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REVIEW ARTICLE

Methods for Assessing Orthodontic Mini Implant Stability

Suhaila Zainal Abidin[1], **Maryati Md Dasor**[1,*]

[1] *Faculty of Dentistry, Universiti Teknologi MARA, Sungai Buloh Campus, Selangor, Malaysia*

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* *Corresponding author.*
Maryati Md Dasor
maryatidasor@uitm.edu.my

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ABSTRACT

Assessing the stability of orthodontic mini implants (MI) is critical for ensuring successful treatment outcomes. This abstract reviews, various methods employed to measure MI stability in orthodontics. Invasive methods include histologic & histomorphometry technique, cutting torque resistance analysis, removal torque analysis and insertion torque analysis. Non-invasive modalities such as surgeon's perception, radiographic examination, finite element analysis, percussion test, pulsed oscillation waveform, Periotest and Resonance Frequency Analysis. Each method contributes uniquely to the assessment of MI stability, aiding orthodontists in making informed decisions regarding treatment planning and anchorage management. Understanding the strengths and limitations of these measurement methods enhances their clinical utility and ensures optimal treatment outcomes in orthodontic practice.

Keywords: Orthodontic mini implants; Stability measurement; Orthodontics

1 INTRODUCTION

The term 'orthodontic anchorage' denotes the nature and degree of resistance to displacement offered by an anatomic unit[1].Orthodontic Mini implants (MIs) have been proven to offer maximum anchoring capabilities, allowing orthodontic tooth movement with minimal side effects and high patient acceptance[2,3]. MIs are widely utilised due to their small size, ease of insertion and removal, and relatively cost-effective nature compared to conventional implants[4,5].

The success of MI depends on achieving proper initial mechanical stability (primary stability) and ensuring the appropriate quality and quantity of loading[6].Primary stability is defined as biomechanical stability following MI insertion, which is often expressed by clinical perception based on the MI's cutting resistance during insertion and quantified using different means. Secondary stability offers biological stability through bone regeneration and remodelling[7,8]. Several methods had been used to measure the stability of MI (Table 1).

While MI stability is widely recognised as the foundation of successful MI as anchorage, advancements in other areas of MI research have not kept up with the development of diagnostic methods that allow clinicians to objectively evaluate implant stability. Measuring implant stability can provide valuable data that supports clinical decision-making in implant therapy, improves case documentation, enhances communication, and boosts patient-clinician trust.

Table 1: Methods for measuring MI Stability

1. Invasive Methods
• Histologic & Histomorphometry technique
• Cutting Torque Resistance Analysis
• Removal Torque Analysis
• Insertion Torque Analysis
• Pullout Test
2. Non-invasive methods
• Surgeon's perception
• Radiographic Examination
• Finite Element Analysis
• Percussion test
• Pulsed Oscillation Waveform
• Periotest
• Resonance Frequency Analysis

2 METHODS FOR MEASURING MI STABILITY

2.1 *Invasive Methods*

2.1.1. *Histologic and Histomorphometric Analysis*

The implant's stability can be estimated indirectly by examining the bone–implant interface. A coloured specimen of the implant and peri-implant bone is used to calculate the amount of peri-implant bone, cell proliferation and the bone-implant contact (BIC). Using this experimental setting, Fontes et al. 2023 discovered that splinting reduced tipping and the displacement of MIs without influencing the enhanced bone development in the peri-implant area caused by a functional orthodontic load[9].Additionally, Luzi et al. (2009) discovered that the bone healing pattern was not adversely affected by initial loading with light forces[10]. These techniques have the potential to assess osseointegration directly, offering the most effective means of establishing secondary stability.

2.1.2. *Cutting Torque Resistance Analysis*

Cutting torque resistance analysis is an invasive surgical method where the torque needed to penetrate the implant into the bone is measured. It was introduced by Johansson and Strid in 1994, who measured the electric current consumed during low-speed threading of implant sites to determine the true cutting resistance of bone. The technique was further evaluated by Friberg et al. when tapping implant sites[11–13] in pig ribs and human autopsy specimens. Since the quantity and quality of the surrounding bone directly impact the torque required to place the implant, this method provides a direct assessment of the implant-bone interface.

Cutting torque has also been applied in orthodontics to enhance the clinician's capacity to identify root contact during the placement of MI[14]. Furthermore, assessing bone quality is only feasible after the osteotomy site has been prepared, which prevents measuring any changes in bone quality over time. The fundamental purpose of its application is to evaluate the hardness of bones before implantation to indirectly determine the level of initial stability.

2.1.3. *Removal Torque Analysis*

The reverse torque test was first proposed by Roberts et al. in their study of acid etched titanium implant surfaces which were screwed into the prepared femurs of 3 – 6 months old rabbits[15] and further developed by Johansson and Albrektsson[16]. It is usually done several weeks following MI implantation to facilitate osseointegration, or implant-bone integration. A torque wrench or motor rotates the implant to measure its resistance during loosening and removal. Higher removal torque values indicate MI stability and osseointegration.

Suzuki and Suzuki believes that the assessment of both insertion and removal torque values should provide important information about the effect of the primary stability on the extent of osseointegration surrounding the immediately loaded MI and they observed an inverse relationship of Maximum Insertion Torque (MIT) and Maximum Removal Torque (MRT) values[17]. Favera et al had established the Removal Torque Value (RTV) of osseointegrated MI used for orthodontic anchorage and average RTV (67.91 ± 12.47 N/cm) were considered compatible with safe, non-invasive removal of the MI followed by rapid anatomical reconstruction of the area involved[18].

2.1.4. *Insertion Torque Analysis*

Insertion torque (IT) is a critical parameter used in orthodontics to assess the initial stability of MIs upon placement into the jawbone. A torque wrench or motor is used to rotate the MI into the bone during MI insertion. Newton-centimetres (Ncm) are used to measure the torque needed for insertion. The resistance that the MI faces when it contacts the bone tissue is reflected in this torque measurement. This test is widely used to assess various implant designs and has gained a great deal of acceptability[19]. Studies have established a correlation between IT and bone density, which in turn influences implant stability[20]. IT measurements provide insights into the underlying bone quality supporting the implant. Specifically, IT has been observed to rise with increasing cortical bone thickness[21].

Suzuki and Suzuki suggest that relatively lower MIT values were more favourable to osseointegration than higher values[17]. Thicker MI needed higher IT and highest IT was recorded with extra alveolar screws. MI placed with an IT above the recommended range tend to fail and break more often[22].

2.1.5. *Pull-out test*

A pull-out test simulates implant stress by exerting controlled force in the opposite direction to its implantation. The force needed to remove the implant indicates its stability and osseointegration. This test provides valuable data on the mechanical retention of the implant and is used to assess the design of implants and the mechanical interface between bone and implants and to determine the primary stability[23].

Salmória et al. observed that pull-out strength is greater immediately after placement of MI and there is no correlation between the pull-out strength and insertion torque at 0,15, and 60 days after MI (1.6 mm in diameter and 6.0 mm in length) placement[24]. According to Leung et al.'s[25], pull-out forces from cylindrical 2.0-mm MI attached to miniplates were much higher than those from MI with smaller diameters.

Pull-out testing has the same constraints as insertion torque. Following the test, pull-out tests damage the implant site, making them unsuitable for regular implant-bone interface assessment. This test can only be utilised in laboratory settings, since it cannot be used in typical clinical settings.

2.2 *Non-invasive methods*

2.2.1. The surgeon's perception

Clinical evaluation of MI stability often comprises subjective digital pressure and percussion assessments of MI movement. The assessment regularly relies solely on the viewpoint of the surgeon and is impacted by the cutting resistance and seating torque of the MI during insertion. One factor that could contribute to the idea of "good" stability is the impression of an abrupt stop upon orthodontic MI seating. The opinion of a skilled surgeon is vital as it was observed that the failure rate was higher when MIs were placed by inexperienced operators [(26)].

The reliability and consistency of surgeons' subjective impressions can be questioned when communicating subjective impressions. It's also uncertain how sensitive this approach is to early indicators of instability.

2.2.2. Radiographic examination

MI stability can be evaluated non-destructively by radiographic study. This method can be utilized at all stages of therapy to assess the quality and quantity of the jawbone [(27)].

Radiographic techniques, such as periapical and panoramic radiographs, have been employed to assess the peri-implant bone levels and detect potential signs of instability [(28)]. They provide valuable information regarding the implant-bone interface and the extent of osseointegration, and it can be used in longitudinal clinical studies on orthodontic MIs at the anterior-posterior and lateral-medial locations or longitudinal displacement [(28)]. Additionally, it is used to assess changes in bone quantity and quality, as well as to estimate crestal bone alterations resulting from the osseointegration process after implant placement [(29)].

However, conventional radiography has significant limitations because it produces a two-dimensional image with structural overlap and cannot measure bone quality or density. Although CBCT provides an accurate three-dimensional visualisation of the interradicular space, the two-dimensional intraoral radiograph of the interradicular area provides sufficient information for MI placement. Considering the amount of radiation exposure and cost with the two techniques, it is recommended to use two-dimensional radiographs like periapical radiographs with a surgical guide for a routine MI placement and potential site examination [(30,31)].

But none of these approaches can quantify stability with appropriate accuracy and consistency, hence an accurate and consistent way to evaluate MI stability is required [(32)].

2.2.3. Finite element analysis (FEA)

This approach divides complicated structures like MI and surrounding bone into finite elements and models their mechanical behaviour using mathematical equations. The Poisson ratio, bone density, and Young's modulus are the properties that are typically utilised. FEA accurately analyses stress distribution, deformation, and loading forces on MI stability.

Sarika et al. used FEA to estimate stress patterns around MIs and recommend placing them perpendicularly with sufficient diameter and length to avoid root injury [(33)].

A significant drawback of finite element modelling is that it relies on theoretical assumptions about bone characteristics. Its application in a clinical setting is challenging because it primarily involves static analysis [(34)].

2.2.4. Percussion test

The percussion test is one of the easiest ways to measure osseointegration. The test uses vibrational-acoustic science and impact response theory. Sound from metallic instruments is used to assess osseointegration clinically. A clearly ringing "crystal" sound indicates successful osseointegration; a "dull" sound may suggest no osseointegration. Nonetheless, an important consideration in this method is the clinician's level of experience and personal convictions. Therefore, it cannot be used experimentally as a standardised testing method [(27)].

2.2.5. Pulsed Oscillation Waveform (POWF)

POWF is determined by measuring the implant vibration's frequency and amplitude, which are brought on by a brief pulsed force. The oscilloscope, pulse generator, acoustoelectric receiver (AER), and acoustoelectric driver (AED) make up this system. A piezoelectric element and a piercing needle are the two main components of the AED and AER.

Applying a 1 kHz multifrequency pulsed force to an implant involves softly contacting it with two small needles that are coupled to piezoelectric devices. On an oscilloscope screen, the resonance and vibration produced by a stimulated implant's bone-implant contact are detected. This method is used in experimental and in vitro research, which has shown that load positions and orientations influence the sensitivity of the POWF test [(35)].

2.2.6. Periotest

The Periotest evaluates response of periodontium to a specific percussive force applied to the tooth by an electronic tapping device. By measuring periodontium elastic and viscous properties, structural change can be determined. The latter prevents tooth oscillations in the alveolar bone. A value is calculated and is displayed as a "Periotest value" [(28,36)].

The Periotest devices consist of a handpiece that contacts the implant with a mechanical impulse using a probe. The vibrations that are produced when the probe's tip hits the MI are recorded and examined. The Periotest handpiece uses a probe to mechanically stimulate the implant. The vibrations that are produced when the probe's tip hits the MI are recorded and examined. Periotest measures how these vibrations pass through the MI and the surrounding bone. Stable MI have low vibration and quick damping, indicating a strong bone bond. Slower damping and higher vibration amplitudes may suggest osseointegration insufficiency or possible instability.

A numerical scale ranging from -8 to +50 is utilized to quantify the vibration pattern displayed on the device's screen. Lower values on the scale indicate greater stability or damping effect of the measured MI or tooth. This numerical feedback is instrumental throughout treatment, allowing clinicians to objectively evaluate implant stability. Despite its initial design for detecting natural tooth mobility, Periotest can effectively assess the stability of MIs[(37)].

2.2.7. *Resonance frequency analysis (RFA)*

RFA, which was first introduced by Meredith[(32)], is a non-invasive diagnostic method that measures implant stability and bone density based on vibration of MI within the bone. Two commercial devices were developed to evaluate conventional implant stability. The original method involves connecting the transducer and resonance frequency analyzer directly using electrical wires[(38)]. The second method uses magnetic frequencies between transducer and resonance frequency analyser.

The transducer in the electronic device is an L-shaped cantilever beam that screws-attached to the implant. The implant-transducer combination is stimulated using a piezoelectric crystal on the vertical side of the L beam while a second piezoelectric crystal on the opposite side of the beam is utilised as a receiving element to detect the beam response.

The new magnetic RFA device uses a "SmartPeg," a magnet-containing top component, inserted into the implant head. A handpiece emits 5-15 kHz electromagnetic impulses toward the SmartPeg to determine the MI unit's resonance frequency. RFA uses the Implant Stability Quotient (ISQ) as its measurement unit, which spans from 0 to 100, with higher values indicating greater stability[(39)]. MI systems have ISQ values between 56 and 83, similar to dental implants[(40)]. RFA is regarded as superior to other methods and the gold standard for clinical stability measurement of MI[(41,42)].

At the moment, Osstell® (integrated diagnostics) and Implomates® (BioTechOne) are the two RFA devices used in clinical settings. The Integration Diagnosis Ltd Company has been designing Osstell devices since 1999. Several generations of this device for implant stability measurement have been released over the last two decades: Osstell, Osstell Mentor, Osstell ISQ, Osstell Beacon (Figure 1), and Osstell IDX.

RFA was originally designed to assess dental implant stability, requiring a specialized connector to attach the transducer to the mini-implant head[(42)]. Several efforts have been made to develop a smartpeg that can be used to attach to MIs[(43)].

Fig. 1: Osstell Beacon

3 CONCLUSION

Measurement methods for stability indicate the performance of MIs during orthodontic treatment. Insertion torque, radiographic assessment, pull-out tests, and RFA are critical for evaluating both initial and long-term stability of MIs. These methods enable clinicians to monitor the transition from primary to secondary stability, considering factors like peri-implant inflammation and mechanical loading. RFA initially validated in dental implants, has proven its reliability and validity in stability assessment over the past decade. Its adaptation and validation for MIs are currently areas of ongoing research, showing promising developments. It's crucial to recognize that a significant portion of stability research comes from dental implants, underscoring the need for thoughtful adaptation to the distinct characteristics and clinical requirements of MIs.

These stability assessment modalities can help orthodontists enhance treatment planning, implant success, and patient outcomes. These methodologies can be enhanced to gain a deeper understanding and effectively manage stability of MIs in clinical settings.

4 CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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