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Primary Stability Of Orthodontic Mini-Implants "The Forgotten Frontier": A Narrative Review

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Abstract:
Background*: Orthodontic mini-implants are one of the greatest discoveries in the field of orthodontists. They have broadened the scope of orthodontic treatment in leaps and bounds. These mini-implants are affordable and easy to use with a remarkably high success rate of 87.7%. Primary stability which is the mechanical retention of the mini-implant in the bone is the most important factor that determines the success of the mini-implant. It is influenced by multiple factors such as cortical bone thickness, soft tissue mobility, mini-implant design, diameter, length, insertion depth and angle, insertion torque, timing of loading, amount and duration of force and patient specific factors such as peri-implant tissue health, growth pattern etc. All these factors play an indispensable role in the primary stability and eventual success of the mini-implants. Thus, it is of paramount importance to assess the primary stability. Maximum insertion torque, Periotest, Resonance frequency analysis (RFA) and pullout strength are some of the commonly employed methods for the assessment of primary stability. The orthodontists have often neglected to assess this important parameter in clinical practice owing to practical constraints. Future attempts for chair-side evaluation of this critical parameter should be made possible with novel affordable equipment.*

Key Word*: Orthodontics; Mini-implant; primary stability; maximum insertion torque; assessment.*

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I. Introduction

Mini-implants, since their advent, have pushed the boundaries of orthodontics. An orthodontic mini - implant is a screw type device that is temporarily fixed to the bone for the purpose of enhancing orthodontic anchorage either by supporting the teeth of the reactive unit or by obviating the need for the reactive unit altogether, and which is subsequently removed after use[1]. They are manufactured from the most widely used titanium alloy ($TiAl_6V_4$) $\alpha + \beta$ ASTM (American Society for Testing and Materials) grade 5, which contains 6% aluminium and 4% vanadium. They are high in strength but have a relatively low ductility. The orthodontic mini-implants are of two types: pre-drilling mini-implants and self-drilling mini-implants. Orthodontic mini-implants do not require a separate tapping procedure, hence in that sense all the orthodontic mini-implants are self-tapping[2]

They have broadened the orthodontic treatment options by eliminating the major nightmare of any orthodontist - "anchorage". Since anchorage preservation was no longer a concern, complicated biomechanics like enmasse retraction, intrusion, whole arch distalisation, molar protraction, disimpaction, maxillary skeletal expansion etc became a child's play even to a novice. These mini-implants have an astoundingly high success rate of 87.7%[3] but in contradiction a recent systematic review and meta -analysis reported a 13.5%[4] failure rate in the mini-implants.

The factors related to the clinical success of a mini-implant can be divided into mini-implant related factors, host factors and management factors. Mini-implant related factors include diameter, length and design of the mini-implants; host related factors constitute oral hygiene, arch of placement, site of placement, bone quality and quantity, soft tissue mobility at the site of placement, skeletal pattern and age; management factors include insertion method, insertion torque, angulation of insertion, onset of force application, duration and magnitude of the force applied.[5]

Primary stability is one of the critical factors affecting the success of mini-implants.[5,6,7] It is determined by mechanical retention, as a result of a tension–compression state generated at the bone–screw interface and is affected by insertion site characteristics, root proximity, geometric design of the screw, peri-implant tissue inflammation, operator technique, magnitude and loading time of the orthodontic force and cortical bone thickness[8,9]. Primary stability can be assessed by quantitative methods such as insertion and removal torque, periotest value, resonance frequency analysis (RFA), pull out strength etc. Out of all these methods, insertion torque is the most reliable and relevant measure of primary stability and the rest of the techniques are often used in combination or as a supplement to it.[10] The aim of this review is to understand the concept of primary stability, different methods used to assess the primary stability and the various factors influencing it.

II. Discussion

Biological Process of Primary Stability:

The stability of the orthodontic mini-implants obtained as a result of the mechanical retention of implant in the bone surface is the primary stability and it is more important than osseointegration for orthodontic mini-implants as they are loaded immediately. The unique features of orthodontic mini-implants are the early/immediate loading, lack of osseointegration and the ability to withstand orthodontic forces.

Dr J.B. Cope[25] explains the biological responses following a mini-implant placement. He classifies the biological response further into two types- for osseointegrated mini-implants and for mechanically retained mini-implants. The insertion of the mini-implant initiates a series of biological processes which includes the formation of a blood clot, an alteration in the nuclear morphology of the surrounding osteocytes adjacent to the implant and the formation of new bone. Osseointegrated mini-implants rely on maximum contact between the implant surface and the bone to achieve osteointegration. Mechanically retained mini-implants have areas of direct bony contact as well as gaps where there is minimal or no bony contact.

Immediately after the placement of the mini-implant, the implant surface come in contact with blood and a biofilm which contains fibrinogen, components of the complement and coagulation system is formed over the implant. Red blood cells, platelets and inflammatory cells mainly neutrophils adhere to this biofilm and form a blood clot in the bone-implant interface. In the first week following implant insertion, there is a decrease in the osteoblast differentiation, proliferation and an increase in osteocyte death with alveolar bone microfractures around the orthodontic implant in direct contact with bone as compared to the areas not directly in contact with the implant. There is a reduction in the inflammatory cells and an increase in the new collagen fibres and osteoblasts. Active remodelling takes places two to four weeks after insertion characterized by multinucleated osteoclasts and blood vessels in the cortical bone surrounding the implant. The entire process of remodelling and osseointegration is completed and there is an increased bone density after six weeks. Orthodontic mini-implants can be loaded immediately before the osseointegration because the mini-implants are clinically stable and are capable of withstanding the orthodontic forces during the healing period.[26]

Methods to assess primary stability:

Though histological evaluation is the best method to access the primary stability, it is impractical in a clinical scenario. Some of the commonly employed methods to evaluate the primary stability of the orthodontic mini-implants are discussed below.

Insertion and removal torque:

Insertion torque (IT)is the gold standard to assess the primary stability of mini-implants. It is a measure of the rotational resistive force experienced by the mini-implant during advancement into the bone and is indicative of the strength of the implant-bone interface.[10] Maximum insertion torque (MIT) is the maximum torque value recorded during the insertion of orthodontic mini-implants and is expressed in Newton centimeters (Ncm). MIT values in the range of 5-10 Ncm is recommended for the success of orthodontic mini-implants.[11]High IT means better primary stability but in cases where the IT values are too high, it causes excessive stress in the bone-implant interface leading to bone necrosis, local ischaemia and delayed healing thus eventually compromising the stability of mini-implants. MIT values increase with increased thickness of the cortical bone and are often higher in mandible than in the maxilla21. It also increased with increasing mini-implant length and outer diameter. In research settings, the insertion torque is often measured with mechanical[12] and digital drivers[13], torque sensors[10,14], automatic torque devices[15,16], torque gauges[17-19] and precision robots[20].

Removal torque, though a reliable method, is often considered as an invasive method to assess the osseointegration around the prosthodontic implants. Only a few studies have assessed the removal torque of the orthodontic mini-implants[13,21-24]. Chen et al[22] reported that the removal torque values were higher in mandible than in maxilla and is dependent mainly on the mechanical retention (primary stability) and to some extent on the osseointegration (secondary stability). Both the insertion and removal torque values thus provide adequate information regarding the stability of the mini-implants but it is very difficult in clinical settings to measure them because they often require complicated, precise and expensive devices.

Periotest:

Periotest is a percussion device which measures the mobility of the implant based on the mini-implant's resistance to the application of a lateral tapping force. It uses low-amplitude cyclic tapping on a mini-screw in the tangential direction and the dynamic stiffness values are obtained based on the amount of oscillatory loading9. The Periotest device percusses the implant head with a small pestle that will rebound at a specific speed depending on implant stability. During contact, a piezoelectric crystal inside the head of the pestle is deformed creating an electric impulse that reveals the duration of contact. The duration of contact between the pressure sensitive tapping head of the Periotest and the implant, gives the stability of the mini-implant[27]. Periotest was initially introduced by Schulte[28] to assess the mobility of the natural tooth and is dependent on the damping characteristics of the periodontium. It was Bragger[29] in 1996 who used it to assess the implant stability. For osseointegrated dental implants, PTV values are in the range of −8 to 50, −8.0 to 0 indicates a good osseointegration of the implant and the implant can be loaded, whereas PTVs from 1.0 to 9.0 indicates that osseointegration is inadequate and further evaluation is needed, and those over 10.0 suggests poor osseointegration and the implant should not be loaded. For orthodontic mini-implants the PTV usually ranges from 4 to 8[12]. The periotest has to be calibrated before use and the measurements should be repeated thrice and the mean value is considered. Periotest "M" is the recent wireless design used for measuring the stability of prosthetic implants and orthodontic mini-implants.[30] In the clinical settings, it's easier to use and provides reasonable and reproducible results for the orthodontic mini-implants but for osseointegrated implants its reliability is questionable due to poor sensitivity and susceptibility to variables.[31]

Resonance Frequency Analysis (RFA):

RFA introduced in 1998 by Meredith[32] is a non-invasive contactless method to assess the primary as well as the secondary stability of the implants. A L-shaped transducer called the "Smart peg" is attached to the implant head. The RFA device consists of a handpiece which emits electromagnetic impulses in the range of 5 to 15 kHz towards the Smart peg and detects the resonance frequency of the Smart peg implant unit. The Implant Stability Quotient (ISQ) is the unit of measurement of RFA and it ranges from 0 to 100. Higher the value, greater is the implant stability. For osseointegrated implants values above 55 are considered as adequate. It is also similar for the orthodontic mini-implants and the accepted values are in the range of 56 to 85 ISQ.[9] Osstell and Implomates are the two RFA devices that are currently available for clinical use. The major disadvantages of RFA use for orthodontic mini-implants is that the Smart pegs available are usually suitable only for prosthetic implants and in order to achieve a good coupling the Smart peg and sometimes the mini-implant head should be modified and customized. Since it is a sensitive technique, a stable and reproducible connection between the implant and the Smart peg is desirable. Further, the RFA values depend on the size and design of the mini-implants. Since the orthodontic implants are much smaller in size compared to the prosthetic implants, it is impossible to be certain whether the radiofrequency range is suitable for the mini-implants[33]. Owing to these technical difficulties the use of RFA for primary stability assessment is limited in orthodontics.

Pullout Tests:

Pull-out tests assess the mini-implant's resistance to axial forces by measuring the magnitude of force required for the mini-implant removal from the bone and the displacement of the mini-implant in response to the applied force. High axial loads with small screw displacement upon pull-out are indicative of a stable implant. This is a highly invasive procedure and used only in the in-vitro assessment of the primary stability of the mini-implant.[34]

Factors influencing the primary stability of the mini-implants:

Primary stability of the mini-implant, the most important factor determining the success of the mini-implants is influenced by multiple factors.

Tissue-related factors:

Cortical bone thickness and density:

Of all the factors influencing primary stability, the thickness and the density of the cortical bone is the most eminent factor as demonstrated by various studies.[10,36-39]. As the thickness of the cortical bone increases, the insertion torque also increases thus resulting in improved primary stability.[44]

Soft tissue mobility:

Mini-implants placed in the movable[43] and non-keratinized mucosa[42] demonstrated a compromised stability.

Arch of placement:

The mini-implants in the maxilla have a better primary stability than the mandible and a higher success rate. The mandible has a dense cortical bone, high insertion torques are needed for the mini-implant placement. This high insertion torque causes bone necrosis and compromises the stability.[43]

Site of placement:

The mid-palatal region had the highest success rate followed by maxillary posterior region, the mandibular posterior region and the palatal slope region.[43]

Mini-implant related factors:

Mini-implant design features like the diameter and shape of the implant influences the primary stability. Insertion torque of tapered mini-implants is higher than the cylindrical mini-implants[10,36,38,39]. The gradually increasing diameter of the tapered mini-implants is the reason for the improved primary stability. The outer diameter of the mini-implant influences the insertion torque. Diameters less than 1mm had poor stability. Motoyoshi et al[40] recommend a diameter of 1.5mm for better stability. The insertion torque also increases with increasing length of the mini-implant as there is more bone engagement in longer screws[21]. According to Lim et al [43]mini-implants of length 8mm had the highest success rate. The thread pitch and the body length does not significantly affect the primary stability.[21]

Operator-related factors:
Implant site preparation: Pre-drilling vs Self-drilling

In the pre-drilled mini-implants a pilot hole is placed prior to mini-implant insertion. This allows the insertion torque to be maintained within the acceptable range.[10,14] Pre-drilling depth and diameter are the parameters to be considered while preparing a pilot hole for mini-implant placement. Pre-drilling depth should be lesser than the insertion depth of the mini-implant. The width of the pilot drill should be 0.2 to 0.5 mm less than the implant diameter. The greater the predrilling diameter lesser is the primary stability.10 Self-drilling mini-implants are often associated with very high insertion torques.[43]

Insertion Angle:

Mini-implants inserted at an angle of 60° to 70° to the bone surface had a better primary stability than those inserted perpendicular (90°) to the bone surface.[44,45]

Insertion depth:

The insertion depth is another most important factor for increased primary stability. The greater the insertion depth greater is the primary stability.[14,20] The threads of the mini-implant should be completely engaged in the bone for better stability.

Insertion torque:

Insertion torque values of 5-10 Ncm[45] is recommended for the inter-radicular mini-implants. Wilmes et al[10] observed mini-implant fractures at insertion torque values above 23Ncm. Incidence of bone necrosis and microfractures increases with high insertion torques.

Re-insertion:

Mini-implants that have been removed from the bone and then reinserted in a different site exhibited significantly higher insertion torque during the second insertion. This can be attributed to the blunting of the threads of the mini-implant. The suggestions of Holm et al[44] is to either avoid reinsertion in areas of high cortical density or to consider predrilling to reduce the insertion torque.

Patient specific factors:
Age, Gender: Age and gender had no influence on the mini-implant stability.[40]
Oral hygiene:

The peri-implant tissue health is very important for implant success. Poor oral hygiene results in peri-implantitis which prevents the bone remodelling around the mini-implants thus compromising the stability of the mini-implants.[40]

Growth pattern:

Hyperdivergent patients have thinner buccal cortical bone41 as compared to hypodivergent patients and hence the insertion torque and primary stability is lesser in patients with high mandibular plane angle.[40]

Anteroposterior malocclusion:
There was no significant influence of the sagittal malocclusion on the mini-implant stability.[40]

Force related factors:

Time of Loading:

Motoyoshi et al [40] in their study conclude that immediate loading does not compromise the stability as long as the force levels are maintained below 2N. Immediate loading of the orthodontic mini-implants is supported by the literature and it does not adversely affect the primary stability.[47,48,51]

Type of force:

Wu et al[49] in their study found that intermittent forces had a better impact on the primary stability as compared to continuous forces.

Orientation relative to the direction of force:

Pickard et al[50] concluded that mini-implants in which the long axis approximated the line of the applied force had a higher primary stability.

Amount of force:

The mini-implants can successfully withstand a force of 100g-200g as direct anchorage during the early/immediate loading.[51]

III. Conclusion

The success of the orthodontic mini-implant is almost entirely dependent on its primary stability. The literature available in this particular topic is vast and this review attempts to explore this concept in detail by compiling the results of several studies conducted in this area. From this review, we can understand the different factors influencing the primary stability and the various methods used to assess it. The sad reality is that orthodontists in their practice have forgotten this basic concept and often fail to measure the primary stability chairside. Future research should endeavour in making the chairside assessment of primary stability feasible and affordable.

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