

Techniques to measure miniscrew implant stability

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ABSTRACT

The use of miniscrews for anchorage control during orthodontic treatment has the potential to improve the treatment of certain types of malocclusions. However, miniscrew failures will greatly influence the efficiency and efficacy of treatment. Having a better understanding of the healing process that occurs around miniscrew implants will provide valuable information that could enhance the predictability of their use. There are several methods to evaluate the stability. These fall into two main groups, which are invasive techniques and non-invasive techniques. The non-invasive measurement technique, resonance frequency analysis, holds great promise for the clinical evaluation of miniscrew implant stability. It may be used to evaluate the transition from primary to secondary stability, producing a better understanding of the time periods that are high risk for screw failure. The technique also provides a method to determine the effect that a modification of the placement protocol of miniscrew implants might have on the transition from primary to secondary stability. On that basis, this review will cover the methods to evaluate miniscrew implant stability longitudinally, both *in vitro* and *in vivo*.

Key words: Anchorage, miniscrew, stability

Miniscrew Implants in Orthodontics Definitions

Anchorage, defined as a resistance to unwanted tooth movement, is a prerequisite for the orthodontic treatment of dental and skeletal malocclusions.^[1-3] In fact, being able to achieve adequate anchorage during orthodontic treatment is an important determinant of the treatment outcome.^[4] Various methods have been introduced to maintain anchorage. In the past, extraoral headgear, elastics, and a number of other appliances have been suggested as effective forms of orthodontic anchorage. However, the main drawback of these appliances is that they all rely on patient compliance to be successful. Currently miniscrew implants are becoming increasingly popular in orthodontics^[5,6] because they provide absolute and skeletal anchorage for orthodontic tooth movements.^[7,8]

Terms such as *mini-implants*, *miniscrews*, *microimplants*, and *microscrews* have been used to describe the devices for skeletal anchorage. Actually implants and mini-implants refer to systems, which by definition imply that osseointegration sets in prior to loading, whereas screws to self-tapping devices may be used without the condition of osseointegration.^[9] However, since 2004, it has been agreed that the word *mini-implant* should be applied both to palatal implants, to mini-implants, to miniscrews, and to microscrews.^[9]

Papadopoulos and Tarawneh^[5] advocate the use of the term *miniscrew implants* as more appropriate, which will be used in this article instead of the terms mini-implants, microimplants, miniscrews, and microscrews.

Primary and Secondary Stability

There is clinical evidence from dental implantology that it is an implant's primary stability, beyond the factors such as bone quality and oral hygiene, that mainly determines its survival rate and reliability.^[10-12] Implant stability immediately after insertion is called primary stability. Due

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to osseointegration, an implant gains secondary stability, which can be determined after the healing phase or at the end of its use period.

Studies have shown the importance of adequate primary stability or initial stability for orthodontic loading.^[13-16] Insufficient primary stability causes deficient healing and premature loss of the miniscrew implant (failure).^[13] Therefore, the primary stability observed during implantation plays an important role in the success rates of the miniscrew implants.^[14-16] Stability, an indirect indication of osseointegration, is a measure of implant's resistance to movement.^[11] Quantification of implant stability at various time points provides significant information about individual healing times.^[17] The available methods for studying stability can be categorized as invasive, which interfere with the osseointegration process of the implant, and non-invasive, which do not.

Invasive Methods

Histologic and histomorphometric technique

The implant's stability can be estimated indirectly by examining the bone–implant interface. With a microscope, the bone–implant interface can be studied, cell proliferation and local bone morphology can be observed, and the implant's capability to resist movement can be estimated. Histomorphometry is commonly used as a quantitative method for establishing the percentage of bone to implant contact from the ground sections of implants.^[18-20] Typical parameters measured include percentage of bone contact and the bone area within the threads. In addition, the number of osteocytes can be counted.

There are several histomorphometric studies of miniscrew implants. Vannet showed that the amount of osseointegration, estimated based on bone-to-implant contact, was independent of loading time and location.^[21] His findings support previous animal studies in evaluating miniscrew implants^[22-25] and dental implants.^[26-28] Melsen and Lang showed that there was a significant increase in bone-to-implant contact and in bone density after 6 months.^[22] Unlike all other methods, histologic and histomorphometric evaluations evaluate osseointegration directly. Thus, they provide the best methods for establishing secondary stability.

Cutting torque resistance analysis

Cutting torque resistance analysis was originally developed by Johansson and Strid^[29] and later improved by Friberg *et al.*^[30,31] It is based on the energy (J/mm^3) required for an electric motor to cut off a unit volume of bone during

implant surgery. This energy has been shown to be significantly correlated with bone density, which has been suggested as one of the factors that influences implant stability.^[32] Cutting torque resistance analysis can be used to identify areas of low bone density and to quantify bone hardness during the low-speed insertion of implants. In orthodontics, cutting torque has also been used to improve the clinician's ability to detect root contact when placing mini-implants.^[33] The major limitation of cutting torque resistance analysis is that it does not give any information on bone quality until the osteotomy site has been prepared. Furthermore, it does not allow longitudinal changes in bone quality to be assessed. Its primary use, therefore, lies in estimating primary stability indirectly, through the quantification of bone hardness, before placement.

Reverse/removal torque value

The reverse torque test was first proposed by Roberts *et al.*^[34] and developed further by Johansson and Albrektsson.^[35] It measures the critical torque threshold when the bone–implant contact is broken. Removal torque provides information on the degree of bone-to-implant contact in a given implant.

Okazaki *et al.*^[36] used removal torque to evaluate the stability of miniscrew implants placed in dog femurs. They inserted 1.2-mm-diameter miniscrew implants using 1.0 mm and 1.2 mm pilot holes and showed that the removal torque values, compared to initial insertion torque measurements, increased for the implants placed in the 1.2 mm pilot holes and decreased in the 1.0 mm pilot holes. As a result, the removal torque values at 6, 9, and 12 weeks post-insertion were almost equal for the two pilot holes.

Insertion torque analysis

Insertion torque analysis quantifies the amount of force that is applied to the implant as it is inserted. Implant placement insertion torque is initially minimal, and increases rapidly until the cortical layer is fully engaged. The analysis consists of finding the maximum insertion torque value when the screw head contacts the cortical plate. Further insertion of the screw beyond that point leads to fracture of the implant or stripping of the surrounding bone; eventually, the screw spins freely in the hole with its holding strength severely limited.^[37] This test has been generally well accepted and has been used for evaluating various implant designs.^[38] Insertion torque has been found to correlate with bone density, which has in turn been shown to be correlated to implant stability.^[39] In other words, insertion torque measurements allow assumptions to be made about the quality of bone that supports the implant. Insertion torque

has been shown to increase as the thickness of the cortical bone increases.^[40,41] In a study by Lim and coworkers, insertion torque significantly increased with increasing screw length and diameter.^[38] Values of insertion torque less than 15 N cm have been related to failure of both machined and sandblasted miniscrew implants.^[42] Extreme insertion torque values, either too high or too low, have also been related to implant failure.^[15] However, insertion torque has been shown to be limited in certain applications. With self-drilling miniscrews, insertion torque may not reflect differences in the cortical bone thickness.^[40] Moreover, it is impossible to estimate the quality of the bone until you actually start implant insertion. As such, insertion torque measurements cannot be used for the selection of implant sites. Additionally, insertion torque does not offer the possibility of sequential measurements without damaging the bone-to-implant interface; as such it cannot be used to follow implant healing and osseointegration procedures.

Pullout test

A pullout test is another indirect test of an implant's anchorage potential. It usually measures the required tensional force applied vertically to the surface of bone into which an implant has been inserted to pull the implant out of the bone. The force is applied parallel to the long axis of the implant. Pullout tests have been extensively used for the evaluation of dental implants.^[43] Pullout strength has typically been used to evaluate the design of implants and the mechanical interface between bone and implants.^[44]

In orthodontics, Huja *et al.*^[45] showed that pullout measurements are significantly higher in the posterior part of the mandible of dog specimens than in the anterior part. They also found a weak correlation between pullout and cortical bone thickness. Salmoria *et al.*^[46] found that pullout decreases over time, which they related to the resorption of the cortical plate. Their findings have been confirmed by others.^[47] Because they could not establish a relationship between insertion torque and cortical bone thickness, Salmoria *et al.* concluded that pullout measurements are more efficient (easier to show difference) than insertion torque.^[46] Miniscrew pullout tests have also been used to evaluate different designs. Carano *et al.*,^[48] who studied three different designs of miniscrews of the same dimensions, concluded that screws with asymmetric cut show higher pullout values. Leung *et al.*^[49] found that cylindrical 2.0-mm miniscrews connected with mini-plates produced significantly higher pullout forces than miniscrews of lesser diameters. Pullout tests suffer from the same limitations as those of insertion torque. Since the procedure is invasive, the implant site is destroyed after the test has been performed, making it impossible to

use pullout tests to evaluate the implant–bone interface periodically. Because it cannot be used in normal clinical situations, this test is limited to laboratory experiments.

Non-invasive Methods

Non-invasive methods to measure implant stability differ from the invasive methods by virtue of the fact that the use of these measurements does not disturb the bone–implant interface. Consequently, they can be used to study the changes in the stability of individual implants over time.

Radiographic analysis

Radiographic analysis was one of the first methods applied to evaluate the implants after they had been placed. The density, and therefore the physical properties of the surrounding bone, can be indirectly estimated through radiographs. This method is more commonly used and more efficient with dental implants, due to their position after placement. Dental implants are oriented with their long axis parallel to the long axis of the surrounding teeth, which makes them well suited for radiographic analysis. Hermann *et al.*^[50] described how the technique of taking successive bitewing radiographs could be used to evaluate the height of crestal bone around dental implants. These radiographic techniques may not be useful to evaluate miniscrew implants. Miniscrews are rarely oriented in the same direction as dental implants, so bitewings cannot be used to evaluate the bone level. To evaluate the changes over time, radiographs must be standardized; otherwise, they can become distorted and useless.

Finite element analysis

Two- and three-dimensional finite element models provide a computer-simulated, theoretical analysis, based on known material properties. Young's Modulus, the Poisson ratio, and bone density are typically the properties used. By altering the boundary conditions, such as the bone level, finite element modeling can theoretically be used to calculate the anticipated stresses and strains in various simulated peri-implant bone levels.^[51,52]

Finite element modeling has been used to study the stress and strain provided by miniscrew implants.^[26,53] Dalstra and Melsen^[26] used the finite element method for stress/strain analysis of complex bone–implant interactions. Their study showed that the miniscrew implants' dimensions and geometry play a significant role in the transfer of load from the implant to the bone. The diameter and the length of the implant were especially important.^[26] Miyajima *et al.*^[53] noted that the further away from the surface of the bone that the orthodontic forces are applied, the higher the stress in both the alveolar bone and the miniscrew. A serious limitation of

finite element modeling is that it is a theoretical approach, based on assumptions derived from average bone properties. It is essentially a static analysis that is difficult to apply in clinical situations.

Percussion test

A percussion test is one of the simplest methods that can be used to estimate osseointegration. It is based upon vibrational acoustic science and impact response theory. A clinical judgment about osseointegration is made based on the sound heard upon percussion with a metallic instrument. A “ringing” sound indicates successful osseointegration, whereas a “dull” sound indicates no osseointegration. However, this method heavily relies on the clinician’s experience level and it is very subjective. It has not been used experimentally and is difficult to standardize clinically.

Pulsed oscillation waveform

Pulsed oscillation waveform is based on the frequency and amplitude of the implant vibration induced by a small pulsed force.^[54-57] Kaneko *et al.*^[54] used a pulsed oscillation waveform to analyze the mechanical vibrational characteristics of the bone-to-implant interface using forced excitation of a steady-state wave. An *in vitro* study showed that the sensitivity of the pulsed oscillation waveform test depended on load directions and positions; sensitivity was low for the assessment of implant rigidity.^[55]

Impact hammer method

The impact hammer method is an improved version of the percussion test. The response detection was enhanced using various devices. Although it was developed for measuring natural tooth mobility,^[58] the Periotest method has been reported to be reliable for evaluating implant stability.^[58-60] Periotest uses an electromagnetically driven and electronically controlled metallic tapping rod located in a handpiece. The implant’s response to striking is measured by a small accelerometer incorporated into the head of the device. Contact time between the test object and tapping rod is measured and then converted to the Periotest value (PTV). There has been great interest using the Periotest for evaluating miniscrew stability. Orquin *et al.*^[61] used the Periotest to show that neither the length nor the diameter of miniscrew influences their primary stability.

Resonance frequency analysis

Resonance frequency analysis (RFA) is a method used to determine implant stability based on vibrations of the implant within the bone. According to resonance frequency theory, any object has a tendency to oscillate at larger

amplitudes for certain frequencies. RFA uses this concept to excite a dental implant or miniscrew implant by some mechanical means and then measures the oscillation pattern of the implant/bone complex in order to determine the stability of the implant in the bone. The current device that uses resonance frequency for evaluating the stability of dental implants is the Osstell Mentor device.^[62,63] The results are presented as the implant stability quotient (ISQ). ISQ is based on the underlying resonance frequency and ranges from 1 (lowest stability) to 100 (highest stability). For the measurement of miniscrew implant stability in bone with RFA, a horizontal force that is perpendicular to the long axis of the miniscrew implant is used.

The Osstell device has been found to be better than the Periotest device for measuring dental implant stability in the clinical^[64] and laboratory environments.^[65] Current FRA systems are battery driven and use third-generation transducers that are precalibrated by the manufacturer.^[63]

Substantial literature exists that supports this method for evaluating dental implant stability, but only limited literature demonstrating its efficacy in measuring miniscrew implant stability is available. Using a third-generation Osstell Mentor device, Katsavrias^[66] showed that the device was reliable when measuring miniscrew implants with a length of 11 mm and an external diameter of 1.6 mm placed in synthetic bone. In an *in vitro* study, Veltri *et al.*^[67] showed that resonance frequency could be used for different types of miniscrew implants.

Conclusions

With their increased popularity, miniscrew implants will soon be implemented extensively in everyday clinical practice. Their possible failure will heavily influence the outcome and efficiency of the treatment. As such, an *in vivo* method to evaluate miniscrew implant stability would hold great clinical implications. By quantifying stability, it would be possible to follow the changes that occur during the transition from primary to secondary stability. Changes in stability due to inflammation of the peri-implant tissues, overloading, etc. could also be evaluated. Resonance frequency has been used to quantify implant stability in dental implants for the last 10 years. There is substantial support for the method in the literature, especially when compared to other available methods. RFA also holds great potential for quantifying the stability of miniscrew implants. Finally, it should be kept in mind that most of the literature regarding stability of implants is provided for dental implants, therefore it should be carefully evaluated when miniscrew implants are under consideration.

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