

CAD/CAM design and 3D printing of a personalised rapid palatal expander for maxillary transverse deficiency

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Abstract

Bone-borne rapid maxillary expansion appliances can achieve skeletal expansion while avoiding the undesirable dental side effects caused by a conventional rapid palatal expansion appliance. Typically, these (bone-borne appliances) included prefabricated devices, which can have limitations such as inadequate palatal adaptation leading to anchorage loss. In addition, as bone thickness is not accounted for, prefabricated expanders cannot ensure the primary stability of the mini-implants. These disadvantages can be overcome by customisation. This report aims to describe the digital design and three-dimensional printing workflow for constructing a personalised Miniscrew-assisted rapid palatal expansion (pMARPE) and present a case depicting its application in a 27-year-old female with 5.0 mm transverse discrepancy between the maxilla and the mandible. The result demonstrated that the pMARPE could be manufactured without the need for conventional impression or laboratory procedures and effectively expanded the palate of an adult patient with maxillary transverse deficiency.

Keywords: Bone-borne rapid maxillary expansion, Maxillary transverse deficiency, Personalised, Mini-implants.

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Introduction

Maxillary transverse deficiency (MTD) often manifests as unilateral or bilateral posterior cross-bite, crowded dentition, an exaggerated curve of Wilson, buccal tipping of maxillary molars, and lingual tipping of mandibular molars. MTD can have a significant impact on facial growth and development, cause unstable occlusion, and deteriorate with age. Therefore, it's important to treat it as soon as possible once it's been diagnosed. Its treatment includes rapid maxillary expansion (RME), which produces skeletal widening of the maxilla by the opening of the mid-

palatal suture without significant dental movement. Age plays an important role in the ease of maxillary expansion as suture fusion increases after adolescence, which can result in lower efficacy of tooth-borne RME devices in adults. Additionally, tooth-borne maxillary expansion devices can produce undesirable effects such as tooth tipping, a decrease in buccal bone thickness, and loss of marginal bone height, especially when used in adults due to high levels of suture maturation.¹ Bone-borne RME devices exert primarily orthopaedic forces, producing skeletal movement and minimising undesirable dental side effects, so these are particularly useful in adult patients. Miniscrew-assisted rapid palatal expansion (MARPE) appliances, typically utilising two to four mini-implants, have been developed and successfully applied for maxillary expansion with minimal damage to the dental and periodontal tissues. These typically included various prefabricated MARPE appliances.² Conventional steps for the fabrication of prefabricated expanders include dental impressions and laboratory construction on stone models, and the placement of mini-implants that serve as temporary anchorage devices. Prefabricated expanders can, however, have several limitations. The construction process doesn't consider bone quality and dimensions at the planned insertion sites as 3-dimensional (3D) bone imaging is not incorporated, which can compromise the accuracy of mini-implant insertion, leading to loss of anchorage.³ Besides, the morphology of the palate can vary widely across individuals and the prefabricated expanders might insufficiently adapt to the palate, especially in high and narrow vault cases. The suitability of prefabricated expanders for patients with narrow palatal vaults has thus been questioned, considering the likelihood of mini-implant deviation or tipping and the consequent risk of failure of palatal expansion. With the rapid advent of digital workflows and three dimensional imaging, including Cone-Beam Computed Tomography (CBCT), customisation of RME appliances has become possible, offering means to avoid the pitfalls of prefabricated expanders, with improved safety, accuracy, and treatment outcomes.^{4,5} Digital workflow-based customised MARPE appliances have been successfully applied in cases with thin palatal bone.⁵

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Herein, we report a protocol for the construction of a novel personalised MARPE (pMARPE) using Computer-Aided Design/Computer-Aided manufacturing (CAD/CAM) and 3D printing techniques. In brief, CBCT imaging was aligned with a digitised model of the upper maxilla, making it possible to measure the palatal bone thickness and plan the optimal position and direction of the mini-implant.⁵ This customised expander body could be closely adapted to the palatal vault, with a reduction in size for increased effectiveness. Importantly, the customisation of slot diameter and height on the customised expander body could ensure precise placement of mini-implants in ideal positions. The present report aims to illustrate the design, workflow, and fabrication procedures of the novel personalised MARPE (pMARPE) appliance using CBCT, CAD/CAM, and 3D printing techniques. We also report the efficacy of palatal expansion in a clinical case.

Case Report

A 27-year-old female patient presented at the Stomatological Hospital of Southern Medical University (Guangzhou, China) with a complaint of chin deviation on February 5, 2019. Intraoral examination showed her mandibular dental midline deviated 3.0 mm to the left side, and the chin was deviated to the same side, accompanied by a left unilateral crossbite in the permanent dentition (Figure 1A, B). The midline of the mandibular dental arch and chin shifted closer to the facial midline in the mandibular postural position.

Approximately 5.0 mm of transverse discrepancy between the maxilla and mandible was noted, based on the University of Pennsylvania CBCT Analysis.⁶ This analysis considers the distance from the right buccal skeletal landmark of the WALA ridge to the left side as the mandibular skeletal width. This skeletal landmark lies approximately at the edge of the cortical bone opposite the furcation of the mandibular first molars.⁶ The distance



Figure-1: Facial and intraoral conditions before maxillary expansion.

Table: Cephalometric summaries

Measurements	Pre-treatment	Post-treatment	Retention
S-N-A (°)	85.16°	85.38°	85.24°
S-N-B (°)	86.03°	86.23°	86.54
A-N-B (°)	-0.87°	-0.85°	-1.3°
N-A/A-Pog (°)	-1.64°	-1.33°	-1.62°
FH/N-Pog (°)	93.78°	93.65°	94.46°
S-Gn/FH (°)	59.59°	59.14°	58.39°
S-N/MP (°)	25.87°	26.54°	26.72°
FH/MP (°)	18.03°	18.95°	18.81°
U1/N-A (°)	29.76°	30.21°	30.05°
L1/N-B (°)	25.21°	25.71°	25.35°
U1/L1 (°)	126.9°	124.93°	125.89°
U1/S-N (°)	114.92°	115.59°	115.3°
IMPA (°)	92.31°	91.94°	92.1°
Pog/N-B (mm)	-0.16	-0.32	0.12

S, Sella; N, Nasion; A, point A; B, point B; Pog, Pogonion; FH, Frankfort Horizontal plane; Gn, Gnathion; MP, Mandibular Plane; U1, Upper Incisor; L1, Lower Incisor; IMPA, Incisor Mandibular Plane Angle.

from the intersection of the right maxillary tuberosity and the zygomatic buttress on the left side was considered as the maxillary skeletal width. The ideal maxillary skeletal width should be 5 mm wider than the mandibular skeletal width. Pre-treatment lateral cephalometric analysis showed a mild skeletal Class III malocclusion (ANB, -0.87; Table), indicating that the mandible was positioned forward relative to the maxilla. Maxillary incisors presented a proclination (U1-SN, 114.9) (Table).

The treatment objective was orthopaedic correction of the 5 mm transverse discrepancy between the jaws using pMARPE to correct the unilateral posterior crossbite before using fixed orthodontic appliances. The patient opted for non-surgical treatment modalities to correct the mandibular deviation and agreed with a pMARPE-based treatment plan. The patient was informed about the relative merits, shortcomings, and risks of pMARPE treatment and agreed to receive the treatment and allow her photos to be published in the journal.

The pMARPE appliance was manufactured using a novel workflow. The digital workflow commenced with obtaining CBCT images (NewTom VGi®, Verona, Italy) and export of the images in Digital Imaging and Communications in Medicine (DICOM) format.⁷ Next, an intraoral scanner (3Shape®, Copenhagen, Denmark) was used to obtain a digital scan of the maxillary arch and palatal vault. Digital scan images were saved in stereolithography (.stl) format. The DICOM and STL image files were superimposed using '3Shape Implant Studio'⁸ (3Shape®, Copenhagen, Denmark), which is a commercially available appliance design software. And then, three landmarks were selected randomly on the digital intraoral images: (1) mesiobuccal cusp of the upper right second molar; (2) distoincisor angle

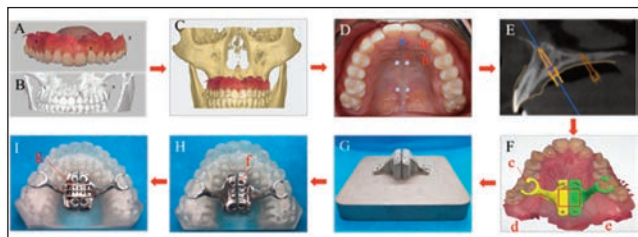


Figure-2:Workflow of the pMARPE.

A-C: Virtual superimposition of intraoral scanner images and CBCT reconstructed images; D: Schematic diagram showing the locations of the planned mini-implants (a: incisive foramen; b: midpalatal suture); E: Simulation of mini-implants placement, viewed in the sagittal plane; F: CAD/CAM model of pMARPE appliance body (c: clasp; d: connector; e: region for prefabricated expansion screw); G: pMARPE body after selective laser melting with the support structure; H: Occlusal view of polished pMARPE body (f: implant slots); I: Occlusal view of pMARPE after welding of the expansion screw (g: prefabricated expansion screw).

of the upper right central incisor; and (3) mesiobuccal cusp of the upper left second molar. Next, the same sites were identified on CBCT reconstruction images (Figure 2A, B). The two images were superimposed using these reference landmarks (Figure 2C).

The thicknesses of the bone and soft tissues were measured on the superimposed images, and the ideal positions of four virtual mini-implants were identified. These ideal positions were symmetrically distributed on both sides of the palatal suture. A region of 3.0–6.0 mm behind the incisive foramen was selected as it can provide sufficient palatal bone thickness for implanting the mini-implant. Higher primary stability of the mini-implants implanted at sites 1.5–2.7 mm from the mid-palatal suture as compared to sites at 0–1.4 mm has been reported, and was thus selected. The optimal direction of the anterior mini-implants is perpendicular to the palatal plate, and all mini-implants were oriented parallel to each other (Figure 2D, E). To enhance the stability of the mini-implants, bicortical anchorage was planned.

The pMARPE consisted of a prefabricated expansion screw (Dentaurum, Ispringen, Germany), and a CAD/CAM designed expander body which included clasps, and connectors (Figure 2F). The clasp surrounded the palatal side of the maxillary first molar. As the expansion screw was not manufactured by 3D printing, a region for welding the prefabricated expansion screw was reserved on the pMARPE body (Figure 2F, G). Four implant slots based on the pre-planned positions were designed on the expander body. The diameter and height of the four slots were designed at 2.2 and 2.0 mm, respectively, slightly larger than the mini-implant dimension (2.0 mm). These slots also served as a mini-implant placement guide to enable the precise placement of four mini-implants with consistent control of the direction of insertion (Figure 2H).

The final virtual design was transferred to a laser-melting machine (Concept Laser®, Lichtenfels, Germany). The

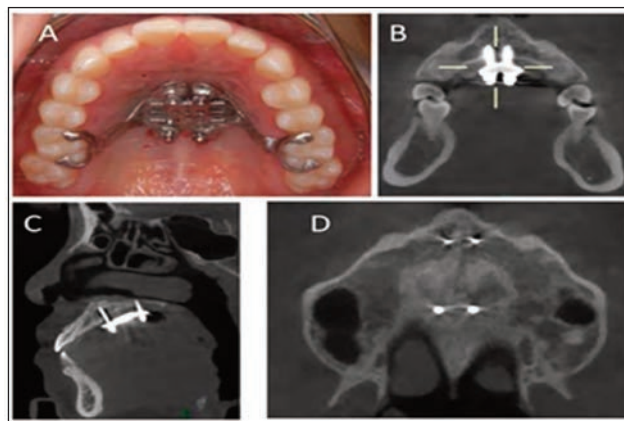


Figure-3: Intraoral situation and three-dimensional position of the implanted mini-implants after implanting four mini-implants. A: Maxillary image after fixing the pMARPE body; B: Coronal plane in CBCT; C: Sagittal plane in CBCT; D: Axial plane in CBCT.

expander body was produced using remanium star metal alloy (Dentaurum®, Ispringen, Germany) which is widely used in prosthodontic dentistry and then polished.⁴ The prefabricated expansion screw was welded to a reserved area on the expander body (Figure 2I).

The optimal length of the mini-implants was determined during virtual planning, taking into account factors such as the bone thickness, soft tissue thickness, slot height, and distance from the slot to the palatal mucosa. These considerations enabled bicortical anchorage for the two-posterior mini-implants, which ensured adequate stability during used as orthopedic-loading devices. The dimensions of two anterior mini-implants were 2.0×12.0 mm, and the dimensions of two posterior mini-implants with dimensions 2.0×10.0 mm for this patient. The pMARPE appliance was placed, and then cemented to the teeth. Subsequently, four mini-implants were inserted into the slots, with local anaesthesia administered for pain relief during the procedure (Figure 3A). The direction of the mini-implants was perpendicular to the palatal plate (Figure 3B, C), and all four mini-implants were parallel in multiplanar views (Figure 3D).

The appliance activation was delayed for two days to allow the patient to get accustomed to the appliance. The prefabricated expansion screw was then activated 1/2 turn (0.4 mm) per day on the following days until a diastema appeared between the maxillary central incisors. Thereafter, the expansion screw was activated 1/4 turn (0.2 mm) daily. The activation phase was performed until the maxillary skeletal width was expanded at least 5.0 mm based on the University of Pennsylvania CBCT Analysis⁶ (Figure 4A, B). Post-activation CBCT images depicted the opening of the mid-palatal suture in the palatal plane and the four mini-implants were parallel to each other. After the



Figure-4: Facial and intraoral conditions after the maxillary expansion. A: Facial photographs; B: Intraoral photographs.

activation phase, the device was left in situ for three months to stabilise the expansion. After the expansion, the maxillary skeletal width was successfully increased, and the left unilateral crossbite was corrected. The mandibular dental midline and chin midline shifted closer to the facial midline. The patient was subsequently treated using fixed orthodontic appliances.

Discussion

The rapid advancement and wide acceptance of digital technologies including intraoral scanning and 3D printing have led to improved accuracy and ease of several orthodontic treatment procedures. This report demonstrates a convenient, digital workflow for fabrication of a pMARPE appliance. Intraoral scanning for digital impression improved patient comfort, while appliance construction using a fully digital workflow ensured accuracy as compared to conventional analog-based processes by avoiding loss of accuracy due to issues such as impression or cast distortion and abrasion of plaster models. The CAD/CAM approach reduces manufacturing time and simplifies the manufacturing process.

Several designs of the MARPE appliance have been reported, with variations in clinical outcomes.⁹ While MARPE can effectively open the mid-palatal suture in adults after the closure of the mid-palatal suture has occurred,² averting the need for orthognathic surgery, prefabricated MARPE appliances impose limitations such as inadequate palatal adaption and difficulty in optimising the position, depth, and direction of the mini-implant.³ The pMARPE appliance was closely adapted to the palatal contour in the relatively narrow palatal vault. Sufficient supporting bone availability is essential to ensure primary stability of the mini-implants. Thus, site selection, dimensions, and orientation assume key importance for treatment success. Digital analysis and planning permitted precise selection

of the position and direction of the mini-implants. The bone thickness in the anterior and mid palatal regions is typically sufficient for the mini-implant placement, whereas the thin posterior palatal bone increases the risk of perforation or mini-implant loss.¹⁰ Bicortical mini-implant anchorage in the palatal and nasal cortices could provide high initial stability of the mini-implant and ensure the parallelism of palatal expansion when compared with monocortical placement. In the present design, four bicortically placed mini-implants were utilised, which would provide sound anchorage. Expanders with 2-rear-bicortical and 4-all-bicortical penetration have shown similar skeletal effects, suggesting that the 2-rear-bicortical penetrating mini-implants were critical to skeletal expansion. An earlier report has documented a digital workflow for a customised MARPE appliance with two mini-implants, over which the current design bears an advantage as it provides for four mini-implants. The present design enabled appliance customisation for individual palatal and dental morphology using a digital workflow, although it included a welded prefabricated expander screw. The successful outcome encourages research focused on this pMARPE appliance design, particularly for patients with narrow palatal morphology.

Conclusion

The case report demonstrates the efficacy of the fully digital workflow for fabrication of personalised rapid maxillary expander, which was closely adapted to a narrow palatal morphology and could expand the mid-palate suture with parallelism in an adult. The digital workflow reduced traditional clinical and laboratory procedures and enabled accurate placement of the mini-implants. The mini-implant deviation between the planned and actual positions was minimal. The present report provides a basis for clinical studies with higher number of patients and prospective designs, including randomised trials to determine the effectiveness and long-term stability of clinical outcomes of the pMARPE appliance.

Disclaimer: The text is based on an academic thesis.

Conflict of Interest: None.

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Author Contribution:

CW, XX: Drafted the manuscript and contributed equally.

CW, XX, QM, CL: Involved in patient management.

CW, CL: Supervised the report.

All authors approved the final manuscript and agreed to submit the work.