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A novel technique for measurement of orthodontic mini-implant stability using the Osstell ISQ device

Yara K. Hosein[a]; S. Jeffrey Dixon[b]; Amin S. Rizkalla[c]; Ali Tassi[d]

ABSTRACT

Objectives: To develop and validate a method for application of the Osstell ISQ device in the assessment of mini-implant stability.

Materials and Methods: An adaptor was developed for attachment of Osstell's SmartPeg onto a variety of orthodontic mini-implants. For validation of the adaptor, Benefit mini-implants were inserted into bone blocks that mimicked different stability conditions. The Osstell device was used to assess mini-implant stability with the adaptor (test measurement) and conventional SmartPeg attachment (gold-standard measurement). Implant stability quotient (ISQ) values were assessed for agreement, repeatability, and reproducibility.

Results: Strong positive correlations were found between ISQ values obtained using the novel adaptor and the conventional attachment. Repeatability and reproducibility of ISQ values with the adaptor were similar to those obtained with the conventional attachment.

Conclusions: A method was developed and validated to assess the stability of orthodontic mini-implants using the Osstell system. The novel mini-implant adaptor provided repeatable and reproducible measurements of mini-implant stability, which agreed with those obtained using a conventional SmartPeg attachment. This adaptor permits noninvasive stability assessment of various designs of mini-implants, most of which are incompatible with the conventional SmartPeg attachment. (*Angle Orthod.* 2019;89:284–291.)

KEY WORDS: Osstell ISQ; Mini-implants; Primary stability

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INTRODUCTION

Mini-implants provide skeletal anchorage during orthodontic treatment; however, failure rates range from 6% to 30%.[1,2] Since these devices are temporary and osseointegration is not a goal, stability is achieved through the mechanical retention formed between the mini-implant and bone.[3] Therefore, quantitative measures that accurately ascertain the extent of mechanical retention should predict the probability of mini-implant failure.[4]

Orthodontic mini-implant stability has been assessed previously using mechanical, radiographic, and histological approaches.[5,6] Some mechanical measures are restricted to research investigations because of their invasive nature (eg, pull-out force, displacement) or limited availability in clinical practice (eg, insertion torque). More recently, attempts have been made to use tools from dental implantology (eg, Osstell Measurement Systems) to assess mini-implant stability.[7–11]

The Osstell Resonance Frequency System comprises a magnetic SmartPeg that is screwed into the internally threaded implant head and a handheld probe

that emits magnetic pulses, which cause vibration. As the vibrational frequency increases, a frequency is reached at which the implant resonates. This resonance frequency, which reflects the stability of the implant in bone, is detected by the probe and recorded as an implant stability quotient (ISQ) value. The higher the ISQ value, the more stable the implant.[12–14] Although the Osstell system has been used to assess the stability of dental implants for tooth replacement, its application to orthodontic mini-implants is not straightforward. Mini-implants are much smaller in diameter than conventional dental implants, and most of their head designs are not threaded to accept the SmartPeg. Consequently, previous in vitro studies[9,10] have attached the SmartPeg to mini-implant heads using cured resins or soldering. However, these techniques render the mini-implant useless because of their invasive nature. Additionally, such approaches have never been validated by direct comparison with stability values obtained using a conventional SmartPeg attachment. Such validation is crucial for researchers and clinicians wishing to use the Osstell system to measure mini-implant stability.

The study objectives were the following: (1) to design and develop a mini-implant adaptor that is compatible with the Osstell ISQ system and that can couple nondestructively to multiple designs of mini-implants and (2) to validate the performance of the adaptor using the Benefit mini-implant (PSM Medical Solutions, Tuttlingen, Germany). This particular mini-implant was selected for study because it incorporates an internal thread that can couple directly to a modified SmartPeg without the need for an adaptor. This permitted direct comparison of ISQ values obtained from the same mini-implant using the novel adaptor and a conventional attachment.

MATERIALS AND METHODS

Design and Development of the Mini-implant SmartPeg Adaptor

The geometry of commercially available mini-implants were first analyzed to ensure that the Mini-implant SmartPeg Adaptor (MISPA) would be compatible with multiple mini-implant designs. Design concepts for MISPA were developed to meet the following requirements: (1) size adjustable to mini-implant diameter; (2) secure coupling to mini-implant head; (3) ease of attachment and removal; (4) strength and durability; and (5) ability to accept SmartPeg threads. The final design was created using Solidworks (Dassault Systèmes SolidWorks Corporation, Waltham, Mass) and machined from aluminum by Western University Machine Services.

Validation of MISPA

The Benefit mini-implant has a head design with internal screw threads. Type 1 SmartPegs (Osstell, Gothenburg, Sweden) were modified by Osstell to fit the internal thread of these mini-implants, which were then used to test and validate the MISPA. These mini-implants were specifically chosen since they could couple to the MISPA as well as directly to the modified conventional SmartPeg (Figure 1). Sixty mini-implants ($\varnothing = 2$ mm, length $= 9$ mm) were manually inserted into pre-drilled holes in artificial bone blocks (Sawbones®, Pacific Research Laboratories, Vashon, Wash) with cortical bone densities of 0.64 or 1.63 g/cm³ and similar cancellous bone density (0.32 g/cm³). Pre-drilling was performed to a depth of 4 mm with two different drill diameters: 1.4 or 1.8 mm (McMaster Carr, Aurora, Ohio). The differences in cortical bone density and drill diameters yielded different stability outcomes for the mini-implant. Thus, there were four groups based on the cortical density and drill diameters (n = 15 implants per group).

Immediately following insertion (day 1), mechanical stability of the mini-implants was assessed using two approaches. First, the MISPA was attached to the head of the Benefit mini-implant, a modified Type 1 SmartPeg was inserted into the MISPA, and the Osstell ISQ system was used to obtain an ISQ value (ie, test measurements) (Figure 1A). Second, the MISPA was removed, the SmartPeg was attached directly to the mini-implant (conventional SmartPeg attachment), and Osstell ISQ values were again recorded (ie, gold-standard measurements) (Figure 1B). In both cases, SmartPegs were replaced periodically to avoid the potential problem of thread corruption. For ISQ measurements, the handheld probe was positioned perpendicular to the longitudinal axis of the mini-implant. For each mini-implant, four ISQ measurements were taken at 90° intervals around the circumference of the mini-implant. The entire assessment (test and gold-standard measurements) was repeated on separate days (days 1, 2, and 3) to determine "test-retest" repeatability. Note that elsewhere in this article, the term "adaptor" refers to the MISPA, and the term "attachment" refers to the conventional SmartPeg attachment.

To determine whether ISQ measurements obtained using the MISPA were reproducible with multiple Osstell devices, the same mini-implants were assessed using two devices (devices 1 and 2) on separate days. Five implants from each of the four stability groups (0.64 or 1.63 g/cm³ cortical bone density, and 1.4- or 1.8-mm drill diameter) were assessed using the MISPA (n = 20 mini-implants).
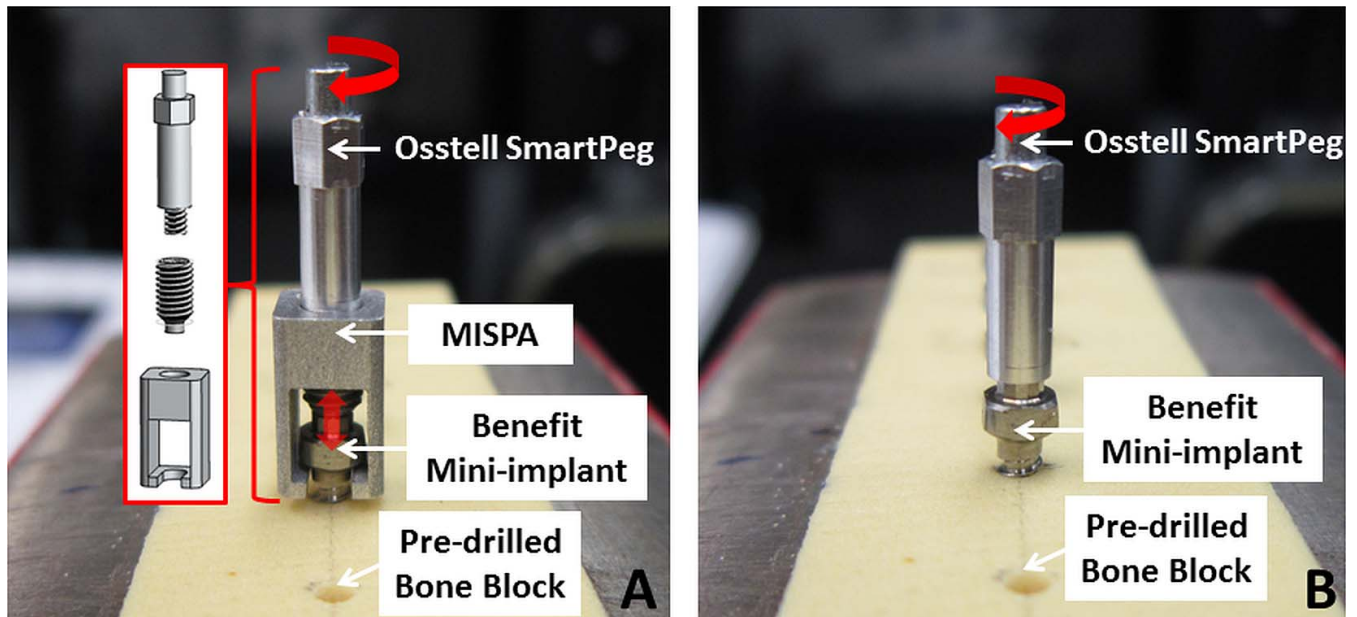
Figure 1. Experimental setup for validation testing. (A) Mini-implant SmartPeg Adaptor (MISPA) and (B) conventional SmartPeg attachment, each attached to the Benefit mini-implant inserted into artificial bone. The MISPA can be secured onto multiple mini-implant designs by clamping to the implant head without the need for a screw attachment. When securing the MISPA onto the mini-implant, the modified Type 1 SmartPeg was inserted into the top of the MISPA via a screw mechanism (A). The exploded view of this mechanism is shown in the inset image of (A), with the SmartPeg at the top, the MISPA set screw in the middle, and the MISPA body at the bottom. For securing the MISPA, the SmartPeg was screwed directly into the MISPA set screw, and the combined screw unit was further screwed into the MISPA body. During insertion with the MISPA body, the combined screw unit contacted the head of the mini-implant and, as it was tightened (circumferential arrow in A), the MISPA fastened onto the mini-implant head (double-ended arrow). This ensured a secure fit of the Osstell SmartPeg onto the mini-implant head. To secure the conventional SmartPeg (B), the modified Type 1 SmartPeg was introduced directly into the internal threads of the Benefit mini-implant (circumferential arrow in B).

Data Analysis and Statistical Tests

Normality of all data was assessed using the Shapiro-Wilk test. To compare the agreement of the MISPA (test measurement) with that of the conventional attachment (gold standard) for each test day, Spearman correlation, linear regression, and Bland Altman analyses were used.

Kruskal-Wallis with Dunn's multiple-comparison tests was used to compare stability differences. This multiple comparison allowed determination of whether stability measurements obtained using the MISPA showed similar statistical differences to those obtained using the conventional SmartPeg attachment.

To assess repeatability, Bland Altman analyses were used to test the differences in ISQ measurements across the three test days for both the MISPA and the conventional SmartPeg attachments. Reproducibility of ISQ measurements obtained using the MISPA was assessed using a second Osstell ISQ device. The clinical allowable difference for reproducibility was set at 5 ISQ units, as this coincided with Osstell's ISQ threshold for clinical differences in the stability of dental implants.[15]

RESULTS

Development of the MISPA

Although orthodontic mini-implants have variable head designs, a commonality is the larger diameter of the head relative to the mini-implant screw body. As such, the MISPA was designed to clamp around the larger diameter head of the mini-implant and to couple to the SmartPeg (Figure 1A). The MISPA was able to fasten onto various mini-implant designs securely, including the Benefit mini-implant, which was used for testing and validation.

Validation of the MISPA

When comparing mini-implant stability across the three testing days, ISQ values obtained using the conventional attachment (gold standard) were consistently greater than those from the MISPA (test), by approximately 26 units (Figure 2). Results from the Spearman coefficients showed strong positive correlations (average $r = 0.87$; $P < .0001$) between stability measurements acquired with the conventional attachment and those acquired with the MISPA (Figure 2). The repeatability of ISQ measurements across test
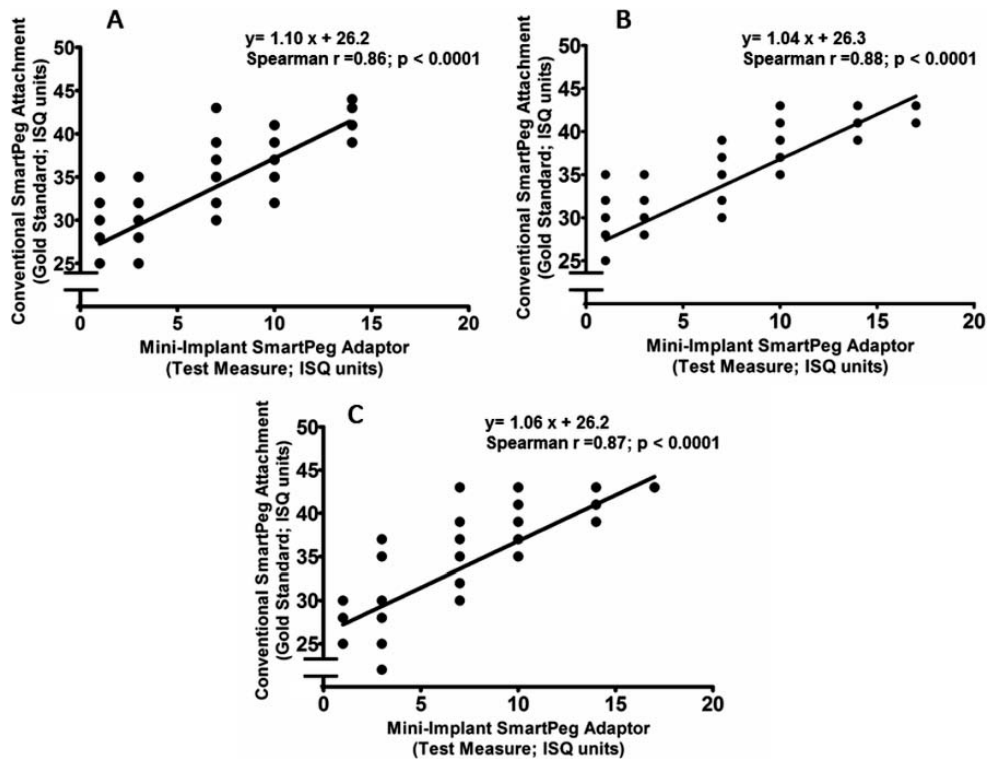
Figure 2. Validation of the Mini-implant SmartPeg Adaptor (MISPA). Mini-implants were inserted into bone blocks with varying cortical density and drill diameters (15 mini-implants per group). ISQ values were obtained using the MISPA and the conventional SmartPeg attachment (four measurements at 90° intervals around each mini-implant). Each data point represents matching ISQ values from a single mini-implant assessed in the same direction using both techniques. Correlations between data from the MISPA and the conventional attachment are shown in A (test day 1). To assess "test-retest" repeatability, measurements were repeated using the same samples on test day 2 (B) and test day 3 (C). Each graph comprises 240 data points (many of which overlapped). Strong correlations ($r \geq 0.86$; $P < .0001$) were found between the ISQ values over the three test days, with consistent offset of approximately 26 ISQ units between the MISPA and the conventional attachment.

days using the MISPA was similar to that obtained using the conventional attachment, for which 95% of the differences fell within ±5 ISQ units (Figure 3).

The stability of the mini-implants inserted into bone blocks with varying cortical density and drill diameters was measured using the MISPA and the conventional attachment. Both techniques yielded similar differences in ISQ values ($P < .0001$) (Figure 4). Greatest stability was found for mini-implants inserted into bone blocks with 1.63 g/cm³ cortical layer and 1.4-mm drill diameter. Least stability was found for mini-implants inserted into bone blocks with 0.64 g/cm³ cortical layer, with no significant effect of drill diameter.

The offset in ISQ (26 units) between the conventional attachment and the MISPA was likely due to the difference in height of the SmartPeg above the implant head (26). To confirm this, additional tests were performed using the conventional SmartPeg with a connector that extended its height to match that of the MISPA (Figure 5A). Under these conditions, the conventional attachment yielded ISQ values similar to those obtained using the MISPA (Figure 5B), with average difference of only 0.2 ISQ units (Figure 5C).

Measurements obtained using two Osstell devices (devices 1 and 2) showed reproducible results (Table 1), for which no statistically significant differences were found in ISQ measurements ($P > .05$).

DISCUSSION

Stability is an important measure in the clinical evaluation of mini-implants as skeletal anchorage devices in orthodontic treatment. However, there are currently few objective measures of mini-implant

Table 1. Reproducibility of Implant Stability Quotient (ISQ) Measurements Obtained with the Mini-implant SmartPeg Adaptor (MISPA), as Assessed Using Two Osstell Devices[a][b]

Cortical Bone Density, g/cm³, and Drill Diameter, mm	Osstell ISQ (Mean ± SD)	
	Device 1	Device 2
0.64; 1.8 pre-drill	3.0 ± 0.0	3.0 ± 0.0
0.64; 1.4 pre-drill	3.0 ± 0.0	3.0 ± 0.0
1.63; 1.8 pre-drill	6.9 ± 1.6	6.9 ± 1.6
1.63; 1.4 pre-drill	10.4 ± 1.2	10.2 ± 0.9

[a] SD indicates standard deviation; n = 5 Mini-implants per stability group, 20 mini-implants in total.
[b] $P > .05$; no statistically significant differences were found between ISQ values obtained using the two Osstell devices.
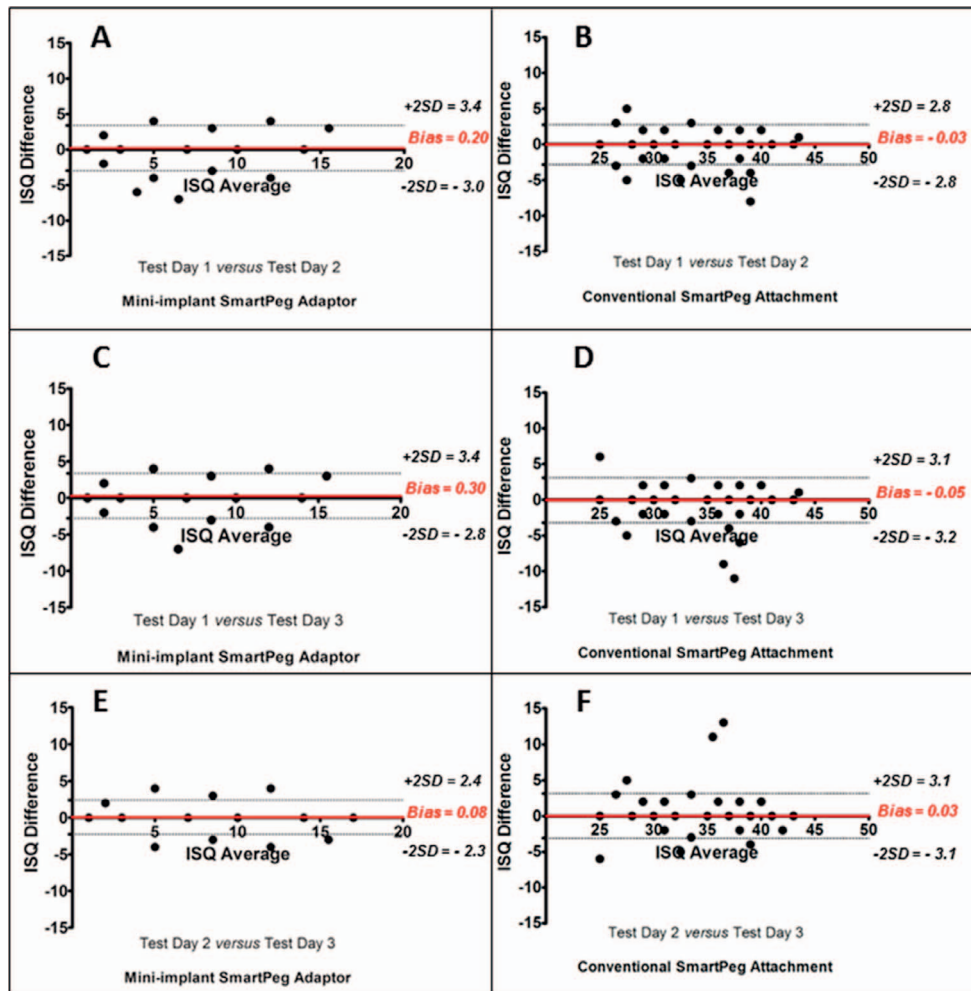
Figure 3. Repeatability of measurements obtained using the MISPA (A, C, E) compared to those obtained using the conventional SmartPeg attachment (B, D, F). Data were from the experiment illustrated in Figure 2. Bland Altman plots of the conventional SmartPeg attachment showed little difference (biases) between test days 1, 2, and 3, whereas differences with the MISPA were slightly greater (0.08–0.3 ISQ units). The majority of differences (for both the MISPA and the conventional attachment) fell within ±5 ISQ units, the threshold for clinical differences in implant stability.

stability. The Osstell ISQ is a clinical device currently used in the assessment of conventional dental implant stability.[7,16–19] However, its application to orthodontic mini-implants has been limited as a result of head designs that do not accept the threaded SmartPeg. Thus, use of the Osstell system to measure stability of a wide range of mini-implants requires an adaptor that couples the SmartPeg to the mini-implant head. The present study developed and validated such an adaptor.

The Benefit mini-implant used in the present study is, to date, the only mini-implant that has an internally threaded head that can permit attachment to a modified SmartPeg. This mini-implant is similar in dimension to most commonly used mini-implants. Therefore, results reported here are likely representative of overall mini-implant stability response.

The MISPA showed promising results in its representation of mini-implant stability when compared to the conventional method of SmartPeg attachment. The MISPA and the conventional attachment yielded similar differences in mini-implant stability dependent on cortical bone density and drill diameter. Across three test days, the MISPA showed repeatable measurements that were comparable to those obtained with the conventional SmartPeg attachment. Additionally, strong correlations were found between ISQ measurements obtained with the MISPA and those obtained with the conventional method, although a consistent offset of approximately 26 units was found (conventional method > MISPA).

Previous studies[12,20] described the height of conventional dental implants above bone as a factor that can affect ISQ readings. Therefore, it was hypothesized
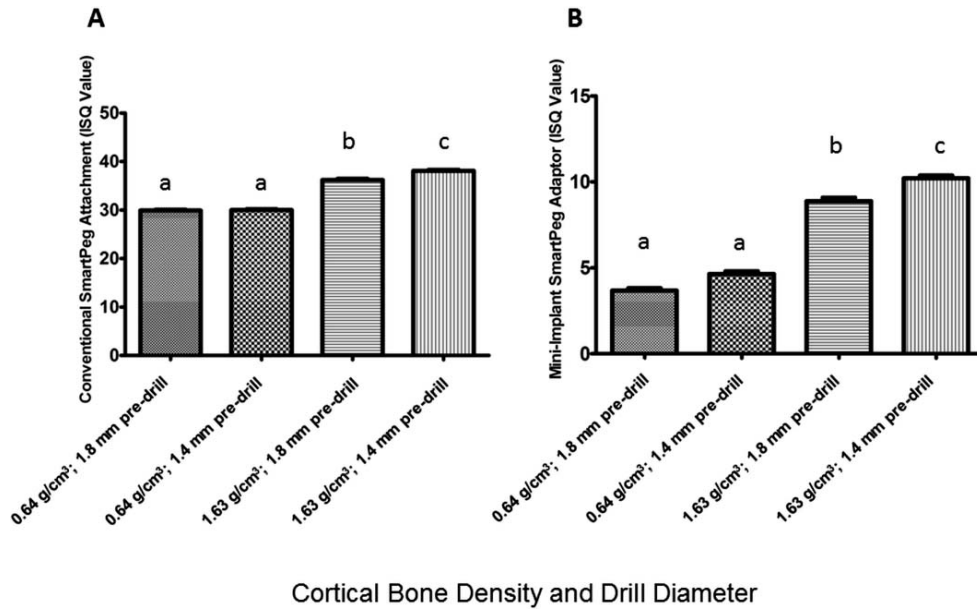
Cortical Bone Density and Drill Diameter

Figure 4. ISQ measurements for the various stability levels obtained using conventional SmartPeg attachment (A) and the MISPA (B). Bars represent means ± SEM, n = 180 ISQ values per group (15 mini-implants per group × 4 ISQ measurements per implant × 3 test days). Kruskal-Wallis tests detected similar differences ($P < .0001$) among the various stability levels for both attachment techniques. Dunn's multiple-comparison tests were used to assess differences between groups; different lowercase letters indicate significant differences between groups ($P < .05$).
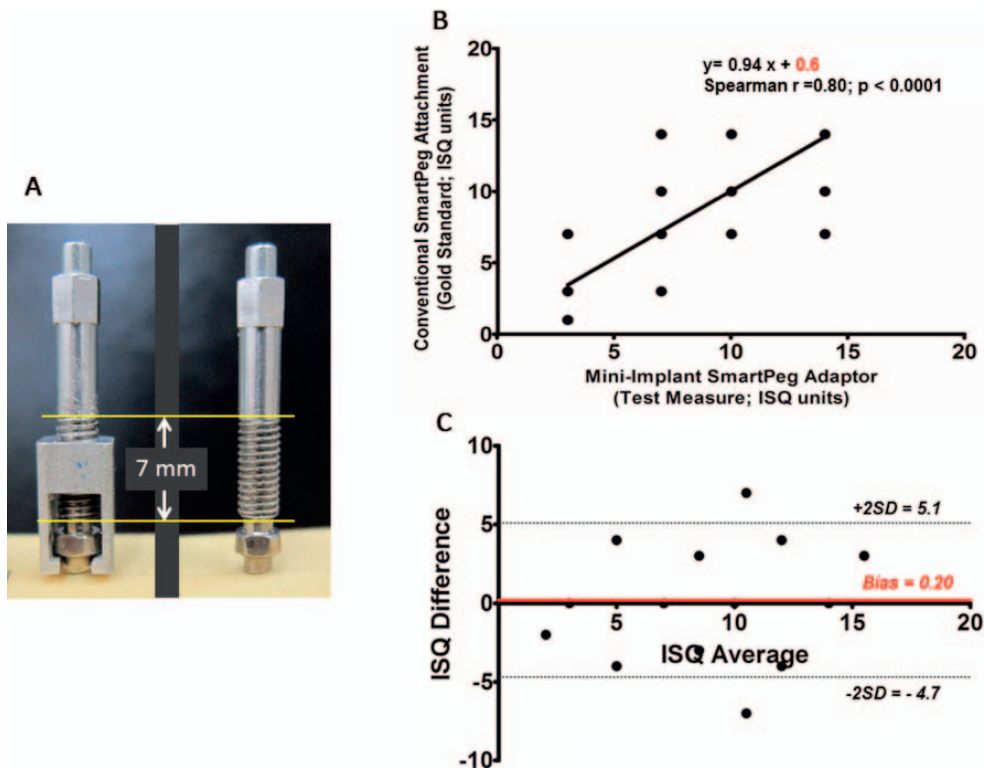

Figure 5. Effect of extending conventional SmartPeg height. (A) Left image shows the MISPA and SmartPeg mounted on the Benefit mini-implant. Right image shows height-adjusted conventional SmartPeg secured onto the mini-implant. Both setups had an equal height of 7 mm above the mini-implant head. (B) Correlation between ISQ measures obtained with the MISPA and those obtained with the height-adjusted conventional SmartPeg. Validation experiments were similar to those described in the legend of Figure 2. Strong correlation was found between ISQ measures obtained with the MISPA and the height-adjusted conventional SmartPeg ($r = 0.80$; $P < .0001$), with minimal offset found between measures (0.6 ISQ units). (C) Bland Altman plot results showed average difference of only 0.20 units (solid line) between ISQ measurements from the MISPA and the height-adjusted conventional SmartPeg attachment. The majority of the differences fell within two standard deviations from the average difference (as indicated by the dotted lines).

that the offset between the MISPA and the conventional SmartPeg attachment was due to differences in height above the mini-implant head. Since resonance frequency assessment of a mini-implant embedded in bone can be simplified as a cantilever beam in bending, the length of the moment arm (height of SmartPeg above the bone) will affect the resonance frequency. To test this possibility, the height of the conventional SmartPeg attachment was adjusted to match the 7-mm extension of the MISPA. With the height adjustment, both methods showed virtually no offset. There was good agreement between data obtained using the MISPA and the extended conventional attachment, as the 95% limits of agreement fell within ±5 ISQ units.

To assess the reproducibility of the MISPA, a second Osstell device was used. ISQ results from the second Osstell device were similar to those from the original, for which the majority of measurement differences fell within ±5 ISQ units.

Overall, this study showed the efficacy of the MISPA in facilitating accurate and reproducible in vitro measurements of mini-implant stability using the Osstell ISQ device. Such a tool would be useful in future research requiring a noninvasive, objective assessment of mini-implant stability.

The findings of this study suggest the potential to use the MISPA with the Osstell device for clinical assessment of mini-implant stability. However, future studies will be needed to validate the use of the MISPA for clinical applications. In addition, use of the Osstell ISQ device for routine assessment of mini-implant stability would require a modified ISQ scale that better represents the stability of smaller diameter, shorter implants.

CONCLUSIONS

- A new device for utilizing the Osstell system to measure stability of orthodontic mini-implants was developed and validated.
- The study describes a universal adaptor (MISPA) that can be used with multiple mini-implant designs without altering the implant itself.
- When tested with the Benefit mini-implant, the ISQ measurements obtained using the MISPA agreed with those from the conventional method, were repeatable across test days, and were reproducible when assessed with two Osstell ISQ devices.

ACKNOWLEDGMENTS

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