Micro-Implants in Orthodontics and Dentofacial Orthopaedics

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Anchorage is one of the most important elements for successful orthodontic treatment. Traditionally, orthodontics employed teeth and extraoral or intraoral appliances for anchorage, often relying on the patient compliance for its effectiveness. Micro-implants (OMIs), also known in orthodontics as temporary anchorage devices (TAD) or mini-implants or mini-screws have been used to realize difficult orthodontic movements. Orthodontic mini-implants can be a powerful aid in resolving challenging malocclusions that require increased anchorage potential. Their use is versatile, minimally invasive, and proves a good ratio between costs and benefits of orthodontic treatments.

Keywords: micro-implants ; orthodontics ; success rate ; insertion ; loading ; biocompatibility ; compliance

1. Introduction

Anchorage is one of the most important elements for successful orthodontic treatment. Traditionally, orthodontics employed teeth and extraoral or intraoral appliances for anchorage, often relying on patient compliance for its effectiveness. Micro-implants (OMIs), also known in orthodontics as temporary anchorage devices (TAD) or mini-implants or mini-screws have been used to realize difficult orthodontic movements. Orthodontic mini-implants can be a powerful aid in resolving challenging malocclusions that require increased anchorage potential. Their use is versatile, minimally invasive, and proves a good ratio between costs and benefits of orthodontic treatments. They can help orthopedic dentofacial treatments by supporting distraction procedures, maxillary protractions, cleft segment expansion, stabilization, and tooth movements into narrow alveolar sites. Anchorage control is essential for an orthodontic treatment's success. The anchorage on micro-implants prevents undesirable movements of tooth elements that were used in classic orthodontic procedures, offers an alternative to orthognathic surgery. As temporary anchorage devices, the use of micro-implants solves difficult problems such as guiding osteo-distractions, fixing maxillary cants after the vertical distraction of a ramus, stabilizing an edentulous premaxilla, moving teeth into atrophic alveolar sites [1]. The skeletal anchorage on micro-implants is a solution to treat adult orthodontic patients with a lack of quantity or quality of dental elements when conventional dental or mobile anchorage is not possible or cases with poor patients' compliance where the wear of mobile devices or elastics is compromised [2]. Their use is the ideal solution in cases where dental anchorage may result in undesirable side effects such as vertical dimension changes produced by the use of conventional inter-maxillary forces [1]. Micro-implants as skeletal anchorage lead to a more effective orthopedic growth modification, and their use helps camouflage orthodontic treatment for those patients who were not eligible for orthognathic surgery [3][4].

Surgical atraumatic techniques, regeneration and osseointegration, an environment favorable for the primary healing, and biocompatible materials are necessary for micro-implants success. Other important issues in using micro-implants as anchorage elements are patients' cooperation and the perception of the pain and trauma produced by surgical insertion and retraction procedures [4].

Many orthodontists avoid using micro-implants as anchorage elements because they are unfamiliar with the surgical procedures required for their insertion or because of fear of failure. Another cause could be a lack of interest in approaching new techniques compared to treatments that are already routine. These limitations should disappear, and orthodontists should also acquire the surgical skills necessary to use micro-implants, The present paper is intended to be a small guide in the practical activity of orthodontists and not only, which can help them in terms of the use of micro-implants by showing the existing types, how to apply them, the clinical situations in which they can be used, and the difficulties that may occur during treatments that use this type of anchorage.

2. The Success Rate of Micro-Implants

The overall success rate of skeletal anchorage using micro-implants was ranged from 79% to 98.2% [4], described by other studies as being 85.0% [5]. A systematic review published in 2010 [6] included fourteen clinical trials and described the mean overall success rate of 83.8 ± 7.4%, with no significant differences regarding the patient's sex. Little diameters of the mini-screws from 1 to 1.1 mm had lower success rates than the greater ones from 1.5 to 2.3 mm; screws less than 8 mm in length and 1.2 mm in diameter should be avoided [6]. One study reported significantly lower success rates for 6-mm vs. 8-mm long mini-screws (72% vs. 90%) [6]. The recommended diameter and length for a micro-implant placed in the alveolar bone were 1.2 to 1.6 mm respectively 6–7 mm in another study [7]. Other authors [8] concluded that the success rate did not depend on sex, age, and side of placement but significantly increased as total bone density and cancellous bone density increased. The OMIs' success rate was not significantly correlated with the cortical bone density.

3. Design

The researchers tried to improve the design of the orthodontic micro-implants to increase torsional strength, stability and reduce bone damage during insertion. An objective function stability quotient (SQ) was built and solved by Korean researchers [9] started from the thread height and pitch of AbsoAnchor SH1312-7 micro-implant (Dentos Inc., Daegu, Korea) as parameters. 3D finite element simulation, torque test, and clinical test led to the creation of four models with optimized tread design and better performance, which indicated that their optimization methodology could be used when designing OMI threads.

The peak insertion torque value is another parameter that influences the OMI's stability. This depends on the manufacturer [10]; the study showed no correlation between the diameter of six different types of self-drilling micro-implants and torque values. Insertion speed did not affect significantly the peak torque values, but the 6 mm OMIs proved to have significantly higher torque values than the 8 and 10 mm ones. Using a screwdriver for limiting the torque or pre-drilling the cortical bone to reduce insertion torque could be a good choice.

4. Anatomical and Surgical Details

Over time, several methods have been devised and developed to avoid accidents using micro-implants, the most important being damage to the roots of the neighboring teeth. A precise surgical plan before OMIs' insertion is crucial. Some researchers described the use of radiographic templates and film holders to make a surgical template for guiding OMIs' insertion [11]. The success rate of OMIs was tested by using panoramic radiographs that showed the position and angulation of the screws [5]. The overall success rate was higher for people more than 20 years old and screws on the left side, for the women than for the men, for extraction than for non-extraction group, for OMIs placed on the inter radicular midline. OMI success rate significantly increased with an increase in the OMI length and placement height, and with a lesser angulation [5].

Other authors claimed that compared with panoramic radiographs, cone-beam computed tomography (CBCT) images can provide more accurate information regarding tooth position, root resorption, and various pathologies; the radiation exposure is less and the cost is lower using panoramic radiographs, which provides acceptable reliability [8].

The efficacy of optical coherence tomography (OCT) was tested comparatively with that of micro-computed tomography (μCT) [12] to detect and analyze cortical bone micro-damage immediately after insertion. The visualization of individual microcracks was highly correlated. Even if the depth penetration of OCT was more limited, it has been able to give high-resolution images of the bone microdamage occurring around the micro-implant. Image quality at the surface of the cortical bone is better when compared with μCT imaging, because of the high contrast and the high-resolution quality of OCT systems [12].

The surgical insertion procedure showed contradictory results between flap or without flap techniques on mandibular mini-implants. Loading and healing periods were not significant in the mini-screws success rates [6].

When using micro-implants is important to evaluate the cortical bone thickness and the inter radicular spaces to create enough stability for the application of orthodontic forces. Park and Cho [7] found using cone-beam 3D images that in the posterior dentition area the buccal cortical bone is 1 mm or thicker, 1.12 to 1.33 mm for maxilla, and 1.25 to 2.98 mm for mandibula. The cortical bone becomes thicker progressively from the cement-enamel junction to the apical zone. The inter radicular distances varied from 1.6 to 3.46 mm in the maxilla with a maximum between the second premolar and the first molar. In mandibula, the inter radicular distances were greater than in maxilla and ranged between 1.99 and 4.25 mm.

The retromolar zones showed cortical bone from 1.96 to 2.06 mm thicker. The widths of alveolar processes were 3.74–5.78 mm for the maxilla and 3.11–7.84 mm for the mandibula. The mid-palatal area at 20–25 mm posterior than foramen incisivum ranged from 7.04 to 6.99 mm. They concluded that a better location for placing micro-implants was buccal between the second premolar and the first molar for maxilla, buccal from the first premolar to the second molar for mandibula, palatal between molars for maxilla, the mid-palatal and retromolar areas [7].

The cortical bone thickness of the inter-dental area of maxilla and mandible for orthodontic micro-implants placement was investigated by cone-beam computerized tomography [13] by a study that was performed on 32 non-orthodontic adults with normal occlusion. Buccal cortical bone was thicker in the mandible. In the maxilla, the cortical bone was thicker buccal than palatal. In the mandible, the buccal cortical bone vas thickest distal to the first molar, and in the maxilla, it was thickest mesial to the first molar; in the palatal side of the maxilla, the cortical bone was thickest mesial to the second premolar. The thinnest cortical bone was found in the buccal side of the maxilla at 4 mm from the alveolar crest and the thickest was at 10 mm, except for the site mesial to the first premolar. The buccal cortical bone thickness mesial or distal to the first inferior molar and palatal cortical bone tended to increase with increasing distance from the alveolar bone [13].

These buccal ideal locations for placing micro-implants were also used in another study that comparatively investigates the anchorage loss in canine retraction with conventional molar anchorage versus titanium micro-implants [14]. In adult patients with a mean age of 19.6 years, the first premolars were extracted to create space for canine retraction. Titanium micro-implants of 1.3 mm in diameter and 9 mm in length were placed between the second premolars and the first molars. The orthodontic mechanics were performed by using closed-coil springs which performed the canine retraction by having on one quadrant a molar anchorage and on the other an anchorage on micro-implants. The results showed no anchorage loss on the micro-implant side and 1.60–1.70 anchorage loss on the molar anchorage side. Other similar studies have aimed to investigate the effectiveness of using mini-implants in canine retraction [15]. The authors used mini-implants of 1.3 mm in diameter and 8 mm in length and their placement was also between the second premolars and the first molars, for each patient in the same quadrants (on the right side), placed at an angle of 30–40° in the maxilla and of 10–20° in the mandible to the long axis of the teeth to increase the contact between the implant and the bone. On the left quadrants, the retraction of the canines was done by using the first molars as anchorage. Orthodontic forces of 100 g were immediately applied; coil springs were used for canine retraction. Results showed that the rates of canine retraction were higher on the implant sides, 0.95 and 0.81 mm/month in maxilla respectively in the mandible and lower on the molar sides, 0.82 and 0.76 mm/month in the maxilla respectively in mandible. The loss of anchorage was less on the implant sides, 0.1 in the maxilla and 0.06 in the mandible and greater on the molar sides, 1.3 mm on the molar side of the maxilla and mandible. There were statistically significant differences between changes in anchorage inclination on the implant side and molar side in both maxilla and mandible: 0.3° on the implant side and 2.45° on the molar side in the maxilla and 0.19° on the implant side and 2.69° on the molar side in mandible. Studies [14][15] demonstrated that micro-implant anchorage is a better alternative to molar anchorage.

Many other studies investigated the ideal insertion angle of orthodontic micro-implants for biomechanical control and cortical anchorage. A study on finite models of maxilla and mandible [16] which used D2 and D3 types of bone and micro-implants of 1.3 mm diameter and 7–8 mm length inserted in different angles on bone's surface shows that the maximum von Mises stress in the implants and the cortical bone decreases as the insertion angle increases. The stress generated at the application of horizontal orthodontic forces was distributed mainly to the cortical bone and less to the cancellous bone. The stress was higher in type D3 bone quality than in type D2. The study demonstrated that the 90° insertion angle is ideal for orthodontic micro-implants stabilization [16]. The shortcoming of the investigation's method was that the ideal angle for insertion of the screw was not determined in all three spatial planes but only in the horizontal one because the direction of application of the orthodontic force was horizontal. Other studies that investigate only micro-implants placed in the upper jaw demonstrated the opposite, namely that the insertion angle of micro-implants, the cortical bone thickness is not important for the success rate of using orthodontic micro-implants [17][18]. The authors measured horizontal and vertical placement angles using cone-beam computed tomography images. The micro-implants success rates significantly increased with the distance to the root surface. Cortical bone thickness was affected by placement angles but root proximity was not affected by insertion angles. Other interesting results were that success rates were higher for screws put on the left side, for adult patients than for teenagers, in women than in men. The success rate increased by increasing the horizontal placement angle but the difference was not statistically significant [17].

Contact between orthodontic mini-implants and dental roots during the insertion process is a common problem because inter-radicular spaces are narrow [19]. Such contacts have been associated with root damage and increased implant failure rates. An accurate test to diagnose implant–root contact is therefore indicated. Using specific insertion torque values (the index test) as a diagnostic test of OMIs with root contact could be more accurate less adverse compared with radiographic images. Torque levels of OMIs inserted with root contact were higher than those without. The highest torque differences were identified in the self-drilling compared with the pre-drilling. It is important to record constantly the torque values during the insertion process.

The stress in the cortical bone during and after insertion of self-tapping orthodontic micro-implants using predrilled holes was simulated with a 3-dimensional finite element method [20]. Results showed stresses during insertion that could fracture the cortical bone; hoop stresses of the ultimate tensile strength and radial stresses of the ultimate compressive strength of cortical bone were developed. After insertion, residual radial stresses that could cause bone resorptions were observed. The high insertion-related stresses showed that the bone's response and the micro-implant prognosis depend on the insertion conditions not on the orthodontic force or the timing of its application.

The primary stability of OMIs is influenced by various insertion angles and the direction of the applied orthodontic force. An opinion is that the highest primary stability values were get at an insertion angle of 45° when the mini-implants were loaded by shear force and at 90° when pullout forces were used [21].

Different OMIs proved a wide range of torque at fracture that depended on the manufacturer and the correlation between the diameter of the screw and fracture resistance was poor. The torque is to be considered at the insertion phase to minimize the risk of screw fracture and much care should be for the areas with high-density bone without predrilling [22].

By sequential fluorochrome staining combined with laser confocal microscopy were visualized the damage of cortical bone at insertion and removal of orthodontic micro-implants (OMI) [23]. The presence of a pilot hole demonstrated a minimal effect on microdamage bone characteristics and a minimal effect on maximum insertion torque. The micro-damages increased with the bone thickness; there was a positive correlation between the bone thickness and the increase in maximum insertion torque. The maximum insertion torque was correlated with the total and diffused bone damaged area. The study concluded that the choice of making pilot holes for orthodontic micro-implants insertion should depend on the thickness of cortical bone. The bone damages evaluated with two different types of OMI, non-drilling, and self-drilling and pilot holes showed that fractional damaged area, fractional micro cracked area, and fractional diffuse damaged area were greater with the self-drilling ones and as the thickness of cortical bone increased [24].

The self-drilling micro-implants create better anchorage than self-tapping ones [25]. Self-drilling micro-implants had higher peak insertion torque and peak removal torque than self-tapping ones. Self-drilling screws demonstrate a higher fracture tendency and better contact between the implant and bone [23][24]; their use is indicated in the maxilla and thin cortical mandibular areas. Negative correlations between Periotest values were mostly demonstrated by the self-drilling micro-implants [26]. The differences between insertion torque values and corresponding assessments of stability scores were higher self-drilling screws.

5. Immediate Loading

In the literature, there has been much discussion about the possibility of immediate loading of mini-implants and how it affects the stability of the screw and bone structure.

Immediate loading doesn't affect the osseointegration of OMIs but the anchorage is not always absolutely stationary, extrusion and tipping were observed in areas with thin cortical bone [27]. Immediately loading with orthodontic forces of 200 g does not influence significantly the stability [6] and seemed to accelerate the shaping of periosteal bone after the surgical intervention; there were no statistically significant differences in bone and implant contact values between the loaded OMIs and the unloaded ones [27].

Another study [28] found by histological analysis good osseointegration, bone apposition, and new bone formation in loaded and unloaded OMIs. The contact between bone and micro-implant was higher in the loaded ones. The study concluded that small diameters (1.2–1.3) OMIs made from Titanium alloy are strong enough for immediate loading even in thin cortical bone areas; in this situation drilling a pilot hole reduces the possibility of micro-implants breakage.

Comparing immediate loading with one-week post-insertion loading of orthodontic micro-implants showed a statistically higher torque loss in delayed insertion; a significant stability loss was seen in both situations in the first week of investigation [29].

Investigating the biomechanical properties of bone around OMIs under immediate loading using nanoindentation testing [30] showed that the trabecular area on the compression site near the implant was significantly harder than in other bone locations.

Another study based on histological, histological-morphometric, and cone-beam computed tomography (CBCT) analysis was performed on autoclave-sterilized OMIs and proved that an immediate, light orthodontic load did not influence the bone healing around mini-screws [31]. The osseointegration and the cortical bone thickness increased with the time passed from the insertion of the implants. The absence of infections during the healing showed that OMIs can be autoclaved in the dental practice before insertion time, with no effect on subsequent osseointegration. The predrilling of thick cortical bone reduced the microfractures. The displacement of the periosteum stimulated the healing of the cortical bone [31].

A review article showed the efficiency of using mini-implants as anchorage and concluded that their success depends on proper initial stability and the quality and quantity of loading [15]. Other factors that could compromise the success of using OMIs are the patient's oral hygiene, coexisting pathologies, smoking, the condition of the mucosa, the timing, quantity, and direction of the loading force direction [2][6]. Thus, the micro-implants success involves factors related to the patient, the orthodontist, and the OMI's design [2][6].

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