Procedure using CAD/CAM-manufactured insertion guides for purely mini-implant-borne rapid maxillary expanders

Benedict Wilmes1 · Nour Eldin Tarraf2 · Renzo de Gabriele3 · Gianluca Dallatana4 · Dieter Drescher1

Received: 11 July 2019 / Accepted: 15 December 2021 / Published online: 21 February 2022
© The Author(s) 2022

Abstract
With traditional rapid palatal expansion (RPE), orthopaedic forces are transmitted to the skeletal structures via the anchor teeth potentially leading to several unwanted dental side effects. To prevent these issues, tooth–bone-borne or purely bone-borne expanders were introduced using mini-implants in the palate. In this paper, the digitally planned Quadexpander is described which permits palatal expansion with only skeletal anchorage. The use of virtual insertion planning allows for insertion in areas of ideal bone, while avoiding roots and vital structures as well as the possibility of insertion into sites which would otherwise not be considered usable. A second advantage of digital planning is that mini-implants and the expander can be inserted in just one appointment.

Keywords Rapid maxillary expansion · Temporary anchorage device · Skeletal anchorage · Mini-implants · Quadexpander

Introduction
Rapid palatal expansion (RPE) was first described by Angle [1] in 1860 and has been widely used to skeletally expand the maxilla. The orthopaedic forces are transmitted to the skeletal structures via the anchor teeth, which may lead to several unwanted dental side effects such as buccal tipping, fenestration of the buccal bone, root resorption, and gingival recessions even in children [2, 5, 7, 25].
adults, resistance to expansion is too high and osteotomies were advocated to facilitate skeletal expansion and reduce the stress on the anchor teeth. However the dental side effects are reduced but not eliminated [8, 22]. To overcome these drawbacks, Mommaerts proposed the purely bone-borne transpalatal distractor (TPD) [9, 14, 19]. However, insertion and removal of these miniplate-borne distractors involves invasive surgical procedures with the need for flap preparation, risk of root injury and infections [9–11, 27].

In recent years, mini-implant supported RPE (MARPE, microimplant-assisted rapid palatal expansion) such as the Hybrid Hyrax [28, 29] and the MSE (maxillary skeletal expander [4, 18]) allow for the load of the expansion to be shared between two or four mini-implants in the palate and two first molars, greatly reducing the dental side effects of RPE and early class III maxillary protraction [20, 21, 30, 31] with minimally invasive placement procedures [3]. However, when expansion is desired in mature individuals it is preferable to avoid any loading of the dentition as the loads transmitted to the teeth would be extreme in case of undetected mini-implant failure during expansion.

Mini-implants have a high success rate in the anterior palate when inserted in the so-called T-zone [12, 17, 32], the area of the bicuspids median or paramedian. This area provides good bone quality and minimal risk of injury to nerves, vessels or roots. However, further posteriorly in the molar area, bone availability is limited paramedian to the suture and mini-implants may be inserted palatally in the alveolar process between the first molar and second premolar [13, 17, 32]. In this area, safe insertion without root damage is crucial. The use of a mini-implant placement guide [6, 33], akin to those used in the placement of dental implants, would significantly aid risk-free mini-implant placement as well as allow the prefabrication of the pure bone-borne expander with four mini-implants (Quadexpander).

Materials and methods

Virtual planning of the mini-implant position and manufacturing of a Quadexpander

Step 1: An STL file of the upper jaw is obtained either via an intraoral scan or a scan of a study model produced using a high-quality silicon impression. The surface mesh of the upper jaw is superimposed with a cone beam computed tomography image to identify an optimal site for mini-implant placement. The superimposition is performed using proprietary software (Easy Driver V 2.0.2019, Unioentech, Parma, Italy) in a two-step process, whereby firstly three common points between the CBCT (Cone beam computed tomography) and the surface mesh are identified and then the cross sections of the digital model and CBCT are matched to produce an accurate superimposition.

Step 2: The virtual planning software is then used to confirm the precise anatomical positioning of the TADs. The employed software allows for the virtual planning and placement of TADs in a variety of lengths and diameters and for the ideal positioning of the screws according to the anatomical variations of each patient. The CBCT allows a three-dimensional orientation to select an area with optimal bone quantity and quality. Using different filters, it is possible to set the level of transparency and to clearly determine the ideal TAD placement.

Step 3: Once the position of the mini-implants is finalized, a 3D printed model is created from the virtual model with the planned mini-implant positions represented by laboratory implant analogues. These steps are done using the software Easy Driver V 2.0.2019 (Unioentech, Parma, Italy, patent protected). The analogues are inserted manually in the marked locations in a 3D printed model or transferred to a plaster model in the orthodontic laboratory. The Quadexpander is then manufactured on this model using a preformed screw (Power Expander, Tiger Dental, Bregenz, Austria) welded to four preformed rings (PSM, Gunningen, Germany) which are positioned on the laboratory TAD analogues and connected to the expansion screw while bending the arms and adapting it to the shape of the palate.

Step 4: The insertion guide is virtually designed around the mini-implant positions and then printed from a biocompatible resin VeroGlaze Med 620 (Seido-Systems, Kortrijk, Belgium) using a 3D printer (Stratasys LTD, Eden Prairie, MN, USA). Intraorally, this guide allows a precise location of the mini-implants. Removable sleeves in the shape of precise cylinders (peek material, brown color) are additionally employed to ensure precise coupling with the mini-implant driver for accurate insertion.

Step 5: Mini-implants with an inner thread (2.3 mm diameter, Benefit, PSM, Gunningen, Germany) are inserted through the surgical guide using a contra-angle screwdriver. A special mini-implant insertions kit including the removable sleeves is used, which is designed to precisely fit into the insertion guide cylinders to ensure correct transfer of the planned mini-implant position very similar to what is used with dental implant placement guides.

Step 6: At the same appointment, the prefabricated Quadexpander is fitted to the four mini-implants using four fixation screws (Benefit system, PSM, Gunningen, Germany) and expansion can commence.
Clinical example 1

An 18-year-old male patient presented with a transverse maxillary deficiency due a narrow maxilla (Fig. 1). Because of the relatively mature age of the patient for conventional palatal expansion and buccal recessions, a purely bone-borne expansion appliance was chosen using orthodontic mini-implants. For the described planning procedure, a CBCT was obtained and superimposed with the digital model. The anterior and posterior optimal positions of the mini-implants were digitally planned (Fig. 2). Subsequently, the insertion guides were produced by the described computer-aided design/computer-aided manufacturing (CAD/CAM) procedure (Fig. 3). The mini-implants and the Quadexpander (with a “Power expander”, Tiger Dental, Bregenz, Austria) were inserted in the same session (Fig. 4). The patient was instructed to turn the expander twice per day resulting in a daily activation of 0.34 mm per day (2 × 0.17 mm). After 30 days, sufficient expansion was achieved (Fig. 4).

Clinical example 2

A 22-year-old male patient presented with a narrow maxilla and buccal recessions (Fig. 5). A Quadexpander with 4 mini-implants was chosen to perform RPE without invasive surgery. The CBCT was superimposed with the digital model for the virtual positioning of the mini-implants (Fig. 6). Subsequently, the insertion guides were produced (Fig. 7). The mini-implants and the Quadexpander were inserted in the same session (Fig. 8). The patient was instructed to turn the expander twice per day resulting in a daily activation of 0.34 mm per day (2 × 0.17 mm). When the maximum capacity of the expander was reached, the
nut was exchanged chairside to continue the expansion. After 32 days, a sufficient expansion was achieved (Fig. 8).

**Discussion**

When attempting rapid maxillary expansion in an adult patient, the resistance to expansion is substantially increased. With the advent of mini-implants, a minimally invasive expansion has been introduced in older teenagers and adults (MARPE). The Quadexpander is a purely bone-borne mini-implant supported maxillary expansion appliance. This eliminates the risk of the anchorage teeth being damaged in case of undetected mini-implant failure. Due to the very thin cortical bone support in the paramedian areas of the posterior palate this insertion area was dismissed. Even though this is an area where MSE [4, 18] screws are placed, the MSE appliance shares the load of expansion with the posterior teeth and it is difficult to estimate the

---

**Fig. 3** Insertion guide (Seido-Systems, Kortrijk, Belgium; Stratasys LTD, Eden Prairie, MN, USA) for case 1: insertion site, depth and angulation are predetermined

**Abb. 3** Insertionsguide (Seido-Systems, Kortrijk, Belgien; Stratasys LTD, Eden Prairie, MN, USA) für Fall 1: Insertionsregion, -tiefe und -winkel sind vorgegeben

**Fig. 4** Clinical procedure of case 1: a Quadexpander with a Power Screw (Tiger Dental, Bregenz, Austria), b temporary anchorage devices (Benefit System, PSM, Gunningen, Germany) after insertion. c,d Before and after expansion

**Abb. 4** Klinischer Verlauf, Fall 1: a Quadexpander mit einer PowerScrew (Tiger Dental, Bregenz, Österreich), b temporäre Verankerungen (Benefit System, PSM, Gunningen, Deutschland) nach dem Einsetzen. c,d Vor und nach Erweiterung

**Fig. 5** Transversal maxillary deficiency in a 22-year-old patient (case 2)

**Abb. 5** Transversale maxilläre Hypoplasie bei einem 22-jährigen Patienten (Fall 2)
real contribution of the posterior mini-implants in actual load bearing and how much of that load is transmitted to the molars. The Quadexpander eliminates this risk by being purely bone-borne. Success of all the mini-implants is crucial when the expander is purely implant-borne as not only will the mini-implants bear the load during the expansion phase but also during the retention period which is likely to be several months for an adult. As a consequence, to avoid any risk of root proximity or injury, insertion guides are proposed for the TAD placement. Insertion guides are now widely used in the placement of prosthetic dental implants [26]. Static computer aided guided surgery (s-CAIS), static implant guides are the most commonly used type [23]. The clinician can gain insight into the placement site, bone quality as well as any anatomical variations. This pre-operative planning allows the clinician to have some peace of mind during the procedure and he or she can focus more on tissue handling and patient management. Most of the guides used in prosthodontic implants use specifically designed implant placement kits [24], which couple pre-
cisely with the drill and placement guides the equivalent of which was not available with orthodontic mini-implant kits. In fact, to date such guides have not been widely used with orthodontic mini-implant placement although there have been several attempts using prebent wire guides in combination with conventional mini-implant placement tools, which do not provide a great degree of precision. The Easy Driver system, however, provides a specifically designed mini-implant placement kit designed to fit the placement guides with very little tolerance, akin to those used with dental implants to allow precise insertion of the mini-implants into the planned position. By preplanning

the position of the implant placement, the area with the best bone can be selected. In addition, using the CBCT as a guide, allows for the use of an implant that not only engages the palatal cortical plate but also the floor of the nose allowing for bicortical engagement, further increasing the primary stability [16] and success of the TADs. Furthermore, the use of a precise placement guide could allow for safe insertion of TADs in the presence of palatally impacted canines or unerupted teeth discovered in late teen or young adults. Studies have also shown that proximity of TADs to tooth roots can predispose TAD failure [15]. The diameter of the TAD can then be varied as well. Several types of expanders have been proposed in the literature using TADs. The described 4-screw expander (Quadexpander) permits safe and easy insertion of the TADs even by orthodontists without much experience in mini-implant insertion. The mini-implant and expander insertion can be done in one clinical session saving significant chair time. Compared to the MSE [4, 18] appliances employment of insertion guides allows high flexibility in the placement of the TADs to ensure all four mini-implants are placed in the best quality bone as opposed being restricted by the fact the screws with MSE must follow the outline of the prefabricated expansion screw which may place one or more screws in an area with lesser bone quality.

The Quadexpander can be used in adolescents and adults, as well as in patients with missing teeth. Since teeth are not needed as anchorage units, this approach might be interesting especially for patients with periodontically compromised teeth, e.g. buccal recessions. Furthermore, it is possible to use the 4-screw expander in conjunction with a surgically assisted RME especially in periodontally com-

---

**Fig. 7** Insertion guide (Seido-Systems, Kortrijk, Belgium; Stratasys LTD, Eden Prairie, MN, USA) for case 2: insertion site, depth and angulation are predetermined

**Abb. 7** Insertionsguide (Seido-Systems, Kortrijk, Belgien; Stratasys LTD, Eden Prairie, MN, USA) für Fall 2: Insertionsstelle, -tiefe und -winkel sind vorgegeben
promised patients, or if the expansion does not progress in older adults by performing a minimally invasive bilateral corticotomy. The fact that the appliance does not include any teeth means that tooth movement can be started independent of the expansion and the retention period required. This seems to be especially relevant if aligners should be used in the second phase of the orthodontic treatment [34]. A further advantage could be in cases where the orthodontist is not willing to place the TADs and the patient is referred to an oral surgeon. By providing the placement guides the orthodontist can be confident that the TADs will be in the desired locations.

The need for additional radiation exposure from a CBCT to manufacture the insertion guides is a disadvantage. However, in the selected cases where this type of expansion is required it can be justified. The following indications can be considered for the digitally planned Quadexpander:

- Minimally invasive skeletal maxillary expansion in older adolescents and adults.
- Maxillary expansion in cases with multiple missing teeth.
- Maxillary expansion in the presence of a periodontally compromised dentition, e.g. when buccal recessions are diagnosed.
- Safe placement of mini-implants for expansion in cases with palatally impacted teeth.

**Conclusion**

To overcome issues of tooth-borne expanders in older adolescents and adults, digitally planned Quadexpander can be employed which permit palatal expansion with only skeletal anchorage. The use of virtual insertion planning allows for insertion in areas of ideal bone while avoiding root damage. A second advantage of digital planning is that mini-implants and the expander can be inserted in just one appointment.

**Funding** Open Access funding enabled and organized by Projekt DEAL.

**Conflict of interest** B. Wilmes, N.E. Tarraf and D. Drescher declare that they provide courses on mini-implant use in orthodontics. R. de Gabriele and G. Dallatana declare that they are co-inventors of the Easy Driver system.

**Ethical standards** All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

**References**

1. Angell EC (1860) Treatment of irregularities of the permanent or adult teeth. Dent Cosmos 1(540–544):599–601
2. Barber AF, Sims MR (1981) Rapid maxillary expansion and external root resorption in man: a scanning electron microscope study. Am J Orthod 79(6):630–652
3. Bazargani F, Magnuson A, Ludwig B (2018) Effects on nasal airflow and resistance using two different RME appliances: a randomized controlled trial. Eur J Orthod 40(3):281–284
4. Brunetto DP, Sant’Anna EF, Machado AW, Moon W (2017) Non-surgical treatment of transverse deficiency in adults using Microimplant-assisted Rapid Palatal Expansion (MARPE). Dental Press J Orthod 22(1):110–125
5. Carmen M, Marcella P, Giuseppe C, Roberto A (2000) Periodontal evaluation in patients undergoing maxillary expansion. J Craniomaxillofac Surg 11(5):491–494
6. De Gabriele O, Dallatana G, Riva R, Vasudavan S, Wilmes B (2017) The easy driver for placement of palatal mini-implants and a maxillary expander in a single appointment. J Clin Orthod 51(11):728–737
7. Garib DG, Henriques JF, Janson G, de Freitas MR, Fernandes AY (2006) Periodontal effects of rapid maxillary expansion with tooth-tissue-borne and tooth-borne expanders: a computed tomography evaluation. Am J Orthod Dentofacial Orthop 129(6):749–758
8. Glassman AS, Nahigian SJ, Medway JM, Aronowitz HI (1984) Conservative surgical orthodontic adult rapid palatal expansion: sixteen cases. Am J Orthod 86(3):207–213
9. Hansen L, Tausche E, Hietschold V, Hotan T, Lagravere M, Harzer W (2007) Skeletally-anchored rapid maxillary expansion using the Dresden Distractor. J Orofac Orthop 68(2):148–158
10. Harzer W, Schneider M, Gedrange T (2004) Rapid maxillary expansion with palatal anchorage of the hyrax expansion screw—pilot study with case presentation. J Orofac Orthop 65(5):419–424
11. Harzer W, Schneider M, Gedrange T, Tausche E (2006) Direct bone placement of the hyrax fixation screw for surgically assisted rapid palatal expansion (SARPE). J Oral Maxillofac Surg 64(8):1313–1317
12. Hourfar J, Kanavakis G, Bister D et al (2015) Three dimensional anatomical exploration of the anterior hard palate at the level of the third ruga for the placement of mini-implants—a cone-beam CT study. Eur J Orthod 37(6):589–595
13. Hourfar J, Ludwig B, Bister D, Braun A, Kanavakis G (2015) The most distal palatal ruga for placement of orthodontic mini-implants. Eur J Orthod 37(4):373–378
14. Koudstaal MJ, van der Wal KG, Wolvius EB, Schulten AJ (2006) The Rotterdam Palatal Distractor: introduction of the new bone-borne device and report of the pilot study. Int J Oral Maxillofac Surg 35(1):31–35
15. Kuroda S, Yamada K, Deguchi T, Hashimoto T, Kyung HM, Takano-Yamamoto T (2007) Root proximity is a major factor for screw failure in orthodontic anchorage. Am J Orthod Dentofacial Orthop 131(4 Suppl):S68–S73
16. Lee RJ, Moon W, Hong C (2017) Effects of monocortical and bicortical mini-implant anchorage on bone-borne palatal expansion using finite element analysis. Am J Orthod Dentofacial Orthop 151(5):887–897
17. Ludwig B, Glasl B, Bowman SI, Wilmes B, Kinzinger GS, Lison JA (2011) Anatomical guidelines for miniscrew insertion: palatal sites. J Clin Orthod 45(8):433–441
18. MacGinnis M, Chu H, Youssef G, Wu KW, Machado AW, Moon W (2014) The effects of micro-implant assisted rapid palatal expansion (MARPE) on the nasomaxillary complex—a finite element method (FEM) analysis. Prog Orthod 15:52
19. Mommaerts MY (1999) Transpalatal distraction as a method of maxillary expansion. Br J Oral Maxillofac Surg 37(4):268–272
20. Ngan P, Wilmes B, Drescher D, Martin C, Weaver B, Gunel E (2015) Comparison of two maxillary protraction protocols: tooth-borne versus bone-anchored protraction facemask treatment. Prog Orthod 16:26
21. Nienkemper M, Wilmes B, Pauls A, Drescher D (2013) Maxillary protraction using a hybrid hyrax—facemask combination. Prog Orthod 14(5):1–8
22. Pogrel MA, Kaban LB, Vargervik K et al (1992) Surgically assisted rapid maxillary expansion in adults. Int J Adult Orthod Orthognath Surg 7(1):37–41
23. Pozzi A, Tallarico M, Marchetti M, Scarfo B, Esposito M (2014) Computer-guided versus free-hand placement of immediately loaded dental implants: 1-year post-loading results of a multicentre randomised controlled trial. Eur J Oral Implantol 7(3):229–242
24. Pozzi A, Polizzi G, Moy PK (2016) Guided surgery with tooth-supported templates for single missing teeth: A critical review. Eur J Oral Implantol 9(Suppl 1):S135–S153
25. Schuster G, Barel-Scherf I, Schopf PM (2005) Frequency of and complications in the use of RPE appliances—results of a survey in the Federal State of Hesse, Germany. J Orofac Orthop 66(2):148–161
26. Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C (2018) The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. Clin Oral Implants Res 29(Suppl 16):416–435
27. Verstraeten J, Kuijpers-Jagtman AM, Mommaerts MY et al (2010) A systematic review of the effects of bone-borne surgical assisted rapid maxillary expansion. J Craniomaxillofac Surg 38(3):166–174
28. Wilmes B, Drescher D (2008) A miniscrew system with interchangeable abutments. J Clin Orthod 42(10):574–580 (quiz 595)
29. Wilmes B, Nienkemper M, Drescher D (2010) Application and effectiveness of a mini-implant- and tooth-borne rapid palatal expansion device: the hybrid hyrax. World J Orthod 11(4):323–330
30. Wilmes B, Nienkemper M, Ludwig B, Kau CH, Drescher D (2011) Early class III treatment with a hybrid hyrax-mentoplast plate combination. J Clin Orthod 45(1):1–7
31. Wilmes B, Ngan P, Liou EJ, Franchi L, Drescher D (2014) Early class III facemask treatment with the hybrid hyrax and Alt-RAMEC protocol. J Clin Orthod 48(2):84–93
32. Wilmes B, Ludwig B, Vasudavan S, Nienkemper M, Drescher D (2016) The T-Zone: median vs. paramedian insertion of palatal mini-implants. J Clin Orthod 50(9):543–551
33. Wilmes B, Vasudavan S, Drescher D (2019) CAD-CAM-fabricated mini-implant insertion guides for the delivery of a distalization appliance in a single appointment. Am J Orthod Dentofacial Orthop 156(1):148–156
34. Wilmes B, Tarraf N, Drescher D (2021) Treatment of maxillary transversal deficiency by using a mini-implant-borne rapid maxillary expander and aligners in combination. Am J Orthod Dentofacial Orthop 160(1):147–154

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.