Comparison of Maxillary Protraction Biomechanics in Mild to Moderate Retrognathism - Tooth-Borne versus Skeletal Anchorage

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Abstract

AIM: To compare two anchorage techniques in facilitating maxillary forward development in mild to moderate maxillary retrognathism.

METHODS: An electronic search of the literature was systematically reviewed using PubMed/Medline, followed by a manual search. The search was refined by time and English language criteria. Keywords and MeSH terms included Cephalometric, Palatal expansion, mini plates, micro-screws, mini implants, skeletal anchorage, orthodontic anchorage. The search yielded 291 articles, which were narrowed down to 10 relevant quality studies, several moderate quality studies, and 4 systematic reviews based on inclusion and exclusion criteria.

RESULTS: The initial database search yielded 1305 records; 32 studies passed the first review phase, and 10 studies were finally selected. Dental anchorage designs consistently demonstrated maxillary skeletal advancement of 2-4mm, accompanied by maxillary forward and upward rotation, and increased vertical dimension. Bone-anchored protraction techniques showed greater forward movement (1 mm more), with fewer unwanted side effects.

CONCLUSION: Skeletal anchorage mechanics produced more skeletal effect in maxillary protraction with less dentoalveolar component compared to dental anchorage techniques. Despite the advantages of skeletal bone anchorage in maxillary protraction mechanics, evidence-based research is limited.

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1 Introduction

Class III malocclusions are one of the most challenging orthodontic problems to treat. Its prevalence varies according to ethnicity and genetic components. Class III malocclusion is prevalent in 1%-5% of white populations (Gallagher, Miranda, & Buschang, 1998), 5% in the Latin population (Smith & English, 1999), and much higher in Asian, especially Chinese, populations (10%-14%) (Solano-Mendoza et al., 2012).

A Class III malocclusion may be caused by an element or combination of mandibular prognathism, maxillary retrognathism, mandibular dental protrusion, maxillary dental retrusion, and mandibular forward rotation. However, most of Class III malocclusion (60%-70%) involves an underlying aetiology of maxillary deficiency, with or without other aetiological components (Sar, Arman-Ozcirpici, Uckan, & Yazici, 2011).

In a developing skeletal Class III malocclusion, there is a general lack of evidence-based research to provide a clear consensus on the definitive path of therapy to be undertaken. Treatment options include early orthopedic intervention for growth modification and late surgical correction. The efficacy and long-term stability of early skeletal changes are limited in the conventional technique of engaging dental anchorage. The use of skeletal anchorage in growth modifications has carved a new path in early orthopedic intervention (Shanker et al., 1996).

The effects of early treatment of mandibular prognathism are limited due to negative skeletal changes, limited ability to retard mandibular growth, dentoalveolar and vertical compensation, and high relapse rate. Late surgical orthodontic and orthopedic correction provides a more predictable and stable option (Cha & Ngan, 2011). However, in the majority of Class III cases, there has been promising evidence that demonstrates the effectiveness in treating maxillary deficiency components in growing Class III patients via maxillary protraction or advancement (Gallagher et al., 1998; Solano-Mendoza et al., 2012).

The objective in Class III correction is to achieve a positive skeletal and dental overjet. This can be achieved via extra-oral devices such as facemasks and reverse-pull headgears, and intraoral appliances such as intra-oral Class III elastics and removable appliances. Growing individuals with Class III malocclusion involving skeletal maxillary deficiency require maxillary advancement, and protraction facemasks are commonly prescribed (Gallagher et al., 1998; Solano-Mendoza et al., 2012).

The anchorage design of these orthopedic appliances will influence the effect of therapy. Currently, two intraoral anchorage modes are available: dental and skeletal. Dental anchorage engages on the teeth to protract the maxilla, e.g., bonded fixed appliance such as expander appliances, Hyrax, Lingual arch, Transpalatal Arch TPA, or other removable appliances. Skeletal anchorage engages on a bone unit to apply protraction forces directly onto the maxilla, e.g., mini plates, temporary anchorage devices (TADs) and micro-implants/mini implants. These can be installed on the maxilla close to the center of rotation in the direction of applied force to prevent unwanted skeletal effects or rotation. Common sites of application are the maxillary zygomatic process, anteriorly between the lateral incisors and canine, or in posterior maxilla between the premolars and first molars (Solano-Mendoza et al., 2012).

Therefore, there are presently two major management options in the protraction of the maxillary bone: traction with dental anchorage and traction with bone anchorage (Solano-Mendoza et al., 2012).

Dental anchorage usually results in a combination of uncertain skeletal and undesirable dentoalveolar changes. These may include maxilla protraction, downward and backward rotation of the mandible causing vertical changes, labial tipping of the maxillary incisors, and lingual tipping of the mandibular incisors. The disadvantages of tooth-borne anchorage devices are loss of anchorage, especially when preservation of arch length is necessary, inefficient biomechanics of orthopedic force application to the maxilla, and long-term instability (De Clerck, Cevidanes, & Baccetti, 2010).

Bone anchorage provides a promising solution to these problems. It can facilitate pure orthopedic maxillary advancement without unwanted vertical changes and dentoalveolar side effects. This is especially useful in severe maxillary retrusion cases, or in cases of deficient or compromised dentoalveolar anchorage (De Clerck et al., 2010).

Clinical studies on skeletal anchorage maxillary protraction remain scarce, and future studies should also evaluate the long-term stability of these orthopedic changes (Heymann et al., 2010). Maxillary protraction with skeletal anchorage in growing children has not been widely and thoroughly reported and investigated, and there are areas of concern with regard to the effects of skeletal implants on normal growth and development. Nonetheless, skeletal anchorage may provide an additional solution to early dentofacial orthopedic therapy in the future (Heymann et al., 2010; Cha et al., 2011).

The aim of this paper is to review the current literature on the effects of maxillary protraction therapy in growing Class III patients, with special focus on different anchorage techniques. This paper will also discuss the effects of different anchorage techniques on skeletal and dental tissues, and based on the available data, aim to provide relative indications and contraindications of each technique.

2 Methods

The literature was systematically reviewed using the PubMed/Medline database, followed by a manual search. The search was refined based on recency (covering the past ten years from 2004 to 2014) and restricted to articles published in English. The search employed keywords and MeSH (Medical Subject Heading) terms including "Malocclusion, Angle Class III" AND "Extraoral Traction Appliances" OR "orthodontics, interceptive" OR "orthodontics, early treatment" OR "Malocclusion, Angle Class III/therapy" OR "orthodontics, reverse pull headgear, facemasks" OR "Orthodontics, Corrective/methods," with surgery being excluded. Additional MeSH terms such as cephalometric, palatal expansion, mini plates, micro-screws, mini implants, skeletal anchorage, and orthodontic anchorage were also utilised.

To determine the most relevant and high-quality studies for review, specific inclusion criteria were established. Eligible articles comprised randomized controlled clinical trials, as well as prospective and retrospective clinical studies, all with a minimum observation period of one year. Only studies published in English were considered, and each study required a sample population of at least five individuals per group. The focus was on interventions involving orthopaedic therapy in young, growing individuals, with comparisons made against control groups using different orthopaedic appliances or no treatment at all. The primary outcome of these studies needed to be related to skeletal Class III malocclusion and the corresponding orthopaedic therapy.

Certain criteria led to the exclusion of studies. In vitro experiments and animal research were not considered relevant. Studies published in languages other than English, or those lacking an English abstract, were also excluded. When multiple reports stemmed from the same study, only the most recent publication was retained. Further, various types of studies were omitted, including case reports, case series, descriptive studies, technical descriptions, opinion pieces, letters, and articles that did not correspond to the primary focus. By applying these exclusion criteria, the selection process ensured the inclusion of the most pertinent and high-quality research.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3 Results

Ten clinical studies investigating various maxillary protraction techniques were evaluated, and the results are summarized in supplementary **Table S1** according to the effects of different anchorage methods on skeletal (maxilla, mandible, vertical, and dental structures). Various maxillary protraction techniques were employed in the selected studies, which can be categorized into four groups:

1. Intraoral traction with dental anchorage: This group includes techniques that use intraoral appliances with dental anchorage, such as a fixed dental appliance with Class III elastics (e.g., TPA with Class III elastics).

2. Intraoral traction with skeletal anchorage: This group consists of techniques that use intraoral appliances with skeletal anchorage, such as mini plates or micro implants with Class III elastics.

3. Extraoral traction with dental anchorage: Techniques in this category utilize extraoral appliances with dental anchorage, such as a maxillary expander appliance with a facemask.

4. Extraoral traction with skeletal anchorage: This group encompasses techniques that employ extraoral appliances with skeletal anchorage, such as mini plates with a facemask.

5. Combination: This group combines multiple techniques, including maxillary expansion (e.g., mini-plates with a facemask for extra-oral traction, with an intra-oral maxillary expander such as a rapid maxillary expander (RME)).

Lateral cephalometric analyses are utilized to assess alterations in skeletal and dental structures. Specifically, modifications in maxillary structures are typically evaluated using the 'A' point and its relationship with other facial landmarks. To document and distinguish the components of these changes (skeletal and dental), superimposition cephalometric analysis techniques employing stable reference points or planes (such as the anterior cranial base or anterior palate) are used (Bjork & Skieller, as cited in Shanker et al., 1996). Notably, superimposition techniques using the maxillary zygoma have been found to be more precise for growing individuals (Shanker et al., 1996).

Common cephalometric landmarks used in the studies are presented in **Figure 1**. Using these cephalometric landmarks, the following changes were recorded:

- Change in maxillary position relative to the cranial base, including skeletal rotations (SNA, A-Nperp, etc.)
- Change in maxillary relation to the mandible (ANB, Wits, etc.), including vertical changes
- Change in dental angulations and relations, including vertical changes (tipping, extrusion, and intrusion)
- Change in vertical dimension (PP-MP, ANS-Me, FH-MP, FH-PP, etc.)

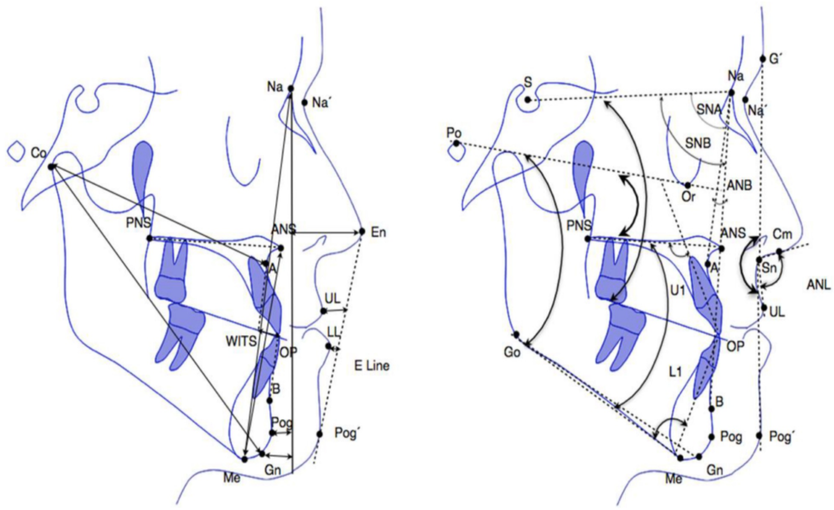

Figure 1. Graphic representation of the cephalometric points and linear and angular measures described by the different literature sources. Points and lines: S: Sella, Po: Porion, Ba: Basion, Or: Orbital, Pt: Pterygoid, Na: Nasion, Na´: Soft nasion, G: Soft glabella, Pog: Pogonion, Pog´: Soft pogonion, Gn: Gnathion, Ch: Chin, Go: Gonion, Co: Condylion, ANS: anterior nasal spine, PNS: posterior nasal spine, OP: Occlusal plane, Wits: Points A and B projected in the occlusal plane, SN: S-Na, FP: Frankfort plane (Po-Or), PP: Palatal plane (ANS-PNS), MP: Mandibular plane (Go-Ch), U1: Upper incisor, L1: Lower incisor, U6: First upper molar, L6: First lower molar, UL: Upper lip, LL: Lower lip, Sn: Subnasal, Cm: Columella, In: Nasal tip, E Line: In-Pog. **Left**: Linear measures: Pog-perpendicular Na: Advance of Pog, Gn-perpendicular Na: Advance of Gn, A-perpendicular Na: Advance of point A, In-perpendicular Na: Advance of nasal tip, Co-A: Maxillary length, Co-Gn: Mandibular length, ANS-Ch: Lower facial height, N-Ch: Total facial height, UL-E Line, LL-E Line, Wits, U6 vertical (SN-perpendicular U6): Upper molar extrusion, L6 vertical (SN-perpendicular L6): Lower molar extrusion, U1-perpendicular A: Position of the upper incisor, L1/A-Pog: Position of the lower incisor. **Right**: Angular measures: ANB, SNA, SNB, L1/Go-Gn: Angulation of the lower incisor, U1/ANS-PNS or U1-FP, Angulation of the upper incisor, PP-SN or PP-FP: Maxillary rotation, MP-SN or MP-FP: Mandibular rotation PP-MP: Intermaxillary rotation, OP/SN: Rotation of OP with respect to SN, NLA (Cm.Sn.UL): Nasolabial angle, G'-Sn-Pog: Facial convexity, Facial Axis: Ba-Na/ Pt-Gn

3.1 Effects on the maxilla

Conventional maxillary protraction with dental anchorage designs has consistently demonstrated that maxillary skeletal advancement of 2–4 mm is achievable (Cozza et al., 2004; Baccetti et al., 2004; Vaughn et al., 2005). This is accompanied by maxillary forward and upward rotation, and an increase in the vertical dimension (Vaughn et al., 2005; Pavoni et al., 2009). Bone-anchored maxillary protraction techniques have shown a greater amount of A point forward movement, i.e., maxillary advancement, compared to dental anchored maxillary protraction (1 mm more), approximately 4 mm more than the untreated controls (De Clerck et al., 2010; Baccetti et al., 2011). These techniques also demonstrated fewer unwanted side effects, such as maxillary rotation and increased vertical dimension. Pure forward advancement of the maxilla has been demonstrated with little or no rotation or vertical downgrowth (De Clerck et al., 2010; Cevidanes et al., 2010). Studies also showed that the use of the RME appliance is not indicated in maxillary protraction, as the results in maxillary advancement are not influenced by the presence of any expander appliance (Cha & Ngan, 2011; Cevidanes et al., 2010).

3.2 Effects on maxillary dentition

Conventional dental anchorage resulted in dentoalveolar changes associated with loss of anchorage and dental compensation (Cozza et al., 2004; Baccetti et al., 2004; Vaughn et al., 2005). Upper teeth proclination and protrusion, loss of arch length via mesial migration of posterior segments, mesial tipping, extrusion, and a high relapse rate are characteristics of dentoalveolar changes in maxillary protraction. Bone-anchored maxillary protraction studies have demonstrated that pure skeletal maxillary changes are possible without dentoalveolar changes (e.g., less mesialisation and extrusion of teeth). Automatic dental improvement and correction have been shown, with improvement in incisor, canine, and molar relations (Cha & Ngan, 2011; De Clerck et al., 2010; Baccetti et al., 2011).

3.3 Effects on the mandible

Conventional dental anchorage maxillary protraction techniques engage the mandible (chin) as a source of anchorage. Skeletal effects of this backward force include downward and backward rotation of the mandible, retrusion of the B point and pogonion, and improvement in MMR and SNB, with an accompanying increase in the vertical dimension (De Clerck et al., 2010; Vaughn et al., 2005; Baccetti et al., 2010). Bone-anchored maxillary protraction techniques have demonstrated limited or no mandibular and controlled vertical change. Some studies have demonstrated backward mandibular deformation; however, the implications of this effect have not been thoroughly investigated (e.g., TMJ effects, passive retrusion of the mandible), and it is unlikely to represent a true horizontal shortening of the mandibular length (Cha & Ngan, 2011; De Clerck et al., 2010; Baccetti et al., 2011).

3.4 Effects on mandibulary dentition

Conventional anchorage techniques, especially intraoral Class III elastics, result in lower incisors retroclination, lower crowding, distal tipping of posterior segments, or arch length gain as dental compensation occurs. Stability is poor, as the relapse rate is high. Accompanying extrusion of posterior segments results in the opening of the vertical dimension, allowing backward and downward rotation of the mandible. Extra-oral protraction techniques have shown incisor decompensation as overjet improves (Feng et al., 2012). Bone anchorage techniques have shown little or no negative effects in the lower dentition, while some have demonstrated automatic dental improvement in incisor angulations (incisor proclination) and crowding situations as dental decompensation occurs with maxillary advancement. Vertical positions of teeth are maintained (Major et al., 2012). The treatment protocol actually led to the decompensation of the lingual tipping, i.e., incisor proclination of the mandibular incisors usually observed in untreated Class III subjects (De Clerck et al., 2010).

3.5 Effects on vertical dimension

All studies noted the effect of clockwise rotation on the mandible and an increase in inferior-anterior and total facial height; this was more pronounced in dentoalveolar therapy than in bone-anchored orthopaedics (Morales-Fernandez et al., 2013). As a result of skeletal and dentoalveolar changes, dental-anchored maxillary protraction showed maxillary downgrowth and rotation, mandibular backward rotation, dentoalveolar tipping or extrusion, or a combination of these, which result in an increase in facial height and vertical dimension. Bone-anchored maxillary protraction has shown skeletal changes to the maxilla with minimal negative effect on the mandible and dentition. Changes in vertical dimension are controlled and usually comparable to, and in line with, untreated control groups (natural growth) (De Clerck et al., 2010; Cevidanes et al., 2010).

4 Discussion

The use of conventional maxillary protraction techniques in growing individuals has been shown to be effective in achieving the dental objectives of Class III skeletal correction. However, the majority of the correction is achieved via dentoalveolar compensation. This approach has proven to be unstable with relatively high rates of relapse post-treatment (Major et al., 2012; Morales-Fernandez et al., 2013). Conventional techniques of engaging dental anchorage do not facilitate pure bony changes. They allow limited skeletal remodeling and result in dentoalveolar changes due to anchorage loss. Maxillary advancement is limited, with most of the correction effected by the mesialisation of the maxillary teeth (arch length loss), forward proclination of the upper incisors, and extrusion of the maxillary posterior segment, effectively causing a forward rotation of the maxillary arch and opening of the vertical dimension. Backward pressure on the mandible causes it to rotate down and back. The result comprises a combination of increases in mandibular angle and vertical dimension, improved maxilla-mandible horizontal relations, anterior bite opening, deep bite correction, improved incisor inclination, overjet improvement, and enhanced dental relationships (Celikoglu & Oktay, 2014). While these approaches can provide some benefits in Class III patients with reduced lower facial height, the same cannot be applied to other Class III patient populations.

The instability of the final results leads to rapid relapse following active therapy (Celikoglu & Oktay, 2014; Chen et al., 2012). This instability can be attributed to dentoalveolar components in orthopaedic treatment, which encourage dental compensation instead of true skeletal correction. Skeletal camouflage is effected by down-and-back mandibular rotation. Further mandibular growth may undermine the results, as there is only a limited amount of dental compensation and skeletal camouflage (bite opening) available to correct the malocclusion. Beyond this, surgical correction might be a more appropriate treatment option. Orthodontic relapse and the necessity for surgical correction remain significant risks in all skeletal Class III treatments and should be appropriately discussed in patient consultations and informed consent procedures (Chen et al., 2012). This is particularly pertinent for growing individuals with poor prognoses, such as poor compliance, high-angle Class III malocclusion, and those with a significant mandibular prognathism component.

Skeletal anchorage in dentofacial orthopaedics is relatively novel. Clinical studies are scarce, but this may present a better alternative to conventional treatment. The use of mini-plates or temporary anchorage devices (TADs) allows orthopaedic forces to be directed squarely on the desired bony maxillary base and can potentially control the amount and direction of maxillary growth by varying the position, magnitude, and direction of applied forces. Recent studies have demonstrated skeletal maxillary advancement significantly surpassing that of conventional techniques within a shorter treatment time (Sar et al., 2011; Sar et al., 2014), with little or no dentoalveolar and mandibular changes other than those expected in normal growth and development, as reflected in control groups. Hence, the undesirable side effects (such as maxillary and mandibular rotation, maxillary teeth mesialisation, proclination and extrusion, mandibular teeth distalisation, and vertical opening) that contribute to instability and relapse are effectively prevented. Compared to untreated Class III individuals, skeletally anchored maxillary protraction has demonstrated an average maxillary skeletal and soft tissue change of about 4 mm, as well as mandibular retrusion of at least 2 mm. This approach promises better treatment outcomes and long-term retention. Further studies are warranted to firmly establish these outcomes (Feng et al., 2012; Sar et al., 2014).

Treatment planning for Class III maxillary deficiency cases necessitates thorough consideration and involves accurate diagnosis, evaluation of growth and development stages, orthodontic and orthopaedic mechanics and designs, as well as risk and potential complication assessments, including undesirable side effects and relapse.

Diagnosis of the stage of skeletal growth and development in Class III cases is crucial to identifying the skeletal and dental components of the malocclusion. Chronological age is an unreliable indicator of skeletal growth. Radiographs (Hand-Wrist) can be employed to assess skeletal maturity. The Cervical Vertebral Maturation (CVM) method by Baccetti et al. (2005) has been shown to be accurate in assessing growth status, peak skeletal growth in height, and mandibular development.

The timing of orthopaedic therapy is critical to capitalise on active skeletal growth to correct the malocclusion. In a growing individual with Class III skeletal malocclusion, orthopaedic therapy requires growth potential to encourage maxillary advancement; however, the same growth potential is undesirable for the mandible, particularly during late growth spurts. Studies have demonstrated that maxillary protraction is effective, whereas mandibular growth modification remains questionable and limited in efficacy over the long term, with a high relapse rate and risks of temporomandibular joint (TMJ) dysfunction (Baccetti et al., 2011; Feng et al., 2012). Consequently, the challenge in treating Class III cases lies in the current inability to accurately identify, determine, and predict the growth potential and peak growth of the skeletal components (Baccetti et al., 2005).

Potential obstacles to bone anchorage techniques include the additional procedural step of surgical installation of anchorage devices. Additional costs, discomfort, and postoperative complications such as loss of anchorage stability and infection further complicate the employment of bone-anchored maxillary protraction. However, various studies (Feng et al., 2012; Major et al., 2012) have shown that while complications do occur, the incidence and severity of postoperative complications (pain, swelling, infection, loss of anchorage devices) and failures in bone-anchored maxillary protraction (BAMP) are relatively low and manageable. Excessive orthopaedic force can risk device anchorage failure; however, this has not been demonstrated in the limited current data. Retrievability and reinstallation of temporary anchorage devices (TADs) or BAMP also contribute to the convenience and safety of such devices.

Age is another factor that may contraindicate such devices. Young patients have limited vertical maxillary height for anchorage installation; thus, BAMP is recommended only at age 10 and beyond. This has the added advantage of reducing therapy time, as maxillary protraction is achieved in a shorter time with BAMP (Sar et al., 2011; Sar et al., 2014), resulting in reduced or shorter Phase 2 orthodontic treatment. Earlier active orthopaedic therapy also allows more time for the patient to outgrow the orthopaedic correction. Therefore, normal growth and development should be encouraged at an early age, with active intervention reserved for late growth during the late mixed dentition.

However, many propose that maxillary growth modification should commence at an early age of 8 years, while the intermaxillary, circummaxillary, and pterygomaxillary sutures remain open. It has been reported that 80% of maxillary growth is complete by age 8 (Baccetti et al., 2004; Baccetti et al., 2005). Additionally, early studies have consistently demonstrated that greater skeletal corrections are achieved at younger ages. However, these studies have also shown high relapse rates, which have been attributed to multiple factors, including myofunctional imbalance and unstable dentoalveolar changes (Solano-Mendoza et al., 2012; Cha & Ngan, 2011).

Myofunctional therapy has been advocated for maxillary-deficient children at an early age to assist with normal growth and development, before more direct intervention at age 10 and beyond with skeletal anchorage maxillary protraction (Baccetti et al., 2004; Baccetti et al., 2005). The effects of bone anchorage devices on normal growth and development are also a concern, especially with regard to transverse development. There is little evidence that these devices cause skeletal growth retardation, and recent studies have reinforced the safe application of skeletal anchorage devices.

In any case, further randomized controlled clinical studies are needed to investigate the correlation in the magnitude of maxillary advancement, age, appliance design, traction force, and side effects, as well as to identify and evaluate other factors that may influence treatment response (Solano-Mendoza et al., 2012). Future studies should also establish firmly and precisely the effects of skeletal anchorage therapy on adjacent bones, sutures, and soft tissues (Yan et al., 2013). Three-dimensional studies involving cone beam computed tomography (CBCT) could evaluate the responses to bone-anchored maxillary protraction more thoroughly, and establish the upper limit of possible maxillary advancement beyond which alternatives such as surgery would be recommended (Heymann et al., 2010).

Skeletal anchorage maxillary protraction offers several advantages over dental anchorage techniques (Sar et al., 2011; Sar et al., 2014). Simultaneous orthopaedic and orthodontic corrections can be initiated concurrently. Skeletal anchorage provides a quicker speed of correction compared to conventional techniques and is much better tolerated during longer treatment times. Orthopaedic forces can also be calibrated and directed more accurately through miniplates or temporary anchorage devices (TADs) compared to dental anchorage, thereby facilitating a more uniform and controlled maxillary advancement with minimal adverse effects associated with the loss of dental anchorage (Baek et al., 2011). Furthermore, the elimination of dental extrusion, mandibular backward rotation, and maxillary canting and forward rotation could eliminate unnecessary orthodontic problems and stability issues in the future. Lastly, orthodontic en masse dental retraction or protraction can be aided with skeletally anchored devices simultaneously. Decompensation or correction of previous Class III dental compensation (e.g., upper labial flaring of incisors, lower anterior retroclination, tipping of posterior segments) can be facilitated more efficiently with skeletal anchorage devices (De Clerck & Swennen, 2011; De Clerck et al., 2009).

With this, the application of the bone-anchored maxillary protraction technique should be employed with utmost care and prudence. Questions remain about the stability of the outcome and the determination of force magnitude, application location, and direction of protraction. Significant clinician competence and patient compliance remain prerequisites in skeletally anchored maxillary protraction. In growing individuals with mild Class III malocclusion, mild to moderate maxillary retrognathism, normal mandibular position and length, normal or reduced vertical dimension, and little or no crowding, the well-documented technique of conventional, dental-anchored maxillary protraction, with or without a maxillary expansion appliance, may be indicated (Solano-Mendoza et al., 2012; Major et al., 2012). The skeletal and dentoalveolar effects of conventional maxillary protraction are tolerated and integrate into the existing dentofacial configuration with limited risks, provided proper compliance and retention protocols are maintained.

In growing individuals with severe Class III malocclusion, skeletal anchorage protocols employing miniplates with facemasks and miniplates with Class III elastics offer valid alternatives to conventional techniques. A facemask can be applied with miniplates attached to the lateral nasal walls of the maxilla. Mandibular symphyseal miniplates or TAD microscrews in the canine region can be engaged with Class III elastics to the posterior maxilla or a maxillary fixed or bonded appliance (De Clerck et al., 2010; Cevidanes et al., 2010). These two bone-anchored maxillary protraction protocols can have varied skeletal and dentoalveolar effects. Extra-oral traction with bone anchorage (facemask with maxillary plates) may be indicated in severe Class III cases with considerable maxillary retrognathism and a high-angle vertical growth pattern. This protocol allows optimal forward advancement of the maxilla with controlled vertical changes (Solano-Mendoza et al., 2012; Major et al., 2012).

In severe Class III cases with a normal or reduced vertical growth pattern and dental compensation (retroclined lower incisors and crowding), intraoral Class III elastics with miniplates or TAD microscrews may be indicated. Class III elastics allow maxillary protraction, mandibular retrusion, and mandibular teeth distalisation, which, together with mandibular backward rotation, will open the vertical dimension to allow overjet and overbite improvement as well as lower incisors proclination and upper incisors retroclination (Sar et al., 2011; Major et al., 2012).

Therefore, the application (force direction, application point, and direction) and effects of bone-anchorage protocols must be fully evaluated before implementation, and the magnitude of skeletal, dentoalveolar, and soft tissue changes should be considered, calculated, and controlled prior to therapy (Yan et al., 2013). Currently, the study of these morphological changes and their clinical relevance is scant and limited with 2D imaging techniques. Three-dimensional (3D) imaging, such as CBCT of facial structures, provides more comprehensive detail, and much research in this field is warranted to improve our understanding and application of skeletal anchorage devices (Nguyen et al., 2011; Hino et al., 2013).

Skeletally anchored orthopaedic techniques offer the possibility of pure skeletal correction and minimise dentofacial and dentoalveolar compensations associated with conventional dental anchorage techniques. However, literature data on the precise effects are scarce, and further studies should be encouraged to strengthen and reinforce scientific evidence-based research in this field.

Conclusions

Maxillary protraction therapy is a common orthodontic-orthopaedic treatment option for a growing individual with Class III malocclusion and a significant component of maxillary deficiency. Conventional techniques engaging on dental anchorage have resulted in limited maxillary improvement, unpredictable skeletal changes, undesirable dentoalveolar side effects and high relapse rate. The use of skeletal bone anchorage provides a clear advantage in maxillary protraction mechanics, as the orthopaedic forces, and their effects, are directed to the maxilla itself. This limits any undesirable skeletal and dental effects, resulting in greater maxillary improvement with little dental compensation. However, evidence-based research on this topic remains scarce and future studies should also focus on the optimal orthopaedic force, direction and long term evaluations to assess the stability of bone-anchored maxillary protraction.

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Not applicable.

Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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