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Stability Assessment of Orthodontic Miniscrew Implants

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Abstract

The objective of this article was to review the recent literature pertaining to stability assessment of orthodontic miniscrew implants. Stability is an important factor for the clinical success of miniscrew implants, and is related to local bone quality and quantity, type of miniscrew implant, and placement technique. Methods of stability assessment reported in the literature included clinical, histological, and biomechanical assessments. It was clear that the stability during functioning as an orthodontic anchorage was an important criterion for the success of miniscrew implants.

Key words: miniscrew implant; orthodontics; stability assessment

Introduction

Recently, the miniscrew implant has been promoted as an improved biomechanical device in orthodontic treatment. The miniscrew implant offers many advantages, such as small size to facilitate placement in any areas of alveolar bone, ease of placement and removal, independence of patient compliance, shortening treatment duration, and ability to withstand immediate loading with adequate anchorage support.[1-14]

Some studies have reported that the miniscrew implant was stable during orthodontic loading.[1,5,8,10,15] Controversially, mobility and displacement of the miniscrew implant, before or during orthodontic loading, have also been reported.[2,3,16,17] The failure rate of miniscrew implants ranged from 3 to 51%.[2,3,16-24] The stability assessments of miniscrew implants included clinical,[15-21,25-31] histological,[26,27,32-34] and biomechanical assessments.[2,13-15,24,30,31,35-39] The objective of this article was to review the recent literature pertaining to stability assessment of orthodontic miniscrew implants.

Clinical assessments

Assessment of clinical mobility

Clinical mobility of the miniscrew implant is an important criterion for success or failure. The clinical mobility assessment, as reported in the reviewed studies, was performed in both human and animal investigations. Some investigations described clinical mobility assessment methods in detail,[17-19] but some did not.[15,16,21,25,27,29]

The clinical mobility assessment methods included the use of an orthodontic tension gauge[17] or cotton tweezers.[18,19] Liou *et al*[17] investigated horizontal miniscrew implant mobility under orthodontic loading. To assess the miniscrew implant mobility, the miniscrew implant head was connected to an orthodontic tension gauge with a ligature wire. The tension gauge was pulled mesially by applying 400 g of force. The horizontal mobility was recorded with a sliding caliper. The scale for horizontal mobility was as follows: '0' (no movement), '1' (≤0.5 mm), '2' (0.5 - 1.0 mm), '3' (> 1.0 mm). It was reported that the clinical mobility scale of all miniscrew implants was '0' (both immediately before force application and nine months later). Park *et al*[19] examined the success rate and investigated risk factors affecting the success of miniscrew implants. The mobility was checked with cotton tweezers five to eight months after placement. Mobility was classified into three groups: 'yes'(mobile), 'no'(not mobile), and 'unknown' (impossible to check because of overlying soft tissue). It was concluded that the inflammation around the miniscrew implant and clinical mobility were relative risk factors for miniscrew implant failure.

In an animal experiment, Kim *et al*[26] inserted miniscrew implants both with and without pre-drilled holes, and investigated miniscrew implant mobility by using the Periotest®, 12 weeks after insertion. They performed histomorphometric assessment by measuring bone-to-metal contact and total bone area within the miniscrew implant thread via an image-analyzing software. They concluded that the Periotest® value, the bone-to-metal contact, and the total bone area within the miniscrew implant thread were better when no holes were drilled than when pre-drilled holes were used, and suggested that miniscrew implants could provide stable orthodontic anchorage without pre-drilled holes.

Assessment of inflammation or infection

Inflammation or infection was associated with greater potential for miniscrew implant failure.[14,16,18-20,25,28,29] Peri-implant infection was defined as persistent pain, swelling and growth of tissue over an exposed miniscrew implant head, when analgesics and antibiotics were also required.[18,20,25,28] In the absence of prescribed medications, the reported symptoms were diagnosed as inflammation. An increased incidence of tissue proliferation was observed when miniscrew implants were placed at the interface between attached and free gingiva. This resulted in coverage of the miniscrew implant head.[21]

Radiographic assessment

Liou *et al*[17] investigated the positional change of miniscrew implant under orthodontic loading by assessing the superimposition of cephalometric tracings (before force application and nine months later). The superimpositions revealed that the miniscrew implants remained stationary under orthodontic loading in nine of 16 patients. However, the miniscrew implants were tipped forward significantly, by 0.4 mm at the miniscrew implant head, and they were extruded and tipped forward in seven of the 16 patients. It was concluded that the miniscrew implant was a stable anchorage for orthodontic loading but did not remain absolutely stationary throughout orthodontic loading. The miniscrew implants might have been displaced because of orthodontic loading in some patients. Tseng *et al*[25] used panoramic radiographs to investigate the stability of miniscrew implants, and reported that the failed miniscrew implants had locked in the bone only about 3 - 4 mm because of very thick surrounding mucosa in the anterior ramus region.

Histological and histomorphometric assessments

Histological and histomorphometric methods have been used as quantitative assessments for establishing the percentage of bone contact and bone contact area from ground sections of miniscrew implants.[38] A light microscope equipped with a computer morphometry programme in a digital image analysis work station has been used to evaluate the percentage of bone contact to the miniscrew implant,[26,32-34] the degree of osseointegration after immediate loading,[26,27] and bone volume.[34]

Ohmae *et al*[32] determined the anchorage potential of the miniscrew implant for orthodontic loading by using clinical, histological, and histomorphometric assessments. The results revealed that all loaded and unloaded miniscrew implants remained stable without any mobility or displacement. The histological investigation of the peri-implant condition suggested that both loaded and unloaded implants showed partial osseointegration. These findings showed that a lower amount of osseointegration did not reflect negatively on the miniscrew implant for orthodontic anchorage. It was also suggested that the miniscrew implant could be used as a temporary implant for orthodontic anchorage.

Deguchi *et al*[34] investigated the differences in the percentages of bone-implant contact, bone volume, and bone formation rates in the maxilla and mandible during various healing periods. The results demonstrated that mandibular implants had significantly more bone-implant contact than maxillary implants. Within each arch, the significant histomorphometric indices (found in the 'three-week unloaded' healing group) were increased fluorochrome labeling incidence, higher woven-to-lamellar-bone ratio, and increased osseous contact. In a histomorphometric and mechanical analysis, other investigators showed that the drill-free technique could offer better stability under orthodontic loading than when drills were used.[26] Heidimann *et al*[33] supported the view that screw/bone contact with drill free screws was superior to that of self-tapping screws.

Miniscrew implant stability and the degree of screw/bone contact depended on the difference in healing times after miniscrew implant placement, the site of miniscrew implant placement, the necessity for anchorage, the type of bone, and the technique of miniscrew implant placement.[26,33-35]

Biomechanical assessments

The mechanical retention of the miniscrew implant should be sufficient to sustain immediate orthodontic loading. The essential factors affecting implant stability included local bone quality and quantity, type of miniscrew implant, and the miniscrew implant placement technique.[36,38]

The stability of the miniscrew implant is used to predict mechanical retention because the histological studies performed in animals have shown that the degree of osseointegration of miniscrew implants was less than half the osseointegration of dental implants.[32,34] Most studies on bone/miniscrew attachment have focused on the effect of shear forces, using torsion strength tests or pullout tests.[13-15,24,35-37]

Torsion strength test and Flexion test

Carano *et al*[14] illustrated some methods for measuring mechanical resistance of the Mini-Screw-Anchorage-System such as torsion to failure testing, and bending to failure testing. Torsion to failure testing was performed by placing screws into a tapped brass block at a thread depth of 6 mm. A dial torque wrench with a recording device was rotated perpendicular to the axis of the screw in a clockwise direction. The maximal torque at failure and the site of failure were recorded. Flexion testing, or bending to failure testing, was performed by placing miniscrew implants into a tapped brass block at a thread depth of 6 mm. A dial bending arm with a recording device was able to deform the axis of the miniscrew implant. The maximal bending at failure and the site of failure were recorded. The results of this study suggested that the Mini-Screw-Anchorage-System screws have a high resistance to failure, and they are suitable for orthodontic use. They indicated that it was possible for a human being to apply a torsion force of more than 40 Ncm (about 4 Kg) and to break the screw.

Bending test

Carano *et al*[35] have used the bending test to evaluate the mechanical properties of three self-tapping miniscrew implant systems. The bending forces that were used resulted in curvature of the screw and, consequently, in deflection of its head. The bending tests were performed on a universal testing machine. The miniscrew implant was maintained horizontally with a specific fixture in the fixed crosshead of the machine. A prismatic bar, connected to the mobile crosshead, applied a vertical force, perpendicular to the long axis of the screw, at a speed of 1 mm per minute. The bending force resulted in a deflection of the head of the miniscrew implant. The results showed that the miniscrew implants had enough resistance to failure during insertion, application and removal in orthodontics. In order to break the miniscrew implant, forces higher than 80 N were required.

Insertion/placement torque test

Carano *et al.*[35] indicated that the tests performed in order to evaluate the torsion moments needed for the insertion of the miniscrew implant, after the site preparation (measurements of insertion torque), are clinically important. These tests determine the effort necessary to insert the miniscrew implant and provide information about the cut design and the drill-screw diameter ratio.[24,35] The interface characteristics between miniscrew implant and bone can be expressed in relation to the implant placement torque when tightening the miniscrew implant into the bone. It is thought that when the cortical bone is stiffer or the miniscrew implant diameter is larger, the implant placement torque required is greater and the stability of the miniscrew implant is enhanced. Conversely, when the implant placement torque is too small, the miniscrew implant is unstable because of its mobility.[24]

In an *in vitro* study, Wilmes[36] investigated the parameters affecting miniscrew implant primary stability. The torque measurement and the computed bone thickness were used to assess the influence of bone quality, implant design and the insertion modalities (pre-drilling diameter and pre-drilling depth) on the primary stability. The miniscrew implants were inserted in a segment of the ileum of country pigs. The insertion torque was measured by using a torque measuring system. The results revealed that the insertion torque of the miniscrew implant was significantly positively correlated with the bone quality (computed bone thickness). The miniscrew implants having a cylindrical shape were inferior to those having a conical shape. The relationship between the shaft diameter and total diameter was responsible for greater miniscrew implant primary stability. Finally, the larger the pre-drilling diameter was, the lower the miniscrew implant primary stability. However, the pre-drilling depth had a minor effect on miniscrew implant primary stability.

In a human study, Motoyoshi *et al*[30] determined an adequate placement torque for obtaining a better success rate for miniscrew implants that were screwed into the buccal alveolar bone of the posterior region as an anchor for orthodontic treatment. Miniscrew implant placement torque was recorded by a torque screw driver that was accurate to 3% as guaranteed by the manufacturer. The mean implant placement torque ranged from 7.2 to 13.5 Ncm, depending on the implant placement position.

Removal torque test

Removal torque is a measure of interfacial strength in shear, and it not only depends on the quality of the bond between the implant and the surrounding tissue, but it is also highly sensitive to the geometry of the miniscrew implant.[38] In an animal study, Buchter *et al*[15] determined the clinical outcome and removal torque value of two different titanium miniscrew implant systems activated with different load regimens. The results were as follows. Firstly, miniscrew implant failure was directly related to the tipping moment at the bone rim. Secondly, by reducing the main tipping moment under a threshold of 900 cNmm (300 cN and 3 mm lever arm), miniscrew implants could be loaded immediately without impairment of either miniscrew implant stability or miniscrew implant success rates. In a human study, the removal torque values of immediately-loaded miniscrew implants after clinical usage were used to confirm the suitability of the implant for anchorage in three-dimensional tooth movements.[37] Titanium bone screws designed for fixation in craniofacial regions were used as orthodontic anchorage. The miniscrew implants were implanted buccally in the posterior alveolar crest as orthodontic anchorage. Upon completion of orthodontic treatment, they were removed, using a screwdriver with an attached torque gauge, under local anesthesia and the maximal torque required to loosen the miniscrew implant was registered. The mean removal torque value of miniscrew implants in the maxilla was significantly lower than that of those in mandible. In addition, the removal torque values of 15-mm and 17-mm miniscrew implants were significantly higher than those of 13-mm miniscrew implants.

Pull out strength test

The pull out strength test is a standardized method of testing mechanical competency, or holding power, of miniscrew implants. It has also been widely used to investigate the influence of surface irregularities on cylindrical implants.[38,40] For pull-out testing, the miniscrew implant must be aligned with the axis of the testing machine. This ensures that no bending moment is created during the pull-out test, and that only axial pull-out strengths are recorded. Huja[40] concluded that the pull-out strength of miniscrew implants in bone depended on the site of insertion in both in the maxilla and the mandible. The maxillary and mandibular anterior regions had the thinnest labial plates (about 1.3 mm), and these anterior plates had significantly different dimensions from the other locations examined. The mandibular posterior region had the greatest mean thickness of approximately 2.41 mm.

Finite element analysis assessment

The finite element analysis is a biomechanical test that has been used to predict the effects of stress on the miniscrew implant and its surrounding bone. The analysis includes load transmission and stress distribution. The finite element analysis consists of a computer model that is used to analyze specific results and to simulate the interaction phenomena between implants and the surrounding tissues as well.[38] Costa and Melsen[2] used the principles of finite element analysis to change the design of miniscrew implants to a conical shape. This shape provides improved strength and mechanical stability.

Motoyoshi *et al*[30] investigated the biomechanical effects of miniscrew implant design (abutment and thread pitches) on stress distribution and stability by using the 3-D finite element method. They concluded that the existence of the abutment was useful in decreasing the stress concentration on the bone, whereas the effect of thread pitch was uncertain. Chen *et al*[31] used a finite element analysis to compare the anchorage effect of palatal osseointegrated and non-osseointegrated implants, under horizontal and vertical forces. The non-osseointegrated implants showed almost the same anchorage effect as osseointegrated implants. The stress on the non-osseointegrated implant surfaces was higher than that on the osseointegrated implant surfaces, but the stress was not high enough to result in failure of the implant. These results suggested that waiting for osseointegration might be unnecessary for an orthodontic miniscrew implant.

Discussion

It is understandable that the stability of miniscrew implants is a major contributing factor to the clinical outcome. The methods reviewed for miniscrew implant stability assessment included clinical, histological and biomechanical assessments. There was no efficient method for the clinical assessment of the primary stability of miniscrew implants. The histological and biomechanical assessments reviewed were invasive methods and not appropriate for clinical practice. Resonance frequency analysis, a non-invasive assessment method, has never been used to assess miniscrew implant primary stability. If the biochemical assessments will be used as clinical diagnostic information, further investigations are needed to reveal proper biomarkers for assessing the miniscrew implant stability.

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บ ท ค ว า ม ป ริ ทั ศ น์

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บทคัดย่อ

วัตถุประสงค์ของบทความนี้เพื่อทบทวนวรรณกรรมข้อมูลปัจจุบันเกี่ยวกับการประเมินเสถียรภาพของรากเทียมเกลียวขนาดเล็กทางทันตกรรมจัดฟัน เสถียรภาพของรากเทียมเกลียวขนาดเล็กเป็นปัจจัยที่สำคัญสำหรับความสำเร็จและเกี่ยวข้องกับคุณภาพและปริมาณของกระดูกเฉพาะตำแหน่ง ชนิดของรากเทียมเกลียวขนาดเล็กและเทคนิคการฝัง กระบวนการประเมินเสถียรภาพประกอบด้วย การประเมินทางคลินิก การประเมินทางวิทยาเนื้อเยื่อ และการประเมินทางชีวกลศาสตร์ เป็นที่แน่ชัดว่าเสถียรภาพของรากเทียมเกลียวขนาดเล็กระหว่างการทำหน้าที่เป็นหลักยึดทางทันตกรรมจัดฟันเป็นเกณฑ์ที่สำคัญเกณฑ์หนึ่งสำหรับความสำเร็จ