INNOVATION

ORIGINAL RESEARCH

CTOR Plates: A new invention for non-surgical treatment of complex malocclusions

Alikhani M [a,b], Sangsuwon C [a], Alansari S [a], Nervina JM [a], Oliveira SP [a,c], Teixeira CC [d]

a *CTOR Academy, Hoboken, New Jersey*

b *Harvard University, Department of Developmental Biology, Boston, Massachusetts*

c *Department of Mechanical Engineering, Polytechnic Institute of Viseu, Viseu, Portugal*

d *New York University, Department of Orthodontics, New York, New York*

Corresponding Author:
Mani Alikhani
mani.alikhani@ctor.academy

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ABSTRACT

Temporary anchorage devices (TADs) have changed Orthodontics treatment significantly. However, TAD placement in an area with poor bone quality jeopardizes their stability and, therefore, their usage. On the other hand, when TADs can be placed in areas with adequate bone quality, their position may present a new challenge, namely to establish a proper mechanical set up from what may be a less than ideal TAD position. These factors can discourage clinicians from incorporating TADs in their daily practice. Here we introduce a new bone anchorage device, the CTOR Plates, that overcome many challenges affecting treatment with conventional TADs. The CTOR Plates are customizable devices that can be placed without a surgical flap, and are cost effective, comfortable to the patients, easy to replace and adjust, and most importantly compatible with applying forces and moments needed for both orthodontic and orthopedic movements. CTOR Plates can significantly increase the limits of Orthodontics and Dentofacial Orthopedics corrections in many complex Orthodontics cases.

Introduction

Applying a force to a tooth, segment of teeth, or the whole dental arch is accompanied by reaction forces on the anchor unit. Temporary anchorage devices (TADs) are used to prevent unwanted tooth movement of the anchor unit either by replacing it (direct application) or by reinforcing the anchor unit (indirect application). However, restrictions on the TAD's stability, accessibility and biomechanics design have limited their clinical usage [1].

A TAD's stability depends on the cortical bone's quality and quantity. TADs transfer force to the bone, which needs to withstand the reaction forces if stability is to be achieved. Therefore, TAD failure is due primarily to excess resorption of the surrounding bone [2, 3].

While stability is necessary for successful use of TADs, accessibility is another important factor. To increase stability, many clinicians try to place a TAD in high quality cortical bone, which is often in areas further away from teeth, such as more apical bone, the retromolar area, the buccal shelf, infra-zygomatic bone, and palatal bone [4-6]. These placement strategies can significantly increase TAD stability, but they also often decrease their accessibility and practicality.

Another limiting factor in the use of TADs is their biomechanical properties. While TADs respond well to unidirectional forces, counter-clockwise moments are contraindicated as they may unscrew the TADs and destabilize them. Based on these limitations, applying a one- or two-couple system from a TAD is not recommended, which significantly limits their clinical applications.

Moments generated on a TAD are not the only biomechanical challenge. An individual TAD cannot tolerate higher force magnitudes often applied during orthopedic treatment. To address this deficiency, many orthodontists have suggested using surgical plates with multiple screws to increase the resistance against orthopedic forces [7]. However, placing and removing these plates requires surgical flaps, which are invasive and require involvement of another specialist, adding to the treatment time and cost, which can deter a patient's acceptance. The expense and the discomfort significantly increase if, in case of an emergency, the plate needs to be adjusted or replaced. In addition, conventional surgical plates are not very versatile in their design and therefore their mechanical use is limited. Due to these limitations surgical plates are not popular among Orthodontists and their patients.

To overcome all these impediments to TAD and conventional surgical plate usage, we have designed CTOR Plates, which can be placed non-surgically and address a wide variety of mechanical needs while taking advantage of better quality cortical bone located farther from teeth. CTOR Plates are flap-free and can be effortlessly placed and removed by the Orthodontist. They can be easily adjusted outside of the mouth without the need for repeated administration of anesthetic agents, and are very comfortable for the patient. CTOR Plates offer a cost-effective and practical solution to treat challenging malocclusions.

General characteristics of CTOR Plates

CTOR Plates were developed in a collaboration between CTOR (Consortium for Translational Orthodontics Research, www.orthodonticscientist.org) and PSM (PSM North America Inc, Germany, www.psm.ms). CTOR Plates have several clinically beneficial design and usage features:

1. No need for surgical soft tissue flap during insertion or removal
2. No soft tissue contact, thereby preventing irritation
3. Maximize cortical bone contact
4. Can be adjusted outside of the mouth
5. Easy to change the point of force application
6. Can be used for multiple targets (dental or skeletal) simultaneously.
7. Can tolerate moments and forces that may unscrew or destabilize conventional TADs
8. Easy to replace based on the patient's needs as treatment progress without additional anesthesia.
9. Easy to access in case of emergency

General characteristics of TADs used to support CTOR Plates

CTOR Plates require fixation with TADs. These TADs present the following characteristics:

1. Have a platform to support the CTOR Plate (Figure 1A)
2. Have a central cylindric hole with a proper thread to secure the plate in the chosen position with a "screw on" cap (Figure 1A). This design allows easy placement, changes, and removal of the plates without disturbing the stability of the TADs.
3. The height of the platform allows CTOR Plates to be placed approximately 1 mm away from soft tissue (Figure 1B).
4. To increase the contact point with cortical bone, and protect the TADs against the unscrewing moments or heavier orthopedic forces, each plate requires a minimum of two TADs.
5. To give the clinician flexibility to place the TADs in high quality bone and improve accessibility, CTOR Plates are design so that the two TADs can be placed 1 to 6 mm from each other without affecting the stability or function of the plates (Figure 1C)
6. To decrease the armamentarium for inserting the TADs, they are designed to be placed manually or with a rotatory device as the ones used for inserting conventional TADs.

CTOR Plates Design and Clinical Applications

CTOR Plates are designed in different shapes to increase their versatility in treating a broad range of malocclusions.

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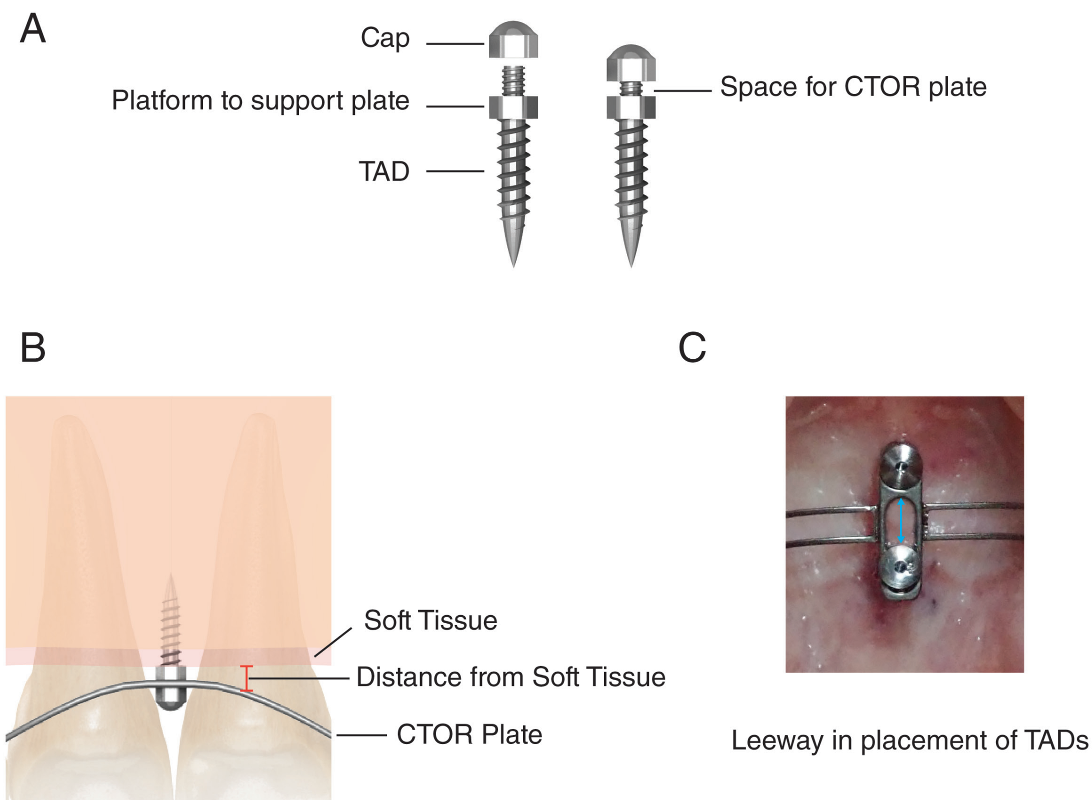

Figure 1: Characteristics of TADs for CTOR Plates. *TADs for CTOR Plates require a platform to support the CTOR Plate and a removable cap that secures the plate in place (A). The design of the TAD allows the CTOR Plate to stay at least 1 mm away from soft tissue, in this example the soft tissue of the palate (B). In addition, CTOR Plates are designed to be secured by two TADs. To allow some flexibility in TAD placement (based on cortical bone quality, accessibility or anatomical limitations), a leeway of 6 mm has been incorporated into the CTOR Plate design (C).*

Intrusion-Plates (I-Plates)

This design is used for bilateral intrusion of posterior teeth in the upper arch (Figure 2A). The I-plate can be easily shaped by hand or pliers to follow the patient's palatal contour (Figure 2B). Buttons on the lingual surface of posterior teeth can be connected to the I-Plate using power thread or power chain. The design allows intrusion of several posterior teeth simultaneously (Figure 2C). This design can also simplify treating complex open bite cases caused by extruded maxillary posterior teeth (Figure 3).

Mesialization-Plates (M-Plates)

M-Plates are installed on the palate and are used to mesialize maxillary posterior teeth (Figure 4A and B). By rotating the plate 180 degrees, M-Plates can be used to retract and distalize premolars and canines. If unilateral mesialization is necessary, one wing of the plate can be easily removed and the plate can be used directly for unilateral protraction of posterior teeth. The M-Plate design includes multiple hooks allowing the clinician to use these plates to directly apply force based on the height of the center of resistance of the moving tooth simply by changing the point of force application. These plates are very useful in mesializing maxillary teeth, especially when patients prefer to avoid braces on their anterior teeth.

M-Plates can be very useful to protract posterior teeth in cases when anterior teeth do not need significant retraction or they cannot function as adequate anchorage for protracting posterior teeth (Figure 5).

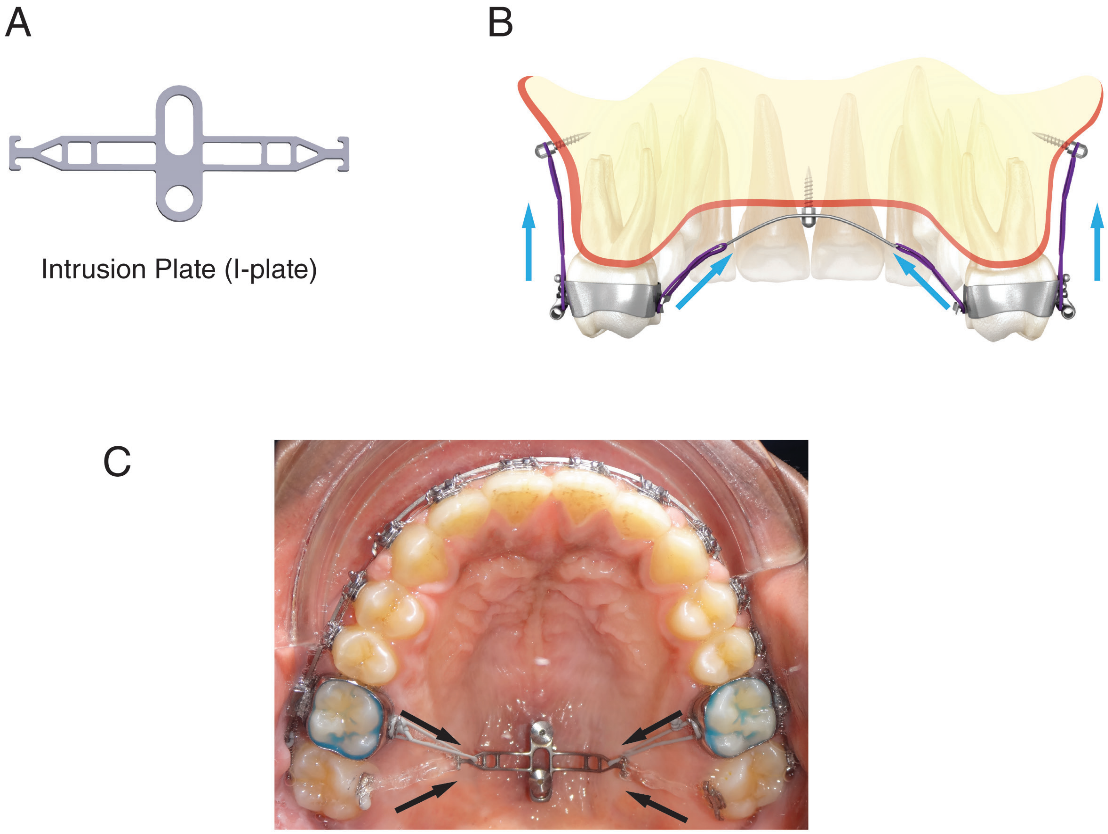

Figure 2: Intrusion Plate (I-Plate) design. *The I-Plate has been designed for intruding maxillary posterior teeth (A). This design can be used in combination with buccal TADs, depending on the type of the patient's problem (B, intrusion forces shown as blue arrows). I-Plates can be connected to posterior teeth through power chain or elastic tread for simultaneous intrusion of several posterior teeth (intrusion forces as black arrows in C).*

Figure 3: Intrusion of maxillary posterior teeth using the I-plate. *In this adult patient with a severe open bite and Class III skeletal relation, significant intrusion of maxillary posterior teeth was achieved using I-Plates after maxillary expansion.*

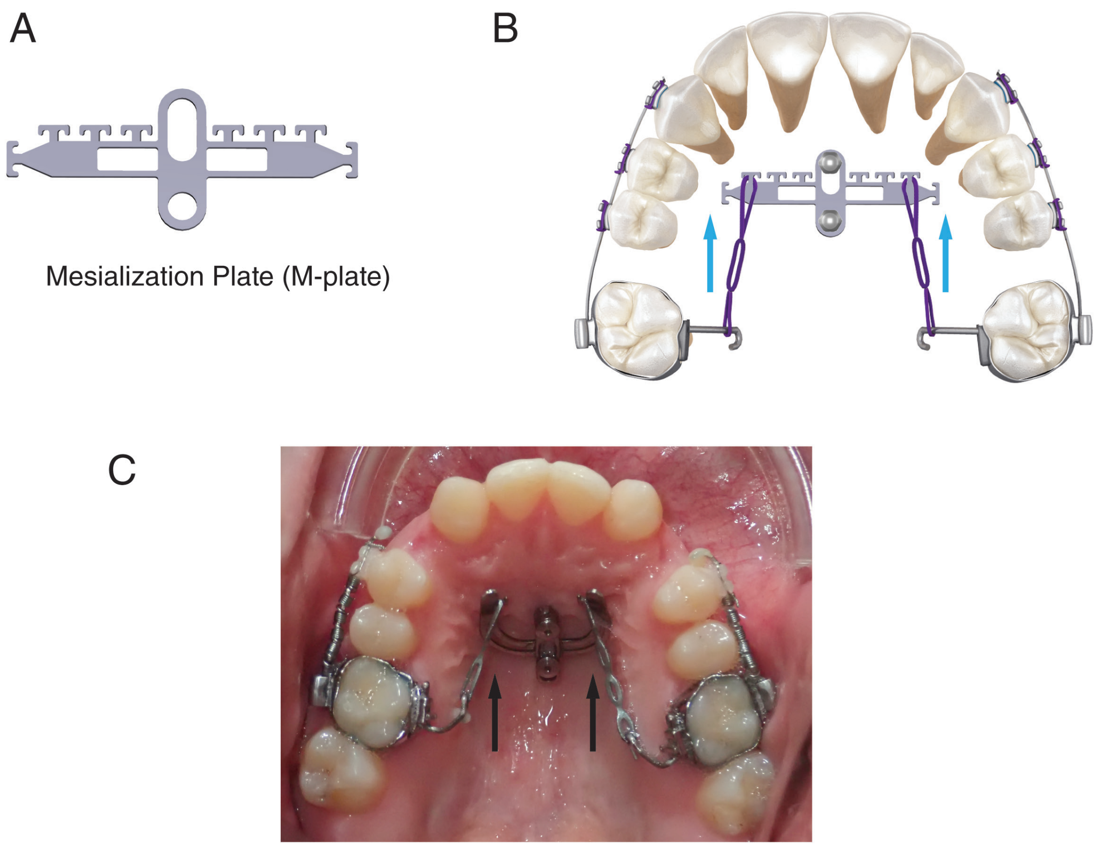

Figure 4: Mesialization-Plate (M-Plate) design. *M-Plates have been designed to protract posterior teeth without significant stress on anterior teeth (A). By incorporating several hooks into the design of the plate, its is possible to adjust force direction according to the center of resistance (B, protraction forces shown as blue arrows). By stabilizing the molars with the M-Plate, we can use the molars as anchor units to protract premolars and canines (C, open coil used to protract premolars).*

Figure 5: Protracting posterior teeth using a M-Plate for space closure. *In this patient, significant posterior teeth protraction was needed. However, since the anterior teeth did not need significant retraction, we utilized a M-Plate for protraction. First molars were stabilized as anchor units using the M-Plate, while the premolars and canines were protracted. Finally, the molars were protracted directly using the same M-Plate.*

Distalization Plate (D-Plate)

D-Plates are designed mostly to distalize posterior segments in the maxilla (Figure 6A). In cases when the patient's anatomy allows extending the arm distal to the last tooth, the clinician can easily apply distalization forces both lingually and labially without involving the rest of the dentition (Figure 6B). Due to this property, D-Plates can be used with clear aligners, significantly increasing the range of correction with these appliances. On the other hand, D-Plates can be combined with fixed appliances to apply a lingual force through the hook to one tooth, while stabilizing the adjacent tooth for simultaneous application of a distalizing force buccally, for example using an open coil (Figure 6C, distalizing forces as blue arrows). By cutting one wing of the D-Plate, we can apply a unilateral distalizing force (Figure 6D). D-Plates can be especially useful to unravel crowding of maxillary teeth following mesial migration of teeth into unrestored extraction or evulsion spaces (Figure 7).

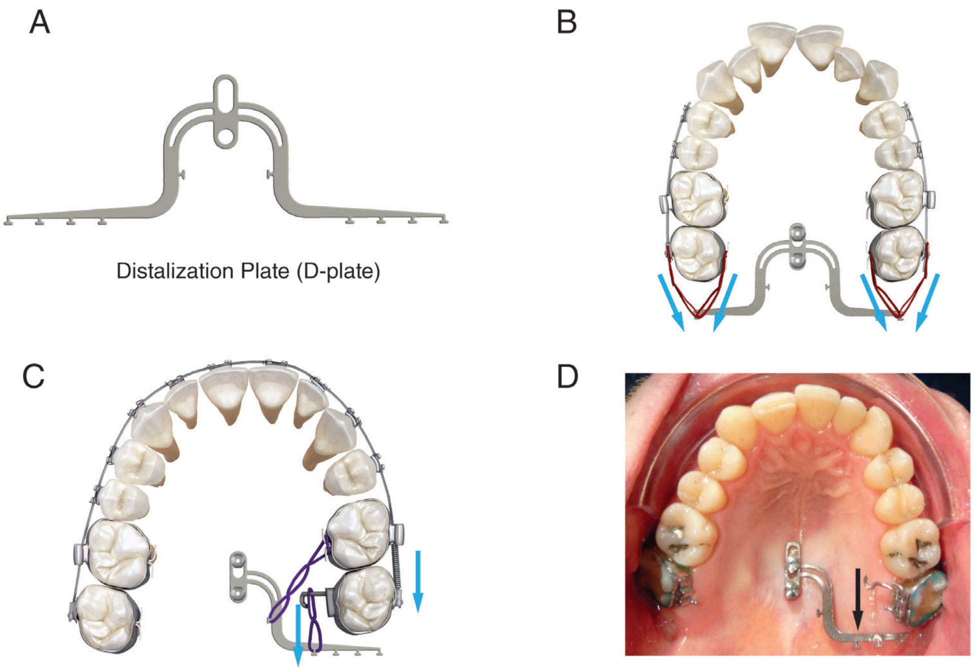

__Figure 6: Distalization Plate (D-Plate) design.__ D-plates have been designed for retracting posterior teeth (A). These plates can be used directly for retracting posterior teeth, especially when the patient is missing third molar or even second molars, by simultaneously applying buccal and lingual distalizing forces (blue arrows in B). This plate can also be used to simultaneously apply a lingual force directly to the target tooth, while securing the adjacent tooth (anchor tooth) for application of a buccal force (C, distalization forces shown as blue arrows). By modifying the D-Plate shape, and removing one wing, it can be used for unilateral distalization (D).

__Figure 7. Bilateral maxillary posterior tooth distalization to address dental Class II malocclusion.__ In this patient a D-plate was used to achieve bilateral distalization of maxillary posterior teeth, followed with retraction of the anterior teeth.

Anterior Plate (A-Plate)

A-Plates come in three types. Type I and Type II are primarily designed for buccal use, although they can be used palatally if desired. Type III plates are used palatally and require two TADs (Figure 8A). These plates include a tube instead of a hook that can be used for one-couple or two couple systems that can easily unscrew individual TADs due to the moments generated. A-Plates are safe for applying one- or two-couple systems because moments will not transfer to the TADs directly, but instead appear as unidirectional forces (Figure 8B). This system can be used to treat anterior deep bites or open bites without causing any reaction moments on posterior teeth. This is especially beneficial for adult patients when the clinician does not want to change the occlusal plane (Figure 9). Type I and Type II A-Plates can be used in the maxilla and the mandible to control the vertical tooth position.

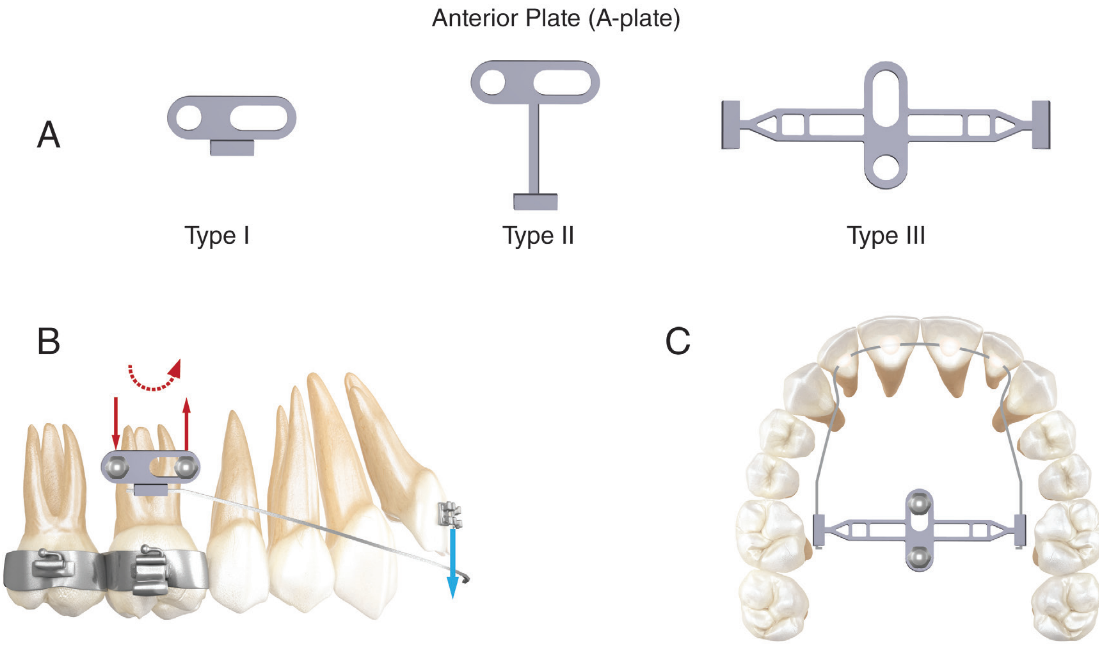

Figure 8. Anterior Plate (A-Plate) design. *A-Plates have been designed for intruding or extruding anterior teeth without changing posterior tooth position. A-Plates come in three forms. Type I and Type II are designed primarily for buccal placement, while Type III is suitable for palatal usage (A). When a TAD is used to generate vertical forces, a counter-clockwise moment appears on an individual TAD that may significantly jeopardize its stability. By connecting the tube to the A-Plate, and using it for vertical corrections, these moments translate into unidirectional forces that are easily tolerated by the 2 TADs (B, extrusion of anterior, couple shown as straight red arrows and moment on the TAD showed as dashed red arrow, extrusion force shown as blue arrow). Type III A-plates can be used with a one -couple system design for vertical corrections of anterior teeth (C) without need for fixed appliances.*

Figure 9: A-Plate used to correct anterior open bite. *In this patient, the posterior teeth had proper position, making it preferential to close the open bite without changing the position of these teeth. An A-Plate was used to produce a one-couple system to apply an extrusion force on the anterior segment. A moment produced by a one-couple system can worsen an open bite and, therefore, requires extensive anchorage preparation to prevent TAD destabilization. The A-Plate allows us to apply force without any moment or force on the posterior teeth or jeopardizing the TAD stability.*

Elastic Plate (E-Plate)

E-Plates come in two types (Figure 10A). Each type can be used in either jaw and in any location the clinician chooses to apply elastics to retract, protract or intrude posterior and anterior segments (Figure 10B). In addition, E-Plates are very useful for applying orthopedic forces, for example in combination with a facemask (Figure 10B). In Class III patients E-Plates can be easily placed and they eliminate the need for surgical plates (Figure 11).

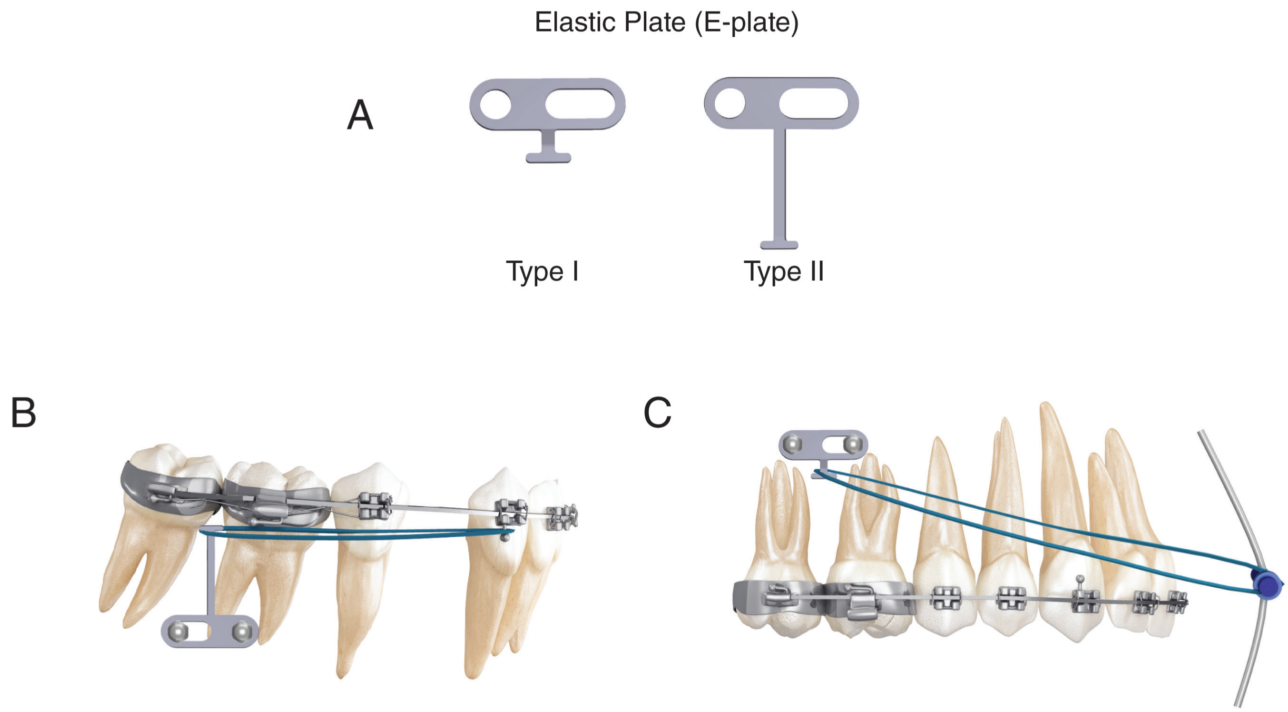

Figure 10: Elastic Plate (E-plate) design. *The E-Plate can be used in any condition when a rubber band is required but an individual TAD is either not stable or not accessible due to anatomical limitations. E-Plates are made in two type (Type 1 and Type II) that can change the accessibility and direction of the force (A). E-Plates can be used to retract maxillary of mandibular teeth (B) or to apply Orthopedics forces, without a need for flap surgery for plate placement or removal.*

Figure 11. Application of E-Plate for maxillary protraction using a facemask to correct a Class III skeletal malocclusion. *In this teenage patient, an E-Plate was used for maxillary protraction using a facemask, establishing a normal overjet and overbite.*

Innovation

CTOR-Plates are an innovation that widens the spectrum of Orthodontics and Dentofacial Orthopedics corrections, especially when cortical bone and soft tissue cannot provide adequate stability for conventional TADs or when accessibility and practicality of conventional TADs are not ideal. By taking advantage of better quality bone and soft tissue conditions without compromising the force system design, CTOR-Plates can increase TAD stability while, at the same time, offering multiple choices for point of force and moment application. The fact that CTOR Plates can be inserted, replaced, and removed without flap surgery allows the clinician to change the plate based on the needs of the patient as the treatment progress. Replacing the plates only requires unscrewing the cap of the TAD, removing the old plate and screwing the new plate in place without the need to change the position of the TADs. This can be accomplished by the orthodontist without surgery or even anesthetic, making these treatment options very cost effective and appealing to the patient. The versatility and maneuverability offered by CTOR Plates increase the ability of orthodontists to treat a wide variety of complex malocclusions non-surgically. In addition, CTOR Plates can compliment clear aligners or limited braces treatment, especially in adults who require comprehensive treatment but, due to social issues, demand more aesthetically appealing solutions.

Discussion

TADs are useful if they are stable and if they can be used to produce adequate forces. However, many factors can affect their stability, accessibility or biomechanical practicality, which lead clinicians to avoid TADs in their practice. Likewise, conventional surgical plates are often eschewed because of the invasive surgical procedure needed for their placement, which can cause discomfort and add cost to orthopedic corrections that patients do not want to incur. CTOR Plates have been designed to overcome all of these problems.

Factors that may affect the stability and practicality of TADs are related to the cortical bone and soft-tissue response to TADs and can be divided into: 1) cortical bone thickness, 2) proximity of adjacent roots, 3) cortical bone response to insertion torque, 4) cortical bone tolerance of tip-moment, 5) cortical bone response to un-torquing moments, 6) cortical bone response to Orthodontics and Orthopedics forces, and 7) keratinized and nonkeratinized mucosal response.

Unlike dental implants that primarily rely on trabecular bone and secondary stability through osteointegration (stimulating bone healing around the implant), TAD stability depends on cortical bone mechanical support [6, 8-11]. Therefore, TAD stability is mostly mechanical rather than biological and is termed primary stability. In primary stability, cortical bone thickness plays a significant role in TAD stability. However, cortical bone thickness varies in different areas of the maxilla and mandible, which can limit treatment options because cortical bone with proper thickness is often far from the desired area [12]. For example, in the maxilla, the palatal bone around the mid-palatal suture anteriorly or posteriorly is usually of very good quality and quantity. However, placing a single TAD in these areas does not provide significant mechanical advantage to efficiently treat the patient. Placing an I-Plate, M-Plate, or D-Plate in these areas and extending their arms to areas mechanically more favorable allows us to execute an ideal mechanical designs by taking advantage of cortical bone with sufficient thickness. This is also beneficial from the point of the soft tissue, since the CTOR Plate can be placed in keratinized soft tissue tightly bound to the underlying bone. In general, it is advisable to leave the TAD head in keratinized and immobile mucosa to prevent mucosal irritation or the possibility of mucosal overgrowth [13, 14] The I-Plate, M-Plate and D-Plate designs allow us to take advantage of such soft tissue conditions.

Another factor that affects the stability and practicality of conventional TADs is the proximity of the adjacent roots. The closer the TAD is placed to adjacent roots, the higher the possibility of failure [15-17]. This factor alone pushes the clinician to place the TAD more apically where there is more space between the roots and thicker cortical bone. However, as the TAD moves more apical the accessibility decreases. This is due to the fact that the alveolar mucosa (below the mucogingival junction) in the buccal area of each arch is mobile. Placing the TAD more apically is not only associated with more soft tissue irritation and discomfort, but also increases the possibility of soft tissue overgrowth around the TAD making direct force application from the TAD almost impossible [18]. Some clinicians try to connect the TAD that is covered with soft tissue to the anchor teeth by a ligature wire and apply a force indirectly through the anchor tooth. However, this is associated with adjustment difficulty and limited stability for the anchor tooth, since a ligature tie cannot provide 3D stability to the anchor unit. E-Plates and A-Plates have been designed to address all these problems. In these cases, CTOR Plates allow the clinician to take advantage of the thicker apical cortical bone without worrying about the possibility of coverage of the TAD by soft tissue. CTOR Plates stand 1 mm above the soft tissue surface and their arms can be adjusted to the desired point of force application. Furthermore, A-Plates provide a tube which offers other mechanical design possibilities and better 3D control.

Since TAD stability depends on cortical bone and not trabecular bone, increasing the TAD diameter to take advantage of more cortical bone surface is more important than increasing TAD length [19]. However, increasing the TAD diameter is associated with an increase in torque during insertion that can significantly add stress to the bone and damage the bone, which indirectly affects the stability of the TAD by excessively stimulating the local bone remodeling machinery [20-22]. In addition, increasing the TAD diameter violates another important biological factor - the proximity to the adjacent roots. These problems have been eliminated in the CTOR Plate designs by using two TADs. Each TAD by itself does not increase the insertion torque significantly or violate the root proximity. Importantly, having two TADs doubles the cortical bone contact. The CTOR Plates have also been designed to give the clinician flexibility to place the TADs at customized distances from each other, to accommodate the patient's anatomy. In addition, the metal that connects the two TADs can be bent with pliers to perfectly adapt the shape to the patient's anatomy. These design features overcome the complexity that would occur if the TADs could only be placed at fixed distances and angles form each other.

Another factor that plays a significant role in TAD stability is the magnitude of applied Orthodontics and Dentofacial Orthopedics forces [7, 10, 23]. Depending on the geometry of the TAD, the stress (load per area) in cortical bone can increase significantly in response to Orthodontics forces. It has been estimated that in response to a 400 cN force on a 1.8 mm diameter TAD, the bone stresses may be as high as 30 MPA [24]. Considering that cortical bone can only tolerate 60-150 MPa, it is clear that applying conventional Orthodontics forces significantly activates the bone remodeling machinery. Therefore, no more than 200-400 g of force can be withstood by a single TAD. This does not allow the clinician to apply higher range forces to achieve the necessary Orthodontics or Dentofacial Orthopedics responses. Having two TADs supporting the CTOR Plates allows these stresses to be distributed over a larger area, thereby decreasing the stress the bone receives far below the tolerance threshold of cortical bone, especially for tip-moments [25]. Tip-moment is the stress magnitude applied to the bone and depends on the height of the TAD head and the magnitude of force applied. High tip-moment can cause significant stress on the bone, activating the remodeling machinery and therefore, increasing the chance of TAD failure. In this regard, it has been suggested that a tip-moment greater than 900 N.cm should be avoided [23]. This magnitude of moment corresponds to applying a 300 CN tangential force to the TAD head located 3 mm away from the surface of the bone. Orthodontics forces on a CTOR Plate are applied closer to the bone, since plates stand only 1 mm away from the soft-tissue surface. In addition, having two TADs connected through a plate allows the tip-moment to be divided between two TADs, rather than being concentrated in only one area. CTOR Plates therefore, allow application of higher Orthodontics and Dentofacial Orthopedics forces.

Counter-clockwise moments are another issue that affects both stability and biomechanics use of TADs. We usually avoid applying counter-clockwise moments on a TAD since it may cause unscrewing the TAD and decrease its stability. Therefore, mechanical designs that require counter-clockwise moments on the TAD, such as a one- or two- couple system, should be avoided. The design of A-Plates allows a moment to be applied without increasing the possibility of unscrewing the TAD. This is due to the fact that moments will be applied to the plate as a couple (two forces in opposite directions), rather than as a moment. The forces of the couple are transferred to the TADs without causing unscrewing effect. This feature allows CTOR-Plates to be used to treat severe malocclusions, such as open bite cases, where applying a one-couple system from an A-Plate can produce extrusion forces on anterior teeth without causing anterior molar tipping, which could worsen the open bite. While a single TAD would not allow us to apply a one-couple system for an extended time, the A-Plate allows us to apply a one- or two-couple system without increasing the possibility of TAD failure.

Use of conventional surgical plates have been suggested for anchorage in challenging malocclusions. However, these plates have limitations. Insertion and removal of these plates require surgery and additional expense, which makes this option unattractive for many Orthodontists and their patients. In addition, these plates cannot be modified or replaced based on the clinical needs at different stages of treatment or in case of emergency. Due to these limitations, conventional surgical plates have not become part of main stream Orthodontics treatment.

The simplicity of placing and removing CTOR Plates allows the Orthodontist to easily change the plates based on patient needs without the need to remove and replace the TADs. Since the CTOR Plates are separate from the TADs, changing the plates does not increase patient discomfort nor does it require any anesthetic. By changing the CTOR Plates, it is possible to change the point of force or moment application to any location that the mechanical design requires.

Conclusion

CTOR Plates can be placed by Orthodontists quickly and safely without the need for a soft tissue flap. This innovative device expands the ability of Orthodontists to treat a wider range of severe malocclusion using an efficient mechanotherapy plan that can be modified at any point during treatment without additional cost or discomfort to the patient.

Acknowledgements

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