Seminars in Orthodontics 000 (2023) 1–7

Contents lists available at ScienceDirect

Seminars in Orthodontics

journal homepage:

A clinician's perspective on indications and failures of bone-borne maxillary expanders

Biondi Guglielmo [a,*], Ludwig Björn [b], Mura Rossano [c], Di Leonardo Bruno [d], Adith Venugopal [e]

[a] Private Practice in Napoli and Vicenza, Italy, Corso Europa 26, 80127 Napoli (NA), Italy
[b] Instructor Department of Orthodontics, University of Homburg Saar Germany, Private Practice of Orthodontics in Traben-Trarbach, Germany, Am Bahnhof 54, 56841 Traben-Trarbach, Germany
[c] Private Practice in Arco, Italy, via Ovo 20, 38062 Arco (TN)
[d] Visiting Professor, Postgraduate Orthodontic Program, University of Trieste, Italy, Private Practice in Arco, Italy, via San Sisto 24B, 38062 Arco (TN), Italy
[e] Associate Professor, Department of Orthodontics, University of Puthisastra, Phnom Penh, Cambodia

ARTICLE INFO

Keywords:
Bone-borne maxillary expanders
Sutural fusion
Maturation stages
SARPE
RME
BONE BORNE EXPANSION failures
Patient-centered treatment

ABSTRACT

With the increasing popularity of bone-borne maxillary expansion in conferences, social media and publications, the promotion of the procedure may outpace the availability of high-quality evidence, leading to potential biases in its use. This paper offers a clinician's perspective on indications and failures in different age groups and stresses the importance of prioritizing diagnostics over appliance-centered treatment. Understanding individual variations in sutural fusion or similar diagnostic strategies will be increasingly crucial in identifying the appropriate expansion method. Depending on the patient's maturation stage, different types of expanders may be employed, utilizing various anchorage strategies, such as permanent or deciduous tooth-borne, bone-borne, hybrid, or surgically assisted expanders. The article provides clinical examples, discussing limited indications and age-related risk factors, and highlights failures to emphasize the importance of a patient-centered approach to treatment.

Introduction

Rapid maxillary expansion/ Rapid palatal expansion (RME/RPE) is a commonly employed orthodontic approach for treating posterior crossbites resulting from narrow maxillae, primarily of skeletal origin.[1] In recent times, there has been a surge in the popularity of bone-borne maxillary expanders, with increasing advocacy observed at conferences, social media platforms, and online forums. However, it is crucial to ensure that the utilization of this procedure is based on high-quality evidence, rather than being influenced by biases arising from its widespread promotion. This paper presents a clinician's perspective on the indications and failures associated with bone-borne expanders across different age groups, highlighting the significance of prioritizing diagnostics over appliance-centered treatment. A comprehensive understanding of individual variations in sutural fusion or comparable diagnostic techniques will be crucial in determining the most effective expansion strategy. Depending on the maturation stage of the patient, various types of expanders, including permanent or deciduous tooth-borne, bone-borne, hybrid, or surgically assisted expanders, may be considered, employing diverse anchorage strategies.[2]

The objective of this article is to provide clinicians with a critical outlook on bone-borne expanders, drawing from case studies and anecdotal evidence. In young children (pre-pubertal), where rapid maxillary expansion is indicated as an early orthodontic intervention, the circummaxillary sutures have not yet fused, rendering temporary anchorage devices unnecessary for achieving expansion.[2] Currently, there is insufficient evidence to support the notion that bone-borne expansion yields significantly superior outcomes compared to other expanders in young children. Therefore, it is not an evidence-based strategy, and its usage in this age group is discouraged. However, bone-borne expansion has garnered substantial evidence supporting its effectiveness in older age groups, particularly during adolescence (11-18 years), especially when combined with a facemask.[3–6] In adults, bone-borne expansion is feasible,[7–9] but without surgical intervention, it carries the risk of failure.[10] Consequently, diagnostic assessments should always precede the use of surgically assisted rapid palatal expansion (SARPE) to ensure its appropriateness. It is important to recognize that bone-borne expansion may have been overemphasized, and the available data supporting its efficacy may not be as compelling as commonly believed. Therefore, clinicians should exercise caution and carefully evaluate its indications (Fig. 1).

What are the components of bone-borne maxillary expanders?

Bone-borne maxillary expanders consist of three main components: expansion screws, anchorage units (which can be deciduous or

* Corresponding author at: 55, Street 180-184 Sangkat Boeung Raing, Khan Daun Penh, Phnom Penh, Cambodia.
E-mail address: brunodileonardo@gmail.com (B. Guglielmo).

https://doi.org/10.1053/j.sodo.2023.05.009

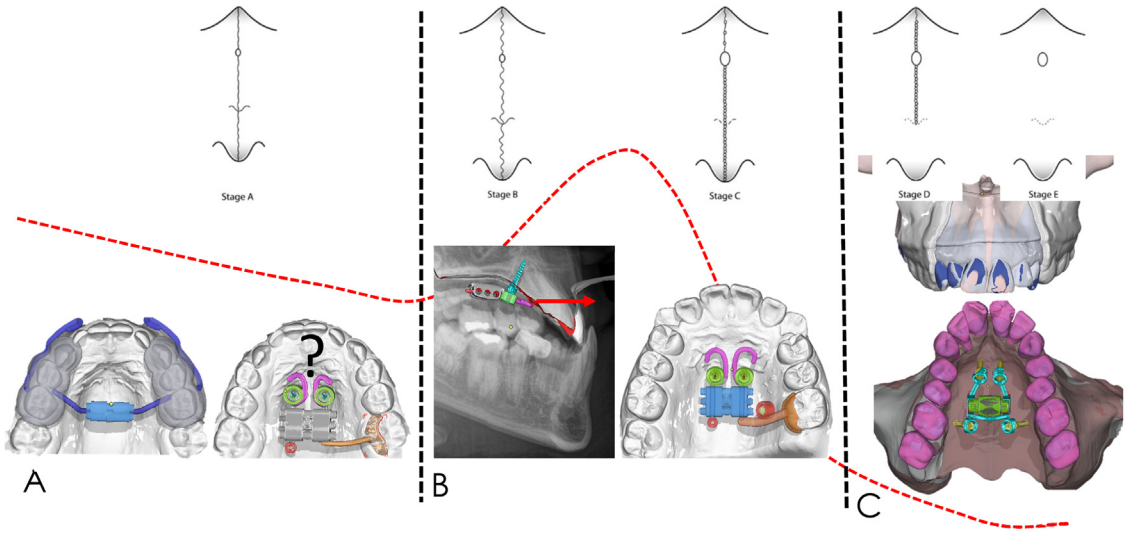

Fig. 1. Depicts the indications for utilizing bone-borne maxillary expanders at various stages of maturation

a) In the pre-pubertal Stage A, the consideration of bone borne expansion should be limited to two scenarios. Firstly, when combined with a facemask to prevent mesial drift of permanent teeth. Secondly, when there is a lack of dental anchorage due to early loss or agenesis. It is essential to always acknowledge the deciduous teeth as potential sources of anchorage, as they can be equally effective.

b) During Stages B and C, which coincide with the growth spurt, bone-borne expanders tend to offer advantages over other tooth-borne expanders.

c) For adults in sutural maturation stages D and E, it is recommended to employ a bone-borne expander alongside surgically assisted rapid palatal expansion (SARPE) to mitigate the risk of bone borne expansion failure.

permanent teeth or temporary anchorage devices [TADs]), and connecting elements that link the anchorage unit to the expander. The design of the anchorage unit, the positioning of the expander in relation to the center of resistance of the nasomaxillary complex, and the rigidity of the connecting elements all play a role in determining the outcome of the expansion. Initially, bone-borne expansion appliances were pre-formed and included an expansion appliance inserted initially, followed by two to four TADs. However, with advancements in digital technology, bone-borne expansion appliances can now be fully customized to meet the specific requirements of each patient.[11-14]

Why is it necessary to seek an alternative to conventional tooth-borne expanders?

According to Jia et al.,[15] bone-borne expansion exhibited a skeletal-to-dental expansion ratio nearly twice as high as that of the hyrax group. Another study[16] reported that tooth-anchored expanders achieved 2.5 times less expansion compared to miniscrew-supported expanders. Studies[17–19] have demonstrated that conventional rapid palatal expansion (RPE) often leads to changes in tooth axis or increased tooth inclination, primarily due to bending of the alveolar bone. The mechanical forces exerted by expansion appliances can cause bending of the alveolar bone and shrinkage of the periodontal membrane, resulting in inclination of anchor teeth.[19] The bone-borne expansion group exhibited significantly reduced tooth inclination compared to the conventional RPE group.[16] Additional miniscrews in bone-borne expansion appliances can bring the expansion force vector closer to the center of resistance, enabling adequate expansion with minimal tooth inclination, as suggested by Koo et al.[20] Lin et al.,[18] and Celenka et al.[16] also found that increased tooth tipping can lead to a reduction in alveolar bone height and thickness, while bone-borne expansion resulted in less buccal bone loss compared to conventional RPE.

Overall, conventional RPE may limit skeletal movement, increase dental tipping reduce buccal bone thickness, cause gingival recession due to marginal bone loss, and contribute to root resorption.[21–24] In contrast, bone-borne expanders offer several advantages, including more predictable skeletal expansion and fewer dental side effects, as previously mentioned.[3,15, 19]

Limitations, anatomy, timing, and staging

Despite the advantages of bone-borne expanders, it is crucial to acknowledge their limitations and carefully consider their indications, especially in different age groups. The development and maturity of circummaxillary sutures play a significant role in determining the suitability of bone-borne expanders.[25–27] The circummaxillary sutural system, which includes sutures such as zygomaticomaxillary, zygomaticotemporal, and pterygopalatine sutures, along with the maxillary buttresses (piriform aperture, zygomatic buttresses, and pterygoid junctions), act as the primary resistance zones for maxillary expansion.[28–30] Traditionally, growth and age were considered crucial factors for successful rapid maxillary expansion (RME).[1] However, recent studies have shown that chronological age is an unreliable indicator of suture morphology and structure. Therefore, studying individual variations in the developmental status of the mid-palatal suture is critical for identifying suitable candidates for RME and exploring less invasive alternatives to surgical-assisted rapid palatal expansion (SARPE).[31,32]

To establish the acceptability of bone-borne expansion treatment and identify individuals who may not benefit from it, it is important to understand the variations in mid-palatal suture fusion in individual patients. Angelieri et al. proposed a new classification for assessing individual mid-palatal suture morphology, based on cone beam computed tomography (CBCT) evaluation. This categorization provides five phases (from stage A to stage E) to better understand sutural fusion.[33] However, one potential disadvantage is the use of CBCT as a diagnostic technique on young children.

In young patients (pre-pubertal), where RME is indicated as an early orthodontic treatment (before the growth spurt), TADs are unnecessary for expansion, particularly in sutural maturation stages A and B.[2,34] Based on anecdotal evidence and limited experience, there may be two scenarios that warrant "early" bone-borne expansion. The first scenario is when it is used in conjunction with a facemask to prevent mesial drift of permanent teeth, and the second is when there is a lack of dental anchorage due to early loss or agenesis. These individual indications are not supported by high-level evidence and require responsible and patient-centered decision-making, taking into account the patient's risks, costs, and benefits. In cases where alternative use of

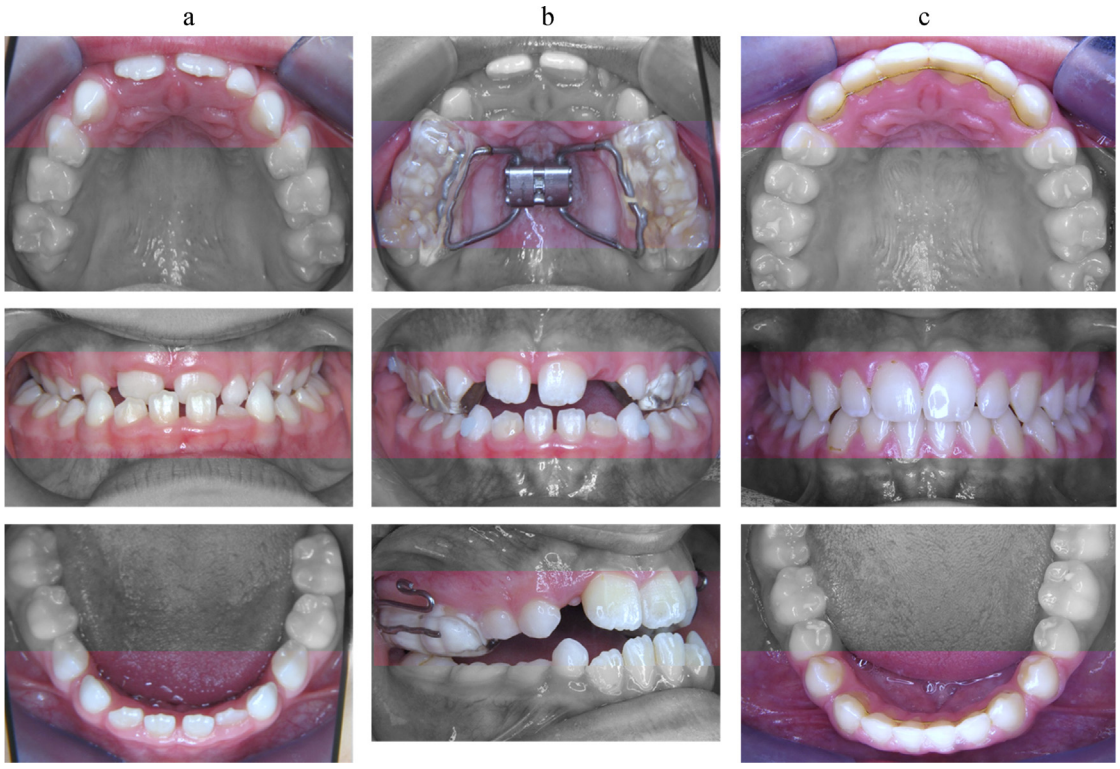

Fig. 2. Treatment of a class III malocclusion in a seven-year-old boy commenced with the use of a deciduous tooth-borne expander and a facemask. b) Following expansion, the patient achieved an improved occlusion. c) After a period of nearly seven years and a brief phase of bracket treatment, the patient continues to maintain a class I occlusal relationship with the assistance of a Fränkel III appliance as a retention device.

bone-borne expanders is considered, an informed consent process must be undertaken.

To illustrate the use of RME in the early mixed dentition, we present a case study utilizing a tooth-borne design supported by deciduous teeth. The aim is to expand the maxilla and use a facemask while avoiding mesial movement of permanent molars (Fig. 2).

In adolescents (11-18 years), the most common reason for using a bone-borne expander, especially in combination with a facemask, is to prevent molar mesial drift.[7] An illustrative case demonstrates a typical stage of bone-borne expansion treatment, likely stage "C." A 13-year-old boy with a pseudo class III malocclusion was treated using a two-implant-borne expander with palatal protraction arms, along with a fixed straight wire appliance with lower lingual bite ramps to facilitate the correction of the bite. Over a two-year follow-up period, the patient experienced improved occlusion that remained stable. The appliance was digitally designed and manufactured using selective laser melting (SLM) technology. Superimpositions of lateral cephalograms revealed significant improvement, particularly in the mandible (Fig. 3).

In adult patients (>18 years), several studies have shown that bone-borne expansion may lead to skeletal expansion.[7–9] However, these patients often fail to achieve mid-palatal suture opening, resulting in no or limited results. According to Sayar et al.,[10] inter-incisal opening is not a definitive marker of posterior region expansion, even in "D" maturation phases, leading to operational failure. Therefore, they suggest that surgical intervention may be more effective in opening the sutures at stages D and E.

The case study of adult bone-borne expansion involves a 35-year-old female patient with a previous history of orthodontic treatment. The patient presented with a maxillary transverse discrepancy of over 5mm. A cone beam computed tomography (CBCT) examination was performed to assess the suture maturation stage, revealing a D/E stage. Digital planning for temporary anchorage device (TAD) insertion guides was undertaken, followed by 3D printing. To address the transverse discrepancy, a bone-borne expander was utilized, followed by a fixed appliance to correct crowding and an open bite. Two surgical guides were created based on the planning, and four mini-implants were placed in a single visit to provide support for the bone-borne expander. However, the expansion process was terminated after 25 turns due to high resistance, inability to activate the appliance further, indications of implant movement through the bone, lack of stability, and patient discomfort. Post-expansion CBCT confirmed no improvement in occlusal or maxillary expansion. A surgical-assisted rapid palatal expander is planned after a brief rest period for the patient (Figs. 4 and 5).

Another case involved a 29-year-old female patient with a narrow maxilla and crossbite. Prior to treatment, a CBCT examination was performed to determine the patient's suture maturation stage, which was classified as D/E. Digital planning was used to design surgical guides, and a one visit protocol was used to correct the transverse discrepancy using a Bone Borne Expander and fixed appliance. During the same appointment, four TADs were inserted into the palate using two surgical guides. However, after 19 turns, the bone borne expander fractured, and no clinical improvements were observed. Post-treatment occlusal views and a follow-up examination confirmed the absence of maxillary expansion, likely due to the patient's D/E maturation stage. Therefore, a surgical-assisted rapid palatal expander is planned and will be performed after a short rest period. Figs. 6 and 7

Discussion

The authors of this article emphasize the relevance of a diagnostic approach to maxillary expansion rather than relying solely on appliance-driven strategies. It is common for doctors to immediately consider expanding the maxilla when a crossbite occurs, overlooking the fact that the mandible is often excessively broad.[35] Wiechmann has recently presented a unique dentoalveolar compensation technique involving both jaws and CAD/CAM expansion and compression archwires to treat posterior crossbites.[35]

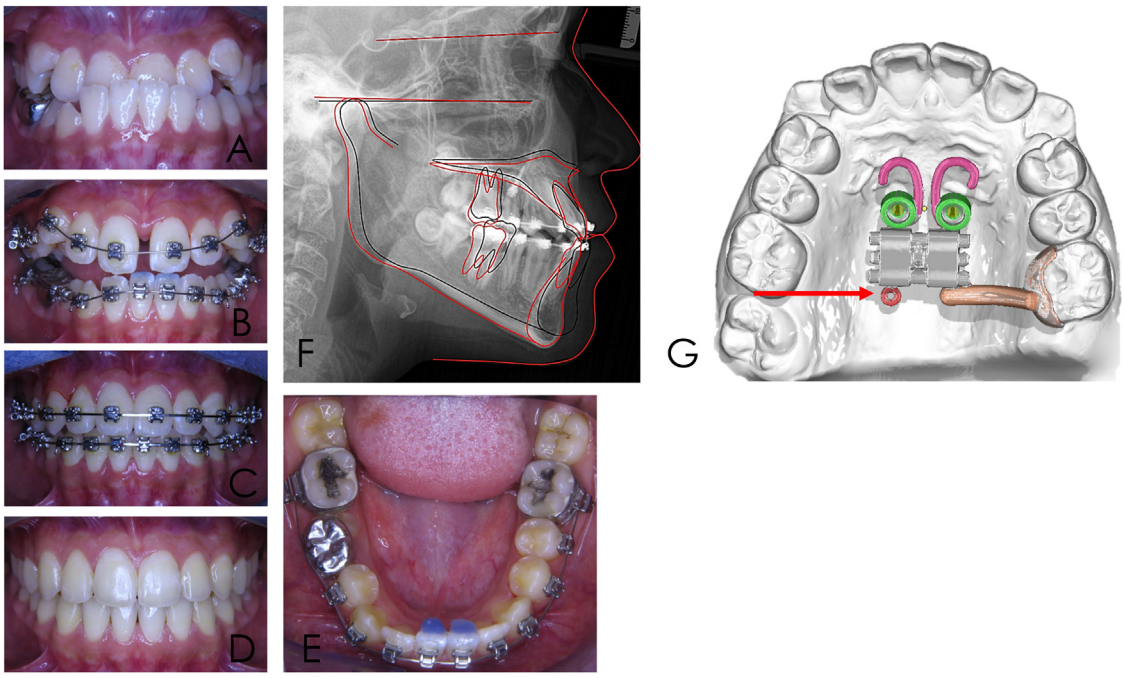

Fig. 3. a) A pseudo class III malocclusion was observed in a 13-year-old boy.
b) He received treatment using a 2-implant borne expander with palatal protraction arms to facilitate wearing a facemask at night.
c) After approximately 9 months, which included the use of a fixed straight wire appliance, the boy exhibited a good occlusion.
d) The situation remained stable after 2 years of retention.
e) To "jump" the bite, the boy was given anterior lingual bite stops.
f) Superimpositions of the lateral cephalograms showed a significant improvement in the pseudo class III malocclusion- interestingly mostly in the mandible
g) The bone borne expander was digitally planned and the appliance was 3D printed using SLM technology
Note that the appliances should be secured either by using an included loop and leash to teeth or by a molar bonding PAD, the hybrid hyrax way.

However, the most prevalent approach to treating posterior crossbites today is by widening the maxillary arch, with or without surgical assistance. The extent of transverse correction required often exceeds what can be achieved through dentoalveolar correction in the maxilla alone, leading to the frequent choice of approaches that include surgical assistance, such as surgically assisted rapid palatal expansion (SARPE) or bone-borne expansion, in adult patients with posterior crossbites.

Research studies utilizing histological and micro-CT techniques have shown that chronological age and gender are not reliable indicators of midpalatal suture fusion.[32,36,37] Complete fusion of the suture has been observed in 15-year-olds, while no signs of fusion have been found in 70-year-olds.[32,36] In light of this dilemma, Revelo and Fishman suggested individual assessments of mid-palatal sutures in all cases, regardless of age or gender, using occlusal radiographs.[38] However, artifacts caused by overlapping structures, such as the vomer and external nose,

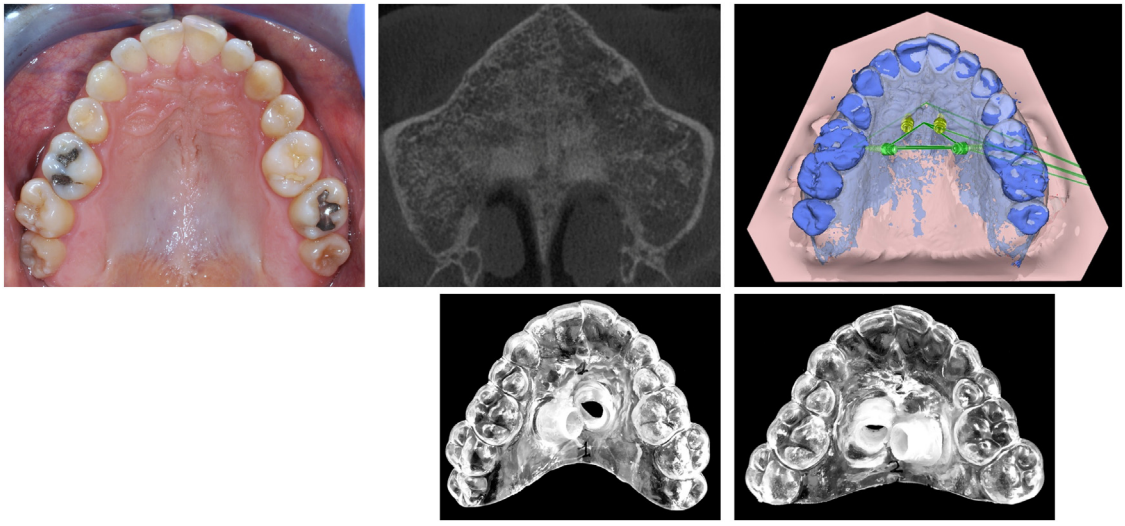

Fig. 4. A female patient, 35 years old, presented with mild anterior crowding in the upper and lower arch and a narrow maxilla. A pre-treatment CBCT examination was conducted to plan the implant position and assess suture maturation staging. Digital planning was utilized to design the placement of four implants, which were used to support and anchor the bone borne expander. Subsequently, surgical guides were created and 3D printed for use during the procedure.

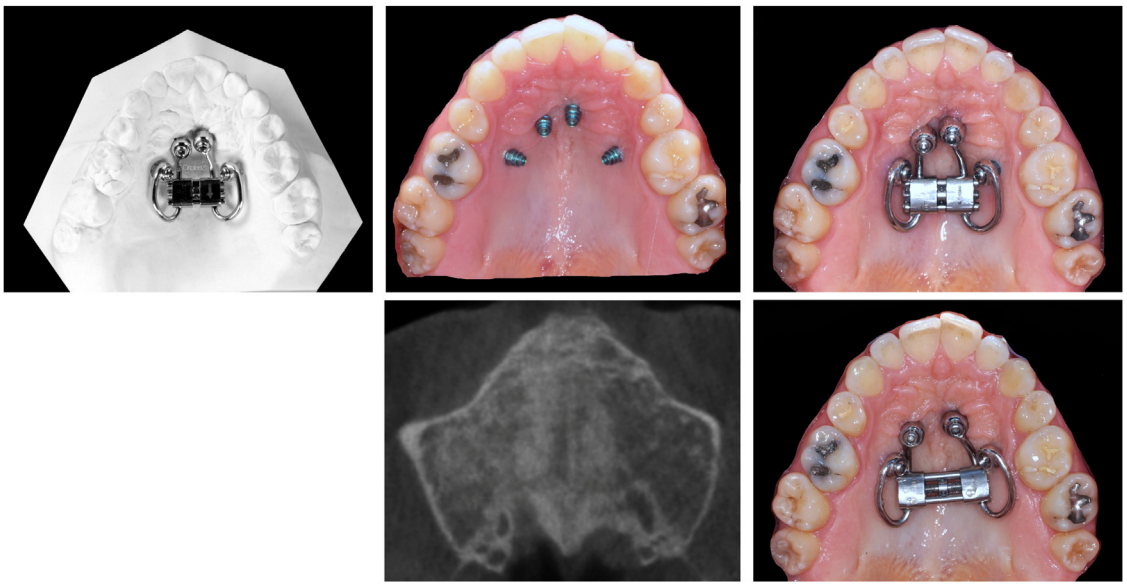

Fig. 5. The clinical procedure for the One-Visit Protocol involved implant placement and fitting of the bone borne expander in a single visit. Pre- and post-treatment occlusal views were compared, and a post-treatment CBCT examination was conducted. However, in this case (Stage E), the expansion procedure failed, and the appliance was deformed, resulting in implant movement without any expansion effect.

can make the diagnosis unreliable and lead to false interpretations.[31] CBCT imaging allows for three-dimensional visualization of the oral and maxillofacial structures, enabling evaluation of mid-palatal suture maturation without the overlay of external structures in the mid-palatal region.[39] Unfortunately, the use of CBCT in young children may present challenges.

In their CBCT study, Angieleri et al. reported that stage A was observed in early childhood (5 to 11 years of age), and stage B was mainly observed up to 13 years of age.[33] A study by Ludy Marileidy Jimenez-Valdivia et al. supported these findings and found a higher prevalence of stage C in the age group of 10-15 years. They also suggested an increased prevalence of stage C in females, indicating earlier maturation of the midpalatal suture in women compared to men. Grünheid et al. confirmed that suture density was the most important factor in predicting the skeletal effects of rapid maxillary expansion.[41] The fusion process of the mid-palatal suture begins with bone spicules from the suture margins and "islands" in the middle of the sutural gap. These spicules are present in multiple locations along the suture and increase with maturation.[42–44] The fusion of the palatine (Stage D) and/or maxillary portions (Stage E) of the mid-palatal suture provides resistance to the forces applied during conventional RME. Therefore, in these stages, particularly stage E, patients are more effectively treated using a surgical approach. Ludy Marileidy Jimenez-Valdivia et al. reported that 60% of subjects older than 18 years showed stages D and E, and the possibility of opening the suture in post-adolescents and young adults was approximately 20%.[40] It is also important to recognize that bone-borne expansion carries some risks. These include palate mucosa swelling or irritation, cleaning difficulties around the device, soft tissue

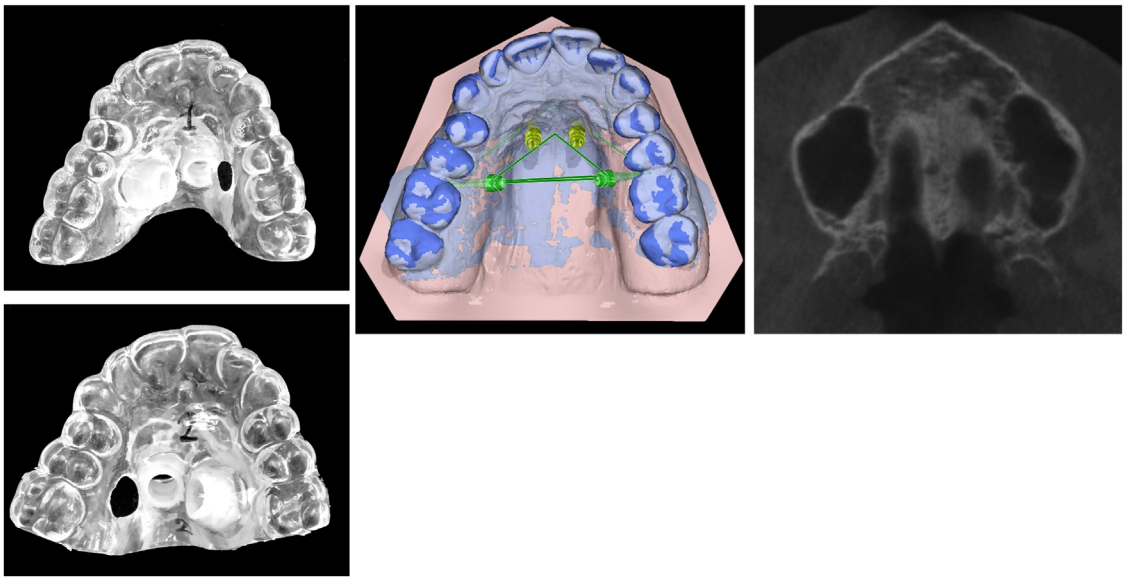

Fig. 6. This case presents a 29-year-old female patient with a narrow maxilla. Prior to treatment, a CBCT examination was conducted to assess the patient's maturation stage (Stage D/E) and digital planning was performed to design surgical guides for the procedure.

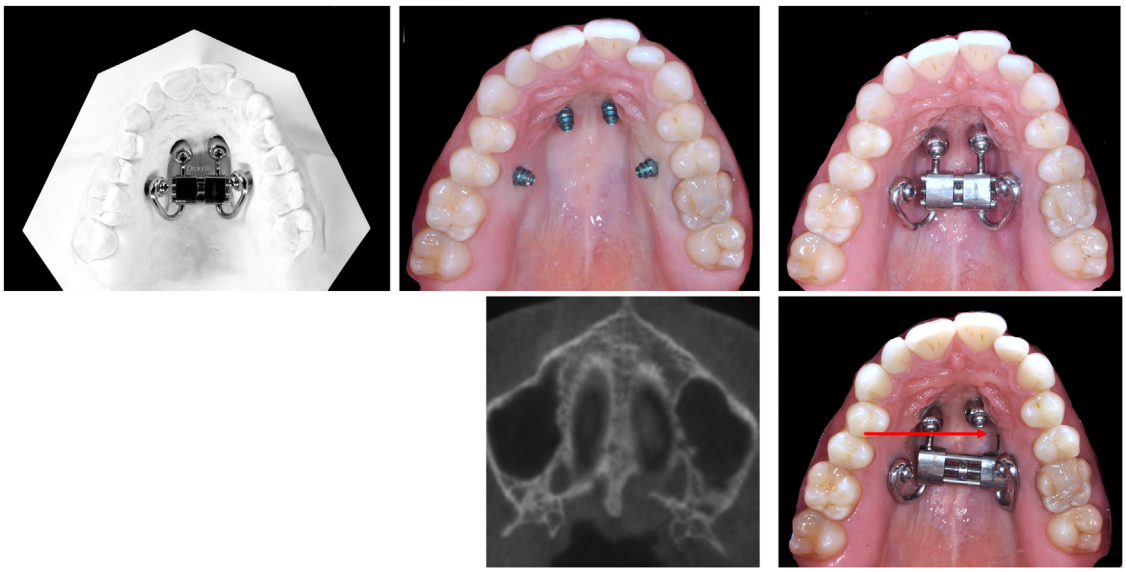

Fig. 7. The one visit protocol was applied but the appliance broke during treatment. Pre- and post-treatment occlusal view comparisons were conducted, followed by a post-treatment examination. However, all diagnostic records showed no expansion most likely due to the patient's D/E stage of maturation.

impingement, device distortion, tinnitus, micro implant loosening, sinusitis, failure of suture opening, and asymmetrical expansion.[45]

Conclusion

1. Diagnostics should take priority: Evaluating the density of the mid-palatal suture is crucial in determining the feasibility of performing rapid maxillary expansion in individuals of different ages. It is recommended that patients aged 15 and above undergo suture maturation staging, as younger patients can generally be assumed to be in stages A to C.
2. Indications for bone-borne maxillary expanders vary depending on the maturation stage

    - In pre-pubertal stages A, early consideration of bone-borne expansion should be limited to two scenarios: when combined with a facemask to prevent mesial drift of permanent teeth or when there is a lack of dental anchorage due to early loss or agenesis. Deciduous teeth should be regarded as potential sources of anchorage, as they can be equally effective.
    - During stages B and C, which occur around the growth spurt, bone-borne expanders tend to offer obvious advantages over other tooth-borne expanders.
    - For adults in sutural maturation stages D and E, it is recommended to use a bone-borne expander with surgically assisted rapid palatal expansion (SARPE) to avoid the risk of bone-borne expansion failure.

The authors emphasize that the emphasis on bone-borne expansion may be overstated, and the supporting data may not be as compelling as commonly believed. Therefore, clinicians should carefully assess the appropriate usage of bone-borne expanders.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

None

References

1. Bishara SE, Staley RN. Maxillary expansion: Clinical implications. *Am J Orthod Dentofacial Orthop*. 1987;91:3–14.
2. Kinzinger GSM, Lisson JA, Buschhoff C, et al. Impact of rapid maxillary expansion on palatal morphology at different dentition stages. *Clin Oral Invest*. 2022;26:4715–4725. https://doi.org/10.1007/s00784-022-04434-9.
3. Kapetanović A, Theodorou CI, Bergé SJ, Schols J, Xi T. Efficacy of miniscrew-assisted rapid palatal expansion (MARPE) in late adolescents and adults: a systematic review and meta-analysis. *Eur J Orthod*. 2021;43:313–323.
4. Choi SH, Shi KK, Cha JY, Park YC, Lee KJ. Nonsurgical miniscrew-assisted rapid maxillary expansion results in acceptable stability in young adults. *Angle Orthod*. 2016;86:713–720.
5. Eui-Hyang S, Sung-Hwan C, Hee-Jin K, Hyung-Seog Y, Young-Chel P. Evaluation of the effects of miniscrew incorporation in palatal expanders for young adults using finite element analysis. *Korean J Orthod*. 2018;48:81–89.
6. Shin H, Hwang CJ, Lee KJ, Choi YJ, Han SS, Yu HS. Predictors of midpalatal suture expansion by miniscrew-assisted rapid palatal expansion in young adults: a preliminary study. *Korean J Orthod*. 2019;49:360–371.
7. Brunetto DP, Sant'Anna EF, Machado AW, Moon W. Non-surgical treatment of transverse deficiency in adults using Microimplant-assisted Rapid Palatal Expansion (BONE BORNE EXPANSION). *Dental Press J Orthod*. 2017;22(2):110–125. https://doi.org/10.1590/2177-6709.22.2.110-125.oin. Mar-AprPMID: 28591289.
8. Lupini D, Retrouvey JM, Decesari D, Cozzani M. A tissue- and boneborne rapid palatal expander. *J Clin Orthod*. 2020;54(4):230–240. AprPMID: 32524702.
9. Suzuki H, Moon W, Previdente LH, Suzuki SS, Garcez AS, Consolaro A. Miniscrew-assisted rapid palatal expander (BONE BORNE EXPANSION): the quest for pure orthopedic movement. *Dental Press J Orthod*. 2016;21:17–23.
10. Sayar G, Kılınç DD. Rapid maxillary expansion outcomes according to midpalatal suture maturation levels. *Prog Orthod*. 2019;20:27.
11. Carlson C, et al. Microimplant-assisted rapid palatal expansion appliance to orthopedically correct transverse maxillary deficiency in an adult. *Am J Orthod Dentofacial Orthop*. 2016;149(5):716–728.
12. Lee RJ, Moon W, Hong C. Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. *Am J Orthod Dentofacial Orthop*. 2017;151(5):887–897.
13. Cantarella D, et al. A new methodology for the digital planning of micro-implant-supported maxillary skeletal expansion. *Med Devices (Auckl)*. 2020;13:93–106.
14. Ludwig B, Venugopal A, Wiechmann D, Nanda R. Boneborne rapid palatal expansion-the virtual way. *J Clin Orthod*. 2022;55(4):239–243. AprPMID: 35708986.
15. Jia H, et al. Comparison of skeletal maxillary transverse deficiency treated by micro-implant-assisted rapid palatal expansion and tooth-borne expansion during the post-pubertal growth spurt stage. *Angle Orthod*. 2021;91(1):36–45.
16. Celenk-Koca T, Erdinc AE, Hazar S, Harris L, English JD, Akyalcin S. Evaluation of miniscrew-supported rapid maxillary expansion in adolescents: a prospective randomized clinical trial. *Angle Orthod*. 2018;88:702–709. https://doi.org/10.2319/011518-42.1. [PMC free article] [PubMed] [Google Scholar].

17. Lim HM, Park YC, Lee KJ, Kim KH, Choi YJ. Stability of dental, alveolar, and skeletal changes after miniscrew-assisted rapid palatal expansion. *Korean J Orthod*. 2017;47:313–322. https://doi.org/10.4041/kjod.2017.47.5.313. [PMC free article] [PubMed] [Google Scholar].
18. Lin L, Ahn HW, Kim SJ, Moon SC, Kim SH, Nelson G. Tooth-borne vs bone-borne rapid maxillary expanders in late adolescence. *Angle Orthod*. 2015;85:253–262. https://doi.org/10.2319/030514-156.1. [PMC free article] [PubMed] [Google Scholar].
19. Huang X, Han Y, Yang S. Effect and stability of miniscrew-assisted rapid palatal expansion: a systematic review and meta-analysis. *Korean J Orthod*. 2022;52(5):334–344. https://doi.org/10.4041/kjod21.324. Jul 18PMID: 35844097; PMCID: PMC9512629.
20. Koo YJ, Choi SH, Keum BT, Yu HS, Hwang CJ, Melsen B, et al. Maxillomandibular arch width differences at estimated centers of resistance: comparison between normal occlusion and skeletal Class III malocclusion. *Korean J Orthod*. 2017;47:167–175. https://doi.org/10.4041/kjod.2017.47.3.167. [PMC free article] [PubMed] [Google Scholar].
21. Garib DG, et al. Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders: a computed tomography evaluation. *Am J Orthod Dentofacial Orthop*. 2006;129(6):749–758.
22. Schuster G, Borel-Scherf I, Schopf PM. Frequency of and complications in the use of RPE appliances—results of a survey in the Federal State of Hesse, Germany. *J Orofac Orthop*. 2005;66(2):148–161.
23. Erverdi N, Tosun T, Keles A. A new anchorage site for the treatment of anterior open bite: zygomatic anchorage. Case report. *World J Orthod*. 2002;3(2):147–153.
24. Akyalcin S, et al. A cone-beam computed tomography evaluation of buccal bone thickness following maxillary expansion. *Imaging Sci Dent*. 2013;43(2):85–90.
25. McNamara Jr JA. Long-term adaptation to changes in the transverse dimension in children and adolescents: an overview. *Am J Orthod Dentofacial Orthop*. 2006;129(Suppl):S71–S74.
26. Lee, SC, et al. Effect of boneborne rapid maxillary expanders with and without surgical assistance on the craniofacial structures using finite element analysis. Am J.
27. Priyadarshini J, Mahesh CM, Chandrashekar BS, Sundara A, Arun AV, Reddy VP. Stress and displacement patterns in the craniofacial skeleton with rapid maxillary expansion—a finite element method study. *Prog Orthod*. 2017;18(1):17. https://doi.org/10.1186/s40510-017-0162-1. DecPMID: 28662636; PMCID: PMC5490799.
28. Bell WH, Jacobs JD. Surgical–orthodontic correction of horizontal maxillary deficiency. *J Oral Surg*. 1979;37(12):897–902. DecPMID: 291754.
29. Chaconas SJ, Caputo AA. Observation of orthopedic force distribution produced by maxillary orthodontic appliances. *Am J Orthod*. 1982;82(5):492–501. https://doi.org/10.1016/0002-9416(82)90429-3. MayPMID: 6958417.
30. Sygouros A, Motro M, Ugurlu F, Acar A. Surgically assisted rapid maxillary expansion: cone-beam computed tomography evaluation of different surgical techniques and their effects on the maxillary dentoskeletal complex. *Am J Orthod Dentofacial Orthop*. 2014;146(6):748–757. hiips://doi.org/10.1016/j.ajodo.2014.09.012. DecPMID: 25432216.
31. Wehrbein H, Yildizhan F. The mid-palatal suture in young adults. A radiological-histological investigation. *Eur J Orthod*. 2001;23(2):105–114. https://doi.org/10.1093/ejo/23.2.105. MarPMID: 11307984.
32. Knaup B, Yildizhan F, Wehrbein H. Age-related changes in the midpalatal suture. A histomorphometric study. *J Orofac Orthop*. 2004;65(6):467–474. https://doi.org/10.1007/s00056-004-0363-8. NovPMID: 15586927.
33. Angelieri F, Cevidanes LHS, Franchi L, Gonçalves JR, Benavides E, McNamara Jr. JA. Midpalatal suture maturation: classification method for individual assessment before rapid maxillary expansion. *Am J Orthod Dentofacial Orthop*. 2013;144(5):759–769. https://doi.org/10.1016/j.ajodo.2013.06.016. NovPMID: 24182509.
34. Bazargani F, Jalalvand A, Shahidi S, Khojastepour L. Skeletal and dentoalveolar effects using tooth-borne and tooth-bone-borne RME appliances: a randomized controlled trial with 1-year follow-up. *European Journal of Orthodontics*. 2021;43(3):245–253.
35. Wiechmann D. Novel concept for posterior crossbite correction: preliminary results. *J Orofac Orthop.*. 2023. https://doi.org/10.1007/s00056-023-00468-0. May 4. English-Epub ahead of print. PMID: 37142772.
36. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. *Am J Orthod*. 1977;72:42–52.
37. Korbmacher H, Schilling A, Püschel K, Amling M, Kahl-Nieke B. Age dependent three-dimensional microcomputed tomography analysis of the human midpalatal suture. *J Orofac Orthop*. 2007;68:364–376.
38. Revelo B, Fishman LS. Maturational evaluation of ossification of the midpalatal suture. *Am J Orthod Dentofacial Orthop*. 1994;105:288–292.
39. De Vos W, Casselman J, Swennen GR. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. *Int J Oral Maxillofac Surg*. 2009;38:609–625.
40. Jimenez-Valdivia LM, Malpartida-Carrillo V, Rodríguez-Cárdenas YA, Dias-Da Silveira HL, Arriola-Guillén LE. Midpalatal suture maturation stage assessment in adolescents and young adults using cone-beam computed tomography. *Prog Orthod*. 2019;20:38.
41. Grünheid T, Larson CE, Larson BE. Midpalatal suture density ratio: a novel predictor of skeletal response to rapid maxillary expansion. *Am J Orthodont Dentof Orthoped*. 2017;151(2):267–276. https://doi.org/10.1016/j.ajodo.2016.06.057.
42. Persson M, Magnusson BC, Thilander B. Sutural closure in rabbit and man: a morphological and histochemical study. *J Anat*. 1978;125(2):313–321. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1232287/.
43. Cohen Jr, MM (1993). Sutural biology and the correlates of craniosynostosis. Am J Med Genet, 47 (5), 581-616. hiips://doi.org/10.1002/ajmg.1320470505.
44. Melsen B. A histological study of the influence of sutural morphology and skeletal maturation on rapid palatal expansion in children. *Transact Eur Orthodont Soc*. 1972:499–507.
45. Tsai H-R, Ho K-H, Wang C-W, Wang K-L, Hsieh S-C, Chang H-M. Evaluation of patients' experiences after microimplant-assisted rapid palatal expansion (MARPE) treatment. *Taiw J Orthodont*. 2021;33. https://doi.org/10.38209/2708-2636.1098. Iss. 1, Article 2.