P < .05$).

Table 4. Two-way ANOVA results showing the effect of the positions of the bone models and the locations of implants on the angle of Anycheck

	Position	Location
Angle of Anycheck	< .001*	< .001*

* indicates statistical significance ($P < .001$).

Table 3. Mean (standard deviation) of the angle between the long axis of Anycheck and the horizontal plane, which is perpendicular to the direction of gravity when measuring implant stability

		URM	UCI	ULM	LRM	LCI	LLM	Total
Outside		3.77 (2.97)^{ABb}	0.35 (0.77)^{Aa}	2.53 (2.79)^{Aab}	1.78 (2.37)^{Aab}	2.60 (1.53)^{Aab}	0.46 (0.84)^{Aa}	1.92 (2.34)^{A}
Inside groups	Supine	1.32 (1.88)^{Aa}	19.02 (4.04)^{Cc}	11.11 (6.68)^{Bb}	21.87 (4.80)^{Bcd}	25.17 (5.37)^{Bd}	15.99 (1.72)^{Cbc}	15.75 (8.96)^{B}
	Upright	5.41 (3.98)^{Cb}	5.93 (5.24)^{Bb}	7.56 (3.82)^{ABb}	0.00 (0.00)^{Aa}	0.75 (1.21)^{Aa}	5.36 (2.91)^{Bb}	4.17 (4.27)^{A}

URM, upper right molar; UCI, upper central incisor; ULM, upper left molar; LRM, lower right molar; LCI, lower central incisor; LLM, lower left molar. Similar superscript letters (uppercase for columns and lowercase for rows) indicate homogenous subsets among the experimental groups ($P < .05$).

https://doi.org/10.4047/jap.2023.15.3.126

ty to determine the factors affecting the reliability of these devices in a clinical setting. The results showed that the patient's position and location of the implant affected the reliability of the implant stability measuring devices, and the three devices were affected by the factors in different ways. Therefore, all the hypotheses were rejected.

According to previous studies, PTV is affected by the length of the fixture and healing abutment, position and direction of percussion, and angle of the handpiece.[15,25] In addition, metal rod in the interior of the handpiece is affected by friction and gravitation.[14] In this study, Osstell showed relatively consistent results regardless of whether it was measured outside or inside the phantom model, whereas Periotest and Anycheck were significantly affected by the position of the bone model. These results suggest that accessibility for measurement has a greater effect on the reliability of DCA devices than that of RFA devices. Measuring implant stability outside the phantom model provides optimal conditions for the examiner, following the manufacturers' instructions. As there are no obstacles in securing a sight and bringing a device, the device can be easily placed at the desired position and angle. Otherwise, measuring implant stability inside a phantom model has the restrictions of low accessibility of the implant to the examiner and a fixed angle of the model. RFA devices may be relatively less affected by obstacles because of the shape of the device for optimizing its operating principle. Osstell has a curved head, which provides the convenience of positioning the device. On the other hand, DCA devices have a straight shape, which is unfavorable for access, although Anycheck is thinner and better for access than Periotest. The straight shape of DCA devices is an inevitable choice because the devices should contain a straight bar with sufficient length, which is accelerated towards an implant by an electromagnet to measure the contact duration of the slug on the target.[26]

Among DCA devices, Periotest was significantly affected by the position of the artificial bone model in terms of impact error, whereas Anycheck showed a consistently low impact error. The results show that Anycheck provides relatively stable measurements, even under unfavorable access conditions. Anycheck was measured while in contact with the implant, whereas Periotest was measured while maintaining a certain distance from the implant. As the measurement is made in the contact state, Anycheck does not move even minutely during the measurement, and it is possible to stably take measurements at the position desired by the operator. A previous study showed that the Periotest was very sensitive to the position at which the device impacted the abutment and to the angulation of the handpiece, and a small change in the angle of the handpiece from 90° to the abutment may cause the rod to hit an inconsistent point on the abutment.[22]

The location of the implant affected the reliability of all devices in this study. In Osstell, a lower reliability was observed in the left molars (ULM and LLM). For Periotest and Anycheck, significantly higher impact errors were observed on the left side than on the right side of the molar. These results seem to be caused by the fact that the right side is easier to access than the left side for the examiner, as the right-handed clinician is familiar with positioning the upper or right side of the phantom model. The results of this study indicate that the clinician should take greater care when measuring implant stability for the implants located in the left side of the patient's oral cavity.

The results of this study also demonstrate that Anycheck should be measured with the patient in an upright position to obtain more accurate measurements. Anycheck showed lower accuracy in the supine position than in the upright position. The different reliabilities of Anycheck depending on the position of the bone model seem to be caused by angulation change. In the upright position, the angulation of the device against gravity is statistically similar to that outside the phantom model. In the supine position, the angulation was significantly higher than that outside. The implant location also affects the angulation of the device. Consistent angulation is critical for the reliability of DCA devices.[23] When the angle is changed, the force vector is divided into directions parallel as well as perpendicular to the long axis of the implant. As implant mobility is a movement that occurs in a direction perpendicular to the long axis of the implant, mobility may change if the angle is changed.[23]

This study aimed to investigate the reliability of implant stability measuring devices in various clinical

conditions by simulating the clinical situation using a phantom head. To analyze the reasons for the different results between the experimental and clinical conditions, the valid impacts and angles formed by the handpiece with the horizontal plane were also evaluated with a customized system. However, this study could not simulate the factors that may affect the results in the oral cavity, including the tongue and saliva. Further *in vivo* studies are warranted for evaluating the reliability of implant stability measuring devices considering these factors.

CONCLUSION

Based on the findings of this *in vitro* study, the following conclusions were drawn.

Osstell showed consistently reliable results, whereas the reliability of Periotest and Anycheck was significantly affected by the position of the bone model and implant location. In all devices, the measurement of implants located on the left side was less reliable.

Periotest was significantly affected by the position of the artificial bone model in terms of the impact error, whereas Anycheck showed a consistent impact error regardless of the measuring conditions.

The angulation of Anycheck against gravity measured outside was statistically similar to that measured in the upright position but was different from that measured in the supine position. The reliability of Anycheck was higher in the upright position than in the supine position.

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Supplementary Table 1. Mean (standard deviation) of ISQ, PTV, and IST

	Position	URM	UCI	ULM	LRM	LCI	LLM
ISQ (Osstell)	Outside	71.20 (1.40)	69.00 (1.63)	76.20 (0.42)	75.50 (1.08)	71.10 (0.99)	65.50 (1.18)
	Supine	70.90 (1.29)	69.80 (1.55)	76.90 (0.74)	75.70 (1.64)	70.90 (1.29)	63.10 (0.88)
	Upright	70.60 (1.17)	68.90 (1.52)	77.10 (0.32)	76.50 (1.84)	71.20 (1.03)	67.00 (0.47)
PTV (Periotest)	Outside	-0.66 (0.55)	-1.02 (0.89)	-2.25 (1.48)	0.92 (0.64)	-0.52 (0.29)	6.63 (1.00)
	Supine	0.94 (0.46)	-2.48 (0.46)	3.01 (1.69)	3.36 (0.97)	1.48 (0.18)	4.98 (2.18)
	Upright	1.27 (0.39)	0.11 (0.31)	3.49 (2.22)	3.15 (1.91)	1.94 (0.28)	6.84 (2.46)
IST (Anycheck)	Outside	68.50 (0.53)	69.10 (2.56)	74.30 (1.49)	69.20 (1.55)	69.10 (1.10)	67.90 (0.88)
	Supine	73.30 (1.83)	74.50 (3.03)	74.10 (1.10)	74.40 (2.84)	69.70 (2.41)	71.60 (1.35)
	Upright	69.60 (3.34)	69.80 (1.32)	74.40 (0.52)	68.80 (0.79)	67.80 (1.23)	69.70 (1.42)

URM, upper right molar; UCI, upper central incisor; ULM, upper left molar; LRM, lower right molar; LCI, lower central incisor; LLM, lower left molar; ISQ, implant stability quotient; PTV, periotest value; IST, implant stability tester (value).

Supplementary Table 2. Statistical results comparing the implant stability values measured inside the phantom head with the values measured outside

	Inside groups	URM	UCI	ULM	LRM	LCI	LLM
ISQ	Supine	.624	.276	< .05*	.751	.702	< .05*
	Upright	.312	.889	< .05*	.160	.828	< .05**
PTV	Supine	< .05*	< .05*	< .05*	< .05*	< .05*	< .05*
	Upright	< .05*	< .05*	< .05*	< .05*	< .05*	.807
IST	Supine	< .05*	< .05*	.737	< .05*	< .05*	< .05*
	Upright	.329	.455	.844	.476	.196	< .05*

ISQ, implant stability quotient; PTV, periotest value; IST, implant stability tester (value); URM, upper right molar; UCI, upper central incisor; ULM, upper left molar; LRM, lower right molar; LCI, lower central incisor; LLM, lower left molar. * indicates a statistically significant difference from the value measured outside.