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Validation of an implant stability measurement device using the percussion response: a clinical research study

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Abstract

Background: Several devices have been developed to measure implant-bone stability as an indicator of successful implant treatment; these include Osstell®, which measures the implant stability quotient (ISQ), and the more recent AnyCheck®, which relies on percussion for the implant stability test (IST). These devices make it possible to measure implant stability. However, no studies have compared the performance of AnyCheck® and Osstell® (i.e., IST and ISQ values) in clinical practice. Therefore, this study aimed to determine the correlation between primary and secondary implant stability using the Osstell® and AnyCheck® devices.

Methods: Ten patients (7 women; age [mean ± standard deviation]: 49.1 ± 13.3 years) with partially edentulous jaws who received a total of 15 implants were included. IST (AnyCheck®) and ISQ (Osstell®) values were measured immediately after implantation and at 1, 2, 3, 4, and 6 weeks post-implantation. Each measurement was performed three times, and the average value was used as the result. The correlation between measurements obtained using the two devices was determined using Spearman's rank correlation coefficient.

Results: The IST values ranged from 79.1 ± 2.87 to 82.4 ± 2.65. The ISQ values ranged from 76.0 ± 2.8 to 80.2 ± 2.35. Spearman's rank correlation coefficient was r = 0.64 immediately after implantation, r = 0.29 at 1 week, r = 0.68 at 2 weeks, r = 0.53 at 3 weeks, r = 0.68 at 4 weeks, and r = 0.56 at 6 weeks. A positive correlation was found in all cases, except at week 1 when the correlation was weak; the IST and ISQ values decreased the most during the first postoperative week and increased during the second week. The IST values were also slightly higher at all measurement points.

Conclusion: The ability to assess implant stability without removing the abutment during healing is essential for determining the timing of loading without the risk of bone resorption. The results of this study suggest that AnyCheck® is useful for determining primary and secondary implant stability.

Keywords: Dental implant, Implant stability quotient (ISQ), Implant stability test (IST), AnyCheck®, Osstell®

Background

In recent years, the use of dental implants has become widespread in the field of dentistry, and various technological advancements have been proposed to improve treatment outcomes [1–3]. For instance, several devices have been developed to measure implant stability as an indicator of the success of implant treatment. The Osstell® device [4] allows the measurement of the implant

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stability quotient (ISQ) using the resonance frequency analysis (RFA) method, whereas the Periotest® device [5] uses the percussion method. More recently, the AnyCheck® device, which also relies on the percussion method, has been developed [6]. Importantly, the insertion torque (IT) of the implant into the bone influences the success of implant treatment; therefore, the ability of these devices to quantify and evaluate implant stability has contributed greatly to the success of implant treatments [7, 8], benefitting both dentist and patients. There are two types of implant surgery: those that allow submerged implant healing and those with non-submerged implant healing. Submerged implant healing is often considered when the primary stability is poor or when bone grafting has been performed [9]. In non-submerged implant healing, removal of healing abutments prior to superstructure placement has been reported to be a cause of accelerated bone resorption [10]. Therefore, the concept of "one abutment–one time," in which the abutment is placed immediately after implantation to control bone resorption, is popular [11]. Despite its long history of use, the Osstell® device requires removal of the healing abutment and the attachment of smart pegs. Of note, AnyCheck® does not require the healing abutment to be attached or removed; therefore, it can measure implant stability without promoting bone resorption. Although there have been various reports on implant stability, thus far, no study has compared the ISQ and implant stability test (IST) values in clinical practice [12]. To address this gap in knowledge, the present study aimed to investigate the correlation between implant stability for the Osstell® and AnyCheck® devices.

Materials and methods

Patients

Ten patients (7 women, 3 men) with partially edentulous jaws who underwent implant treatment at our university hospital (n = 15 implants) were included in this study. The mean age (± standard deviation) was 49.1 ± 13.3 years. Patients were selected based on absence of systemic diseases, smoking status (non-smokers), and non-requirement of bone grafting. The IT was set at 35 Ncm using micromotor and torque wrench for all patients. Healing abutments of the following diameters were attached to the implants: 2 mm in one implant, 4 mm in nine, and 6 mm in five implants. This study was approved by the institutional ethics committee of our hospital (approval #739), and written informed consent was obtained from all patients.

Surgical procedure

All patients were instructed to take an oral dose (1 g) of amoxicillin hydrate (Sawacillin Capsules®; LTL Pharma, Tokyo, Japan) 1 h before surgery. After administration of the anesthetic (Lidocaine/Adrenaline bitartrate®; Showa Yakuhin Kako Co., Ltd., Tokyo, Japan), the alveolar mucosa, including the periosteum, was incised at the top of the ridge and separated. After drilling, implants were placed according to the implant system protocol; the torque and depth of placement were adjusted with a torque ratchet. All implant placements were performed via freehand insertion; additionally, all surgeries were performed in a non-submerged fashion. The implant system used was Straumann® SLActive ϕ 4.1 × 10 (bone level tapered implant; Basel, Switzerland). All surgeries were performed by the same doctor, a teaching Associate in the Department of Implantology at our university hospital.

Measurement of the IST and ISQ values

The IST values were measured using the AnyCheck® device (Neobiotech Co., Ltd., Seoul, South Korea) (Fig. 1). The bone-to-implant stability index was set based on the ISQ values (0–59, not recommended for loading; 60–99, good stability, recommended for loading); the IST and ISQ have similar reference values. Osstell® was used instead of Periotest® in this study. Briefly, to determine the IST value, the healing abutment was struck six times over 3 s, and the contact time

Fig. 1 The AnyCheck® implant stability test (IST) device

with the healing abutment was measured to calculate the stability. Notably, in accordance with the manufacturer's recommendations, the patient was placed in an upright position during measurement, and the contact angle was set at 0°–30°. Since AnyCheck® uses a standard healing abutment height of 4 mm, values for healing abutment heights other than 4 mm were corrected as recommended by the manufacturer (Table 1).

The ISQ values were determined using the Osstell® ISQ device (Integration Diagnostics Ltd., Goteborgsvagen, Sweden) (Fig. 2). In principle, magnetic pulses based on the RFA method stimulate and resonate the smart peg (Integration Diagnostics Ltd.) attached to the implant body in the patient's mouth, making it possible to quantify stability. At the time of measurement, the intraoral healing abutment was removed, and the smart peg was attached to the implant body via hand tightening.

Both the IST and ISQ values were measured immediately after implantation and at 1-, 2-, 3-, 4-, and 6-weeks post-implantation. Each measurement was taken three times, and the mean was used as the definitive result. The ISQ was measured following assessment of the IST. For all implants, impressions were obtained at 4 weeks after placement, and provisional restorations were placed at 6 weeks. All measurements were taken by the same dental surgeon.

Statistical analyses

Correlations between the IST and ISQ values were assessed using BellCurve for Excel (Social Survey Research Information, Inc., Tokyo). Spearman's rank correlation coefficients were used to determine correlations.

Sample size was calculated by one-way analysis of variance using G-Power (version 3.1.9.2). The sample size required to obtain 80% of the effect size of 0.4 at $\alpha = 0.05$ was calculated.

Table 1 Corrected IST values, measured using the AnyCheck® device, based on the healing abutment height

Healing abutment height (mm)	IST value
7	+6
6	+4
5	+2
4	±0
3	−2
2	−4
1	−6

IST, implant stability test

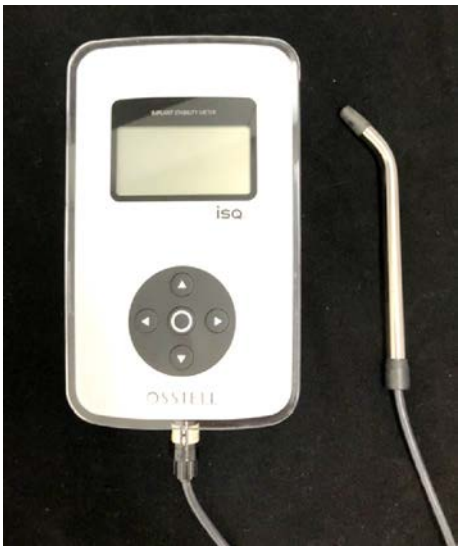

Fig. 2 The Osstell® implant stability quotient (ISQ) device

Results

The IST values immediately, 1 week, 2 weeks, 3 weeks, 4 weeks, and 6 weeks after implantation were 81.0 ± 2.82, 79.1 ± 2.87, 79.7 ± 2.83, 80.5 ± 2.71, 80.9 ± 4.0, and 82.4 ± 2.65, respectively. The ISQ values immediately, 1 week, 2 weeks, 3 weeks, 4 weeks, and 6 weeks after implantation were 79.8 ± 2.89, 76.0 ± 2.8, 77.8 ± 2.63, 79.2 ± 2.44, 79.7 ± 2.77, and 80.2 ± 2.35, respectively (Fig. 3). Of note, both the IST and ISQ values decreased the most in the first week after surgery and increased in the second week; additionally, the IST value was slightly higher at all measurement points. The Spearman's rank correlation coefficients for each measurement period were as follows: r = 0.64 immediately after implantation; r = 0.29 at 1 week; r = 0.68 at 2 weeks; r = 0.53 at 3 weeks, r = 0.68 at 4 weeks, and r = 0.56 at 6 weeks. A positive

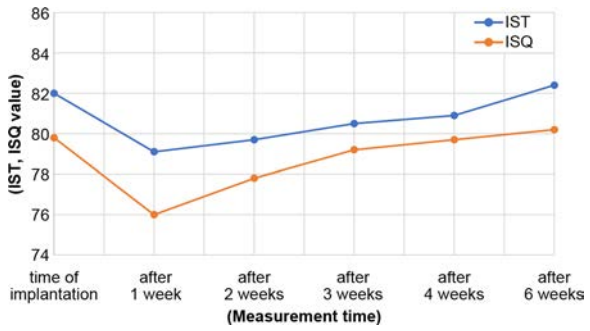

Fig. 3 Comparison of the mean implant stability test (IST) and implant stability quotient (ISQ) values at different times post-implantation

correlation was found in all cases, except at 1 week when the correlation was weak (Fig. 4).

Discussion

This study compared the changes in implant stability using the Osstell® and AnyCheck® devices. Our analysis indicated that the measurements exhibited a positive correlation of > 0.5, except after 2 weeks. This suggested that AnyCheck® had the same performance as Osstell®.

When the IT is high, bone resorption is promoted. Optimization of the IT is considered the key to successful implant treatment [13–15]. In this study, all the implants had an IT of 35 Ncm. However, even in cases of low IT, the use of AnyCheck® allows safe assessment of implant stability. The IST and ISQ values in this study were high. Zwaan et al. [16] placed 163 implants in the maxilla and compared the IT at 50 Ncm, 40–45 Ncm, 30–35 Ncm, and ≤ 30 Ncm and found that the ISQ values were 76.2 ± 5.3, 72.3 ± 5.3, 70.0 ± 6.7, and 68.1 ± 6.2, respectively. The ISQ values were also reported to be higher for tapered implants than for straight implants. Van Eekeren et al. [17] compared bone-level with tissue-level implants and revealed that the ISQ values (at the time of placement and 2, 3, and 12 weeks postoperatively) were 77.8, 75.6, 76.3, and 79.1, and 74.0, 71.8, 72.6, and 76.8, respectively. Importantly, the above results suggest that ISQ values tend to vary according to bone quality, implantation site, and implant shape, in line with the findings reported elsewhere [18]. As reported above, the authors of this study think that the high value was due to the use of bone-level and tapered implants. Oates et al. [19] reported that the stability of SLActive® implants changed from a decrease to an increase at 2 weeks after placement, in line with our results. In the present study, the weakest correlation was observed after 2 weeks. This may be explained by individual differences in the decline of primary stability, resulting in large differences in IST and ISQ.

Park et al. [6] placed an implant into an artificial bone block to verify the accuracy of AnyCheck®; interestingly, the stability decreased as the height of the healing abutment increased and as the contact angle decreased from 30° to 0° (perpendicular to the long axis of the implant and parallel to the ground). Subsequently, Lee et al. [20] placed implants at 10 N, 15 N, and 35 N into artificial bone blocks together with five different diameters of healing abutments of the same height, measured the IST values using AnyCheck®, and compared them with the ISQ values determined using Osstell®. Importantly, they reported that the diameter of the healing abutment did not affect the ISQ and IST values, which exhibited a strong correlation. Consistent with these results, Lee et al. [21] also found that the results for the AnyCheck® and Osstell® devices were correlated in the context of both internal-connection and external-connection implants (within pig bone). Of note, they also reported that the IST values were higher for both implants and that there was no significant difference between the IST and ISQ values. However, neither the IST nor the ISQ values are known to be accurate; they should only be considered as one among several indicators.

In clinical practice, Al-Jamal et al. [22] demonstrated that there was a significant correlation between primary stability and IT using the AnyCheck® device in the context of 40 implants. However, they did not compare their findings with measurements obtained using the Osstell®

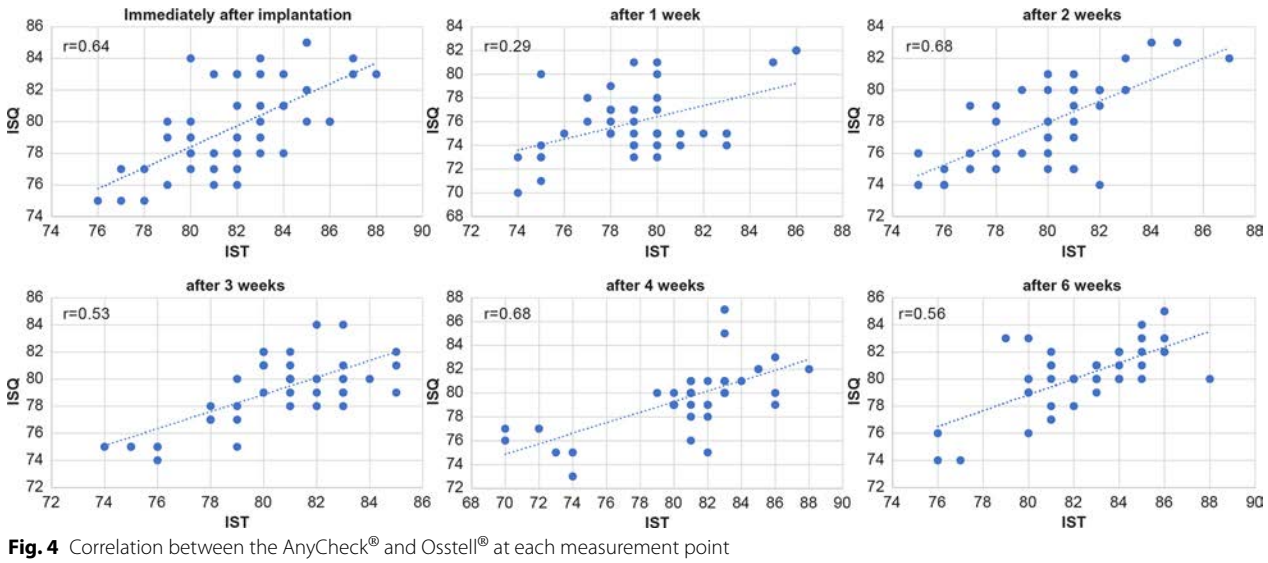

Fig. 4 Correlation between the AnyCheck® and Osstell® at each measurement point

device. The present study is the first in which the IST and ISQ values were measured and compared weekly in clinical practice, from immediately after implantation to 4 weeks later. While the Osstell® is a device with a long history of use and has been explored in many studies to date, its use requires removal of the healing abutment and attachment of the smart peg. The recently released Osstell Beacon® is cordless. However, as before, it still requires a smart peg, and the healing abutment must be attached and removed. Esposito et al. [23] reported that the removal of the healing abutment (three times after implantation until the time of superstructure attachment) led to 0.16 mm of bone resorption per year (*versus* non-removal of the healing abutment). Similar results were obtained by Bressan et al. [24]—0.43 mm of bone resorption over 3 years in healing abutment removal *versus* non-removal contexts—as well as by Koutouzis et al. [25]—0.13 mm versus 0.28 mm bone resorption in 6 months after implantation in the without versus with healing abutment removal context). Importantly, AnyCheck®, which allows the measurement of stability without the need to attach or to detach the healing abutment, reduces bone resorption and can be applied to low-torque cases. In the present study, a positive correlation of > 0.5 was observed at all measurement points, except after 2 weeks. Considering the risk of bone resorption and other factors, the AnyCheck® is expected to perform as well or better than the Osstell®. Since there are no reports comparing the two devices in clinical practice, further validation of this matter is necessary. Furthermore, this study has some limitations. The sample size for this study was small. This was due to the limited number of patients in whom implants of the same system, diameter, and length were placed. In addition, in vitro studies cannot assess changes in implant stability over time. Therefore, studies using models could not be conducted previously. In the future, it is necessary to distinguish between bone quality and implant diameter to obtain more detailed data.

Conclusion

The ability to assess implant stability without removing the abutment during healing is essential for determining the time at which load can be applied without the risk of bone resorption. Altogether, our results suggest the similar performance of Osstell® and AnyCheck®, and, consequently, the usefulness of the latter for the determination of implant stability.

Abbreviations

ISQ: Implant stability quotient; RFA: Resonance frequency analysis; IT: Insertion torque; IST: Implant stability test.

Acknowledgements

Not applicable.

Author contributions

HK, KN conceived the idea and designed the study. YO performed the research. HT, HjK analyzed the data. MA contributed with new methods or models. YO wrote the paper. All authors have read and agreed to the final version of the manuscript.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to privacy and ethical concerns but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Kanagawa Dental University Ethics Committee (approval # 739), and written informed consent was obtained from all patients. All methods were performed in accordance with the 1964 Helsinki Declaration.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Clinical Validation of Dental Implant Stability by Newly Designed Damping Capacity Assessment Device during the Healing Period

Ho-Kyung Lim [1,†], Sung-Jae Lee [2,†], Yujin Jeong [3], Jong-Seok Lee [4], Jae-Jun Ryu [4], Ji-Suk Shim[5,*] and In-Seok Song [2,*]

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Abstract: *Background and Objectives:* To evaluate the stability of a dental implant and the effectiveness of a newly designed damping capacity assessment device by improving the number of blows and strength evaluated by a prospective clinical study. *Materials and Method:* The stability of dental implants was measured in 50 implants in a total of 38 patients. Measurements were performed using Anycheck and Periotest M devices, twice in total, divided into buccal and lingual directions. In addition, measurements were performed on the day of surgery, two weeks, one month, two months, and three months after surgery for a total of five times. After the standardization of the measured values, the differences and changes over time for each device were observed. *Result:* No difference in standardized values between the two devices was observed at any time point. In both devices, stability decreased at two weeks postoperatively but gradually increased thereafter. No differences were observed in the values according to the measurement direction. *Conclusions:* The damping capacity of Anycheck was similar to that of Periotest M. After a slight decrease in stability two weeks after implant placement, implant stability increased over time.

Keywords: dental implants; stability; dentistry; analytic device

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1. Introduction

Osseointegration of dental implants is affected by various factors such as the type of implant surface, density of the alveolar bone, age of the patient, whether or not a bone grafting is performed, and the volume of the alveolar bone [1]. Various methods of measuring the stability of dental implants have been used in clinical practice. The insertion torque value measurement method, such as the Osstell method using resonance frequency analysis (Osstell device, Integration Diagnostics AB, Sa¨vedalen, Sweden), and Periotest M method using damping capacity assessment (Periotest M device, Gulden Messtechnik, Bensheim, Germany) have been widely used [2–4]. Each measurement method has its characteristics. Osstell is a non-contact measurement method, and its measurement values are internationally standardized. However, a separate measuring device (Smartpeg) is required, and there is a risk and inconvenience in releasing the healing abutment for the measurement. Periotest M is convenient and safe for measuring the stability of a healing abutment. However, the measured value is affected by the angle of impact and the high strength of the blow, and the number of blows is rather high (16 times) causing a feeling of rejection in the patient.

The recently developed modified damping capacity measuring instrument (Anycheck, Neobiotech Co., Ltd., Seoul, Korea) has high reproducibility, and it is possible to directly contact the measurement target by improving the hitting method [5]. The number of measurements was also reduced to six, and when the stability measurement was less than 70, the function of hitting the implant was decreased to two times to reduce the impact on the implant. There are several in vitro and animal tests, but there are still few studies on their effectiveness in clinical practice [5,6].

In this clinical study, the stability of implants during the healing period was verified using this new damping capacity assessment device. In addition, the similarity of the measured values was evaluated and compared with that of the existing Periotest M equipment.

2. Materials and Methods

Patients who visited the Korea University Anam Hospital from January 2020 to December 2021 and who had healing abutments placed after implant placement under local anesthesia were included in the study. The following patients were included in the study: those who planned to have a dental implant and healing abutment placed on the day of surgery and those who were older than 19 years who had a firm willingness to participate in this study and eventually agreed to participate in the study. Patients were excluded if the implant was replaced due to previous failure, placed immediately on the same day after tooth extraction, or if the procedure included a large amount of vertical augmentation of the alveolar bone or sinus grafting due to severe bone loss. A total of 38 patients with 50 implants were included in this study. This prospective clinical study was conducted with the approval of the Institutional Review Board of Korea University Anam Hospital (No. 2020AN0105).

Implant-first surgery was performed under block or infiltration anesthesia using 2% lidocaine epinephrine (1:100,000 epinephrine containment) in the outpatient clinic. If bone defects, such as dehiscence, existed, bone grafting using xenografts (BioOss, Geistlich Pharma AG, Zürich, Switzerland) was performed simultaneously with implant placement. Only bone level and internal hex connection fixtures (LUNA, Shinhung Co., Ltd., Seoul, South Korea; IS Ⅱ or IS Ⅲ, Neobiotech Co., Ltd., Seoul, Korea) were used for implant placement. The healing abutment was placed after implant placement, and if the incision was previously made, sutures were made using nylon without tension. Implant stability was measured as previously described. After pressure dressing with a sterile gauze bite was performed, postoperative caution was explained to the subjects. An antibiotic (cephalexin 1000 mg, t.i.d.) and a non-steroidal anti-inflammatory agent (zaltoprofen 80 mg, t.i.d.) were prescribed for 5 days, and 0.12% chlorhexidine solution mouth rinse was administered daily.

Implant stability was measured twice each on the buccal (labial) and lingual (palatal) sides using two different damping capacity analysis devices (Periotest M, Anycheck). The stability value measured by Periotest M is referred to as the Periotest value (PTV), ranging from −8.0 to +50.0, which is closer to −8.0% when the material has more rigidity. It was measured through 16 tapping motions. The value of the implant stability test (IST) measured by Anycheck was designed to be similar to the implant stability quotient value (ISQ scale), ranging from 0 to 100, and was measured through six rounds of slight tapping motion. The IST value was then calibrated according to the height of the healing abutment according to the manufacturer's instructions: no calibration at 4 mm height, +2 per 1 mm shorter, and −2 per 1 mm longer than the height of the healing abutment. When both devices are driven at a point 2–3 mm away from the healing abutment, the stability value is derived through effective hitting (Figure 1).

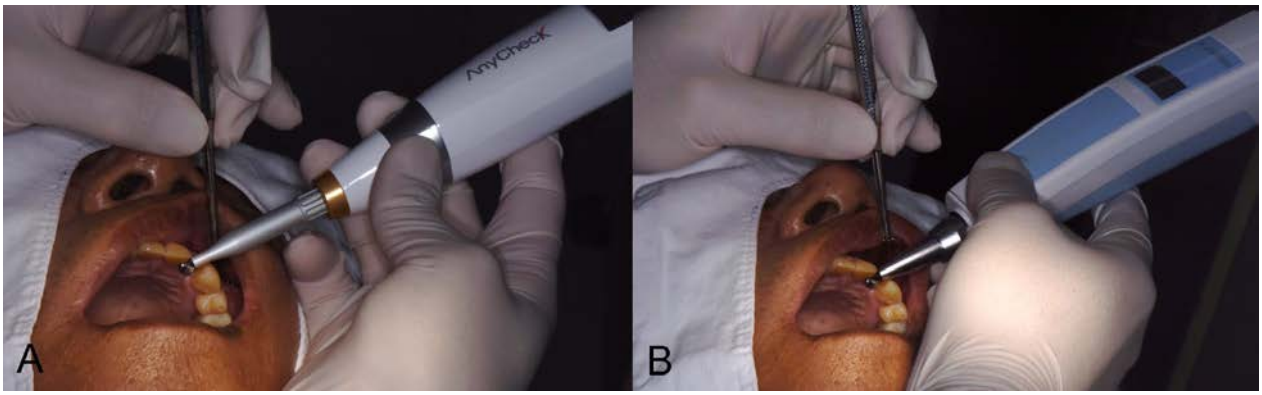

Figure 1. Clinical application of Anycheck and Periotest M equipment. (**A)** Anycheck, (**B)** Periotest M).

The participants were instructed to visit the clinics at 2 weeks, 1 month, 2 months, and 3 months after the first implant surgery. At each follow-up, stability measurements were performed in the same manner as on the operative day. After 3 months, the patients were referred to the prosthodontic department for implant prosthesis restoration, if no major complications occurred, or additional follow-ups were arranged if the stability value was considered insufficient to be loaded (Figure 2). In addition to implant stability, implant sites, type of fixtures, diameter and length of the fixtures, the gingival height of the healing abutments, and bone grafting were recorded at all follow-up periods.

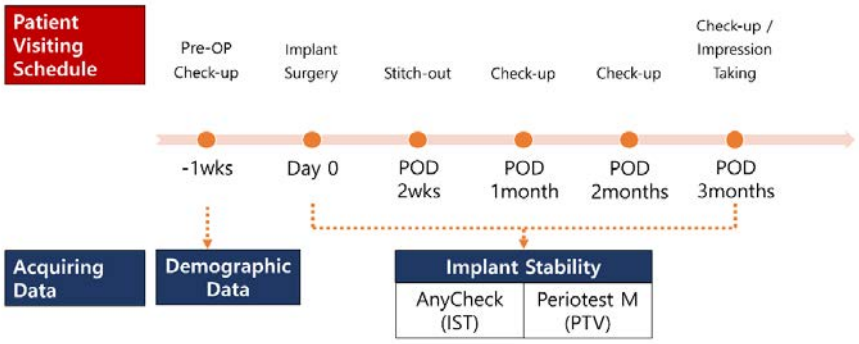

Figure 2. Schematic diagram of the clinical trials.

For statistical analysis, the implant stability measured by damping capacity analysis devices after implant placement was evaluated using covariance analysis of repeated measurements implemented using SAS Proc Mixed (SAS Institute, Inc., Cary, NC, USA). The device (Periotest M or Anycheck) was the between-subject factor and time (on the day of surgery, 2 weeks, 1 month, 2 months, 3 months) was the within-subject factor. MEAN/SD is the observed mean and standard deviation and LSMEAN/SE is the predicted mean and standard error of the statistical model. The scales of the two measurement devices were standardized using the Z-score standardization method. Statistical significance was set at $p < 0.05$. Analyses were performed for the buccal (labial) side, lingual (palatal) side, and total values. Statistical analysis was performed using the Statistical Analysis System version 9.4 (SAS Institute, Inc., Cary, NC, USA).

3. Results

The characteristics of the participants and the implants are presented in Table 1. The mean age was 66 years, and 20 men and 18 women were included in the study. Twenty-three implants were placed in the maxilla, 27 in the mandible, 4 in the anterior region, and 46 in the posterior region. Implant fixtures from the following three manufacturers were used: LUNA (Shinhung, Seoul, Korea), 22; ISII (Neobiotech, Seoul, Korea), 20; and ISIII (Neobiotech, Seoul, Korea), 8. For the fixture size, six short implants and 49 regular implants were used. For the height of the healing abutment, 4 mm was used the most (26 pieces). Bone grafting was performed on 21 patients.

Table 1. Demographic data of the patients and characteristics of the dental implants.

Investigated Item	Number
Patients	38
Age, mean (range)	66 (36–89)
Sex	
Male	20 (53%)
Female	18 (47%)
Total implants	50
Jaw	
Maxilla	23 (46%)
Mandible	27 (54%)
Location	
Anterior	4 (8%)
Posterior	46 (92%)
Fixture (manufacturer)	
LUNA (Shinhung)	22 (44%)
IS Ⅱ (Neobiotech)	20 (40%)
IS Ⅲ (Neobiotech)	8 (16%)
Fixture (size)	
Length	
Short (<8.0 mm)	6 (12%)
Regular (8.0–11.5 mm)	43 (86%)
Long (>11.5 mm)	1 (2%)
Diameter	
Narrow (≤3.5 mm)	1 (2%)
Regular (4.0–5.0 mm)	49 (98%)
Wide (>5.0 mm)	0
Healing abutment (GH)	
3 mm	4 (8%)
4 mm	26 (52%)
5 mm	12 (24%)
6 mm	7 (14%)
7 mm	1 (2%)
Bone grafting	21 (42%)

The mean values and standard deviations of measured stability at each follow-up period are presented in Table 2. When stability was measured using Periotest M, the average stability immediately after surgery decreased at two weeks but gradually increased thereafter, showing overall higher stability at the end of three months than immediately after surgery. In the case of Anycheck, similar to Periotest M, the average of the measured

values decreased in the second week after the operation, but gradually increased thereafter and showed higher stability than immediately after the operation from one month. (Table 2, Figure 3). This trend was similar for the buccal, lingual, and average scores. Contrary to the pattern of the measured values, both the standardized Z-scores of Periotest M and Anycheck showed a significant increase with time after a decrease at two weeks postoperatively (Table 3, Figure 4) ($p < 0.0001$). This is illustrated in Figure 4. This trend was significantly observed in the buccal, lingual, and average areas. It is observed that the "stability dip" is formed between two weeks and one month after implant placement, and the stability increases rapidly as it reaches the third month. At all time points, no difference in the standardized values was observed between the two instruments, Periotest M and Anycheck ($p > 0.01$).

Table 2. The mean value and standard deviation of measured stability at each follow-up period.

Device	Post-op Period	Mean	SD
Periotest M	Op	−4.72	2.92
	2 W	−4.25	4.37
	1 M	−4.62	3.50
	2 M	−4.57	3.34
	3 M	−5.29	2.84
Anycheck	Op	76.10	6.89
	2 W	75.82	9.87
	1 M	76.40	8.42
	2 M	76.50	7.85
	3 M	77.48	6.92

Abbreviation: Op, operation day; 2 W, post-operative 2 weeks; 1 M, post-operative 1 month; 2 M, post-operative 2 months; 3 M, post-operative 3 months.

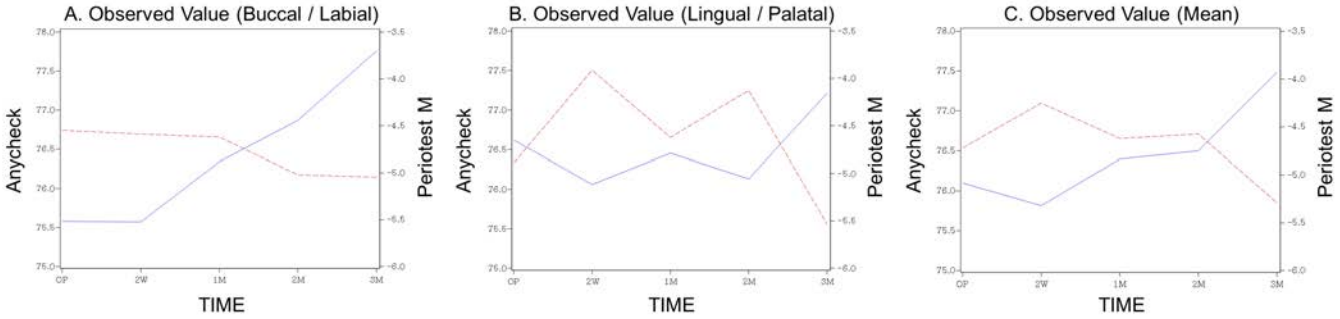

Figure 3. The observed values over time. (**A**) Buccal, (**B**) lingual, (**C**) mean.

Table 3. The implant stability measured by damping capacity analysis devices after implant placement.

	Tapping Location	Mean	SD	LSMEAN	SE	*p*-value
Periotest M	both	0.000	0.999	0.04322	0.07911	0.6626
Anycheck		0.000	0.999	−0.0030	0.07911	
OP		−0.014	0.861	−0.014	0.06071	
2 W		−0.090	1.219	−0.107	0.08685	
1 M		−0.005	1.025	−0.037	0.07259	<0.0001
2 M		0.005	0.942	0.028	0.07063	
3 M		0.157	0.837	0.231	0.06275	
Periotest M	Buccal	0.000	1.000	0.021	0.1192	0.9275
Anycheck		0.000	1.000	0.006	0.1192	
OP		−0.078	0.933	−0.078	0.09283	
2 W		−0.072	1.172	−0.096	0.1178	
1 M		−0.016	1.061	−0.058	0.1053	0.0325
2 M		0.086	0.875	0.099	0.08901	
3 M		0.148	0.861	0.201	0.09207	
Periotest M	Lingual	0.000	1.000	0.066	0.1058	0.5173
Anycheck		0.000	1.000	−0.024	0.1058	
OP		0.049	0.782	0.049	0.07777	
2 W		−0.108	1.270	−0.120	0.1278	
1 M		0.006	0.995	−0.012	0.0998	0.0031
2 M		−0.076	1.003	−0.050	0.1093	
3 M		0.165	0.819	0.238	0.08636	

Abbreviation: Op, operation day; 2 W, post-operative 2 weeks; 1 M, post-operative 1 month; 2 M, post-operative 2 months; 3 M, post-operative 3 months. Device (Periotest M or Anycheck) was the between-subject factor and time (OP, 2 W, 1 M, 2 M, 3 M) was the within-subject factor. MEAN/SD is the observed mean and standard deviation and LSMEAN/SE is the predicted mean and standard error of the statistical model. The scales of the two measurement devices were standardized using the Z-score standardization method. Statistical significance was set at $p < 0.05$.

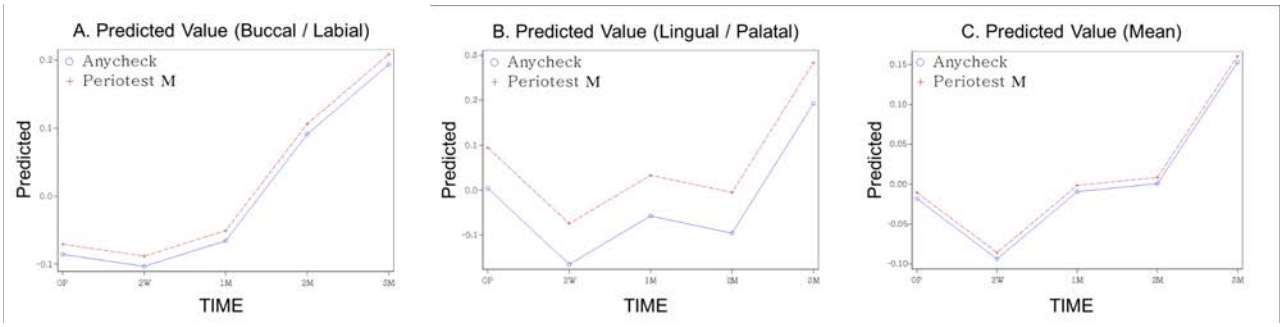

Figure 4. The predicted value over time (Z-score standardized, (**A**) buccal, (**B**) lingual, (**C**) mean).

4. Discussion

The results of this study showed that the damping capacity of Anycheck at all time points and in all hitting directions showed a tendency similar to that of Periotest M. Although the measured values were different, in the corrected values, the results of the two instruments were almost identical. In addition, after a slight decrease in stability two weeks after implant placement, implant stability increased over time, and both devices showed a significant difference with time.

Currently, the most widely used devices for measuring dental implant stability are Osstell, which can measure ISQ values based on resonance frequency analysis, and Periotest M, which is based on damping capacity assessment, as mentioned in the introduction [7]. The advantage of Osstell is that there is no tapping of the implant during measurement; therefore, there is less discomfort for the patient. However, for each implant product, a smart peg with a matching inner surface must be provided, and the smart peg fastening process may affect the fixation of implants with weak initial stability [8,9]. In the case of Periotest M, there is no such connection process, but the blow is strong and the number of blows is relatively large (16), which can cause patient discomfort, and the measured value can be affected by the blow angle [10,11].

The Anycheck device is an improved version of these two devices. It does not require a superstructure connection process such as Osstell for measurement, and the strength and frequency of blows have been dramatically improved compared with Periotest M [5]. In addition, to increase the user's intuition, it is displayed differently in red, orange, and green depending on the range of the measured value, in order that stability can be recognized without reading the number [5]. Therefore, the Anycheck device makes it easier to measure implant stability than existing devices. However, despite having a wider effective striking angle than Periotest M, it can only be measured when the striking angle is in the range of 0° to 30° from the ground, and the final result value must be corrected because the resulting value may vary depending on the length of the healing abutment [6].

Implant stability is divided into two types: primary and secondary. Primary stability refers to the initial mechanical stability, which occurs because of friction through contact between the bone and implant surface [12]. If the initial fixation is insufficient and the micro-movement reaches a level exceeding 50–100 μm, osseointegration may be damaged, and as a result, tissues other than bone, such as fibrous tissue, may be formed around the implant [13]. Secondary stability refers to the stability of the biological form through bone regeneration and remodeling at the implant-tissue interface [14]. Differentiating osteogenic cells migrate to the implant surface to form a mineralized interfacial matrix around the implant and then undergo remodeling to complete osseointegration [15]. Total implant stability is composed of synthesizing this primary and secondary stability, and most of the studies on total implant stability report that the value decreased slightly immediately after implant placement and then gradually increased thereafter [16–18]. This pattern has been described as a drop or dip [19]. In one study, it was mentioned that this dip exists between two and four weeks using a mathematical model through curve-fitting [20], and a similar pattern of stability change was also observed in this study. At the second week after the operation, the measured values of both devices showed a decreasing pattern and then gradually increased thereafter. This means that the theoretical stability dip is also observed in actual clinical practice. Furthermore, this suggests the need to easily and conveniently measure implant stability in order that implants can be loaded at the right timing.

There are many studies on the comparison of Osstell, and Periotest M, which are existing devices for measuring implant stability, and the clinical similarity between the two devices has been verified to some extent [3,6,21–26]. The Anycheck device was developed relatively recently; therefore, there are not many studies using the Anycheck device. In particular, no clinical studies have yet been conducted. However, a high similarity between Anycheck and other devices can be observed consistently in existing studies and in this clinical study. In a validity analysis of an ex vivo study using porcine bones, a very high correlation was observed between the measured values of Anycheck, Osstell, and Periotest M, and a linear relationship between the insertion torque and the measured values was observed [6]. Similarly, in one in vitro study, a high correlation between the three devices was observed, and it was observed that the diameter of the healing abutment did not affect the measured value, unlike the healing abutment length, which affected the Anycheck measured value [5]. A previous study observed a linear correlation between the

vibration frequency and the Anycheck value measured while controlling the peri-implant artificial bone level [27].

This clinical study has some limitations. Although Osstell and Periotest M showed almost equal reliability in numerous studies, Osstell was not applied in this study. However, if comparison with Osstell were performed, abundant results would have been derived. In addition, the fact that the effects of the jaw arch, implant specifications, and bone graft could not be controlled is another limitation of this study. Nevertheless, in the results, a similar and uniform tendency of the Anycheck device could be observed when compared with Periotest M, and the similarity along the timeline could also be observed; therefore, it is considered that the clinical significance of this study is sufficient. Through this prospective clinical study, the new damping assessment device with reduced patient discomfort and high clinical versatility suggested the possibility of clinical replacement by showing implant stability measurements similar to those of existing equipment.

5. Conclusions

During the observation period of three months, the damping capacity of Anycheck showed a similar tendency to that of Periotest M. After a slight decrease in stability two weeks after implant placement, implant stability increased over time. Through this study, the clinical substitution potential of the Anycheck device, which has a simpler measurement method and equivalent implant stability measurement power, was observed.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Furthermore, written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement: The datasets are available from the corresponding author on reasonable request.

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