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CAD-CAM Workflows for Palatal TAD Anchored Appliances

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A B S T R A C T

Mini-implants inserted in the anterior palate are showing the very high success rates of 91.5% - 99%. Compared to other insertion sites, they can be used effectively for molar distalization, space closure, rapid maxillary expansion and protraction, molar intrusion and alignment of impacted upper teeth. In recent years, CAD-CAM techniques such as printed insertions guides and 3D metal printing were integrated into full digital workflows. These new procedures allow mini-implant insertion and appliance fitting in one appointment and may give orthodontists more confidence to insert in the optimum site. Additionally, the CAD/CAM design process may offer the opportunity to further improve orthodontic appliances biomechanically.

Mini-Implants in the anterior palate

Temporary anchorage devices (TADs) have become a common treatment modality in orthodontics within the last two decades. For some clinicians the alveolar process still seems to be the most preferred insertion site.[1-5] As an alternative, extra-alveolar insertions sites such as the buccal shelf and the infrazygomatic crest have been utilized. However, orthodontists are confronted with average loss rates of 16%-68.7 % of mini-implants in these three sites.[6-11] In contrast, failure rates of mini-implants in the anterior palate are reported to be 1-8.5%, which is significantly lower than in other regions.[10-15] The anterior palate stands out because of its superior bone quantity and quality combined with thin attached mucosa and minimal risk of tooth-root injuries.[10,13,16] Mini-implants in the anterior palate can be used effectively for molar distalization,[17] space closure,[18] rapid maxillary expansion and protraction,[19] molar intrusion[20] and alignment of impacted upper teeth.[21] To establish a stable connection between palatal mini-implants and orthodontic wires and to achieve integration into the orthodontic mechanics, mini-implants with interchangeable abutments have been developed (Fig. 1).[22] In recent years, CAD-CAM techniques such as printed insertions guides and 3D metal printing were integrated into the clinical workflows for the utilization of palatal mini-implants (Fig. 2).[23-25]

Mini-Implant placement

Usually, palatal mini-implants can be inserted without any pre-drilling. From our clinical experience, pre-drilling is only recommendable if mini-implants are going to be inserted in the palatal suture in adult patients (2-3 mm pre-drilling depth). A mini-implant diameter of 2 mm or 2.3 mm and length of 9 mm are usually selected providing a high stability.[26-29] Palatal mini-implants can be inserted with or without an insertion guide, either manually using a contra-angle or an electric screw-driver. The ideal zone with the lowest failure rates is directly posterior from the palatal rugae, where an area with sufficient bone volume and a thin soft-tissue layer can be detected.[30,31] In this so-called T-zone (Fig. 3a), mini-implants can be inserted median in adults and adolescents or paramedian in all patients. Very importantly, a paramedian insertion should be in the area of the bicuspids, because in the molar area the paramedian bone was found to be very thin.[31] As recent studies have shown the advantage of paramedian over median insertion in the anterior palate we switched our preferred insertion site from median to paramedian over the last years.[32-34] In most cases the optimal area can be identified just by intraoral inspection or by examination of the patient's model. In more complicated situations, a cephalogram or a CBCT can be very helpful to identify the optimum insertion site and angulation.

Printed insertion guide

Many practitioners are not immediately familiar with the placement of implants in the anterior palate and may be reluctant to use them. A mini-implant insertion guide potentially assist clinicians to overcome their uncertainty, since the optimal position, length and angulation for the mini-implant has been pre-determined for an individual patient using a 3D design software.[23,25] For this purpose, an intraoral scan or model scan is performed. Optionally, the digital model can be superimposed with either a lateral cephalometric radiograph (Fig. 3c) or a (CBCT (cone-beam computed tomography image), Fig. 3d). The optimal site for the mini-implants in the anterior palate is identified by placement of virtual implants (Fig. 3). In contrast to conventional surgical drill guides, a skeletonized design comprising four occlusal posts will not block the practitioner's view on the palate (Fig. 3b, 4, 5). Printing

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Fig. 1. For the anterior palate, mini-implants with abutments are very useful due to an angular stable coupling (Benefit System, PSM, Germany).

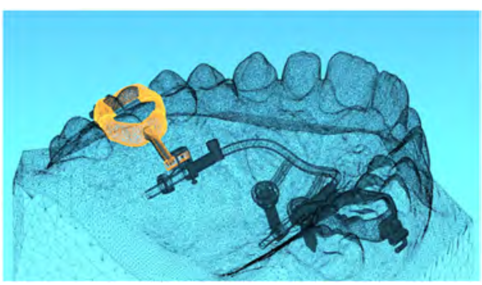

Fig. 2. CAD-CAM techniques offer a wide variety of design opportunities also for mini-implant borne appliances.

the insertion guide with an SLA resin printer gives enough precision to exactly place the mini-implants in the pre-defined position (Fig. 5,6).

Appliance production - Metal printed implant borne appliances

Just as the insertion guide also implant borne appliance can be designed using a 3D design software. To ease the design process, digital appliances are usually constructed from pre-defined components such as abutments, connectors, rails, etc. (Fig. 7). Digital design gives more freedom than conventional appliance construction. Instead of orthodontic bands, digital appliances either comprise bonded shells or bonded tubes. Consequently, separators are no longer needed which saves chair time (Figs. 8, 9). The shells (Fig. 10) and bonded tubes (Fig. 12) are connected by using a composite (e.g. Transbond, 3M Unitek). The guiding rails of sliders now have a rounded rectangular cross section (Fig. 9, 1.2 × 1.4 mm) to provide torque control. Since metal printing implies some geometric restrictions, the conventional palatal sheaths were replaced by the Versalock connector which comprises a palatal prong and a triple tube (Figs. 10, 11). Special emphasis is given to implant hygiene. This is mostly achieved be removing all components that cover the implants giving optimal access for cleaning (Fig. 8). For distalization with the Beneslider (Fig. 7a), 240 or 500 g NiTi open springs are used, for mesialization with the Mesialslider (Fig. 7b), 200 g NiTi closing (pull mechanics, Fig. 13) or 240 g open springs (push mechanics, Figs. 7, 20) are employed. Due to a higher patient comfort and a lower breakage rate, we prefer the use of open springs. The final parts (Slider framework, molar shells, sliding tubes) materialized using metal printing technology (Fig. 14). Out of many metal printing technologies available today, SLM (Selective Laser Melting) is the most often used method in dentistry. Since the implant borne appliances must be very rigid, they are printed from a certified cobalt chrome tungsten alloy (Cobalt-Chrome-Remanium star metal alloy, Dentaurum, Ispringen, Germany). Of course, the whole variety of implant-borne appliance can be produced this way, such as transpalatal bars or the Hybrid Hyrax.

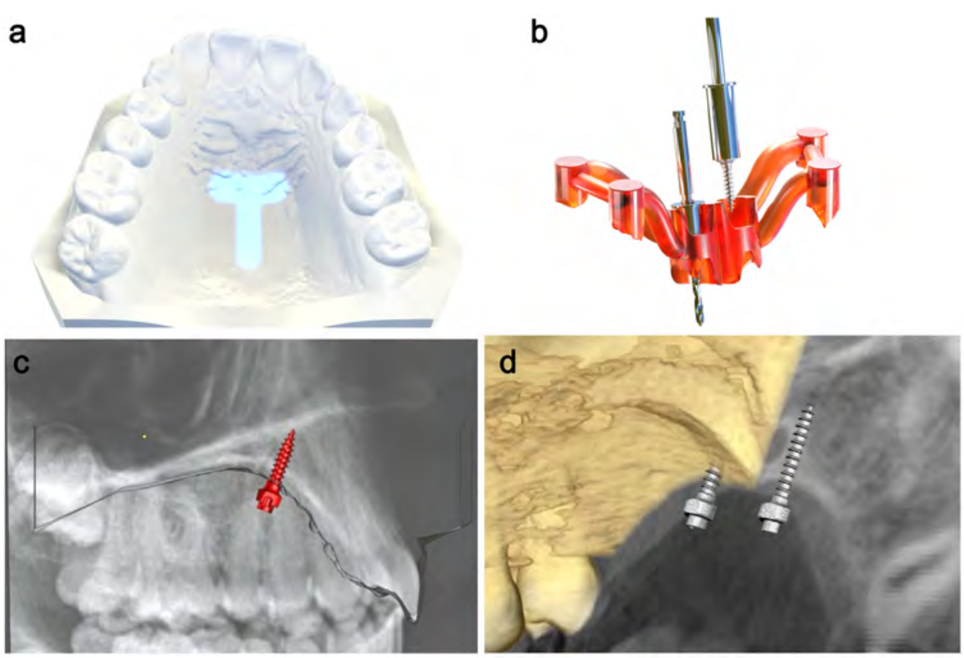

Fig. 3. a: the T-zone is the ideal insertion site in the palate. b: digital designed insertion guide for both TAD insertion and pre-drilling (if needed). c: virtual TAD insertion after superimposition of an intraoral scan and a cephalogram. d: virtual TAD insertion after superimposition of an intraoral scan and a CBCT.

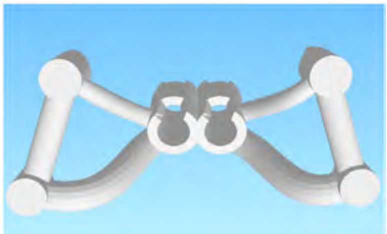

Fig. 4. For the digital workflow a STL file of the CAD insertion guide including the palate is needed. Ideally, palatal TADs are inserted in the T-zone.

Fig. 5. Printed model and insertion guide.

Clinical workflows

Printed insertion guides and appliances allow for new clinical workflows. The most elegant and time saving workflow is called the “full digital workflow” or “one appointment workflow” which implies the insertion of the implants and the appliance in one appointment.[24,35,36] It is defined as follows:

Fig. 8. Proper slider design to facilitate optimal mini-implant hygiene.

1) Intraoral scan
2) Creation of a digital model in the 3D design software
3) In complicated cases: superimposition of the model with the lateral cephalogram or CBCT
4) Virtual implant placement
5) Virtual Design of a mini-implant insertion guide
6) Digital appliance design on the virtually placed implants
7) 3D-Printing of the metal appliance and the mini-implant insertion guide

As an alternative, it is also possible to first insert the mini-implants either free hand or with an insertion guide. The intraoral scan is taken

Fig. 6. Full digital workflow for palatal TAD applications: CAD-CAM insertion guide and metal printed appliances.

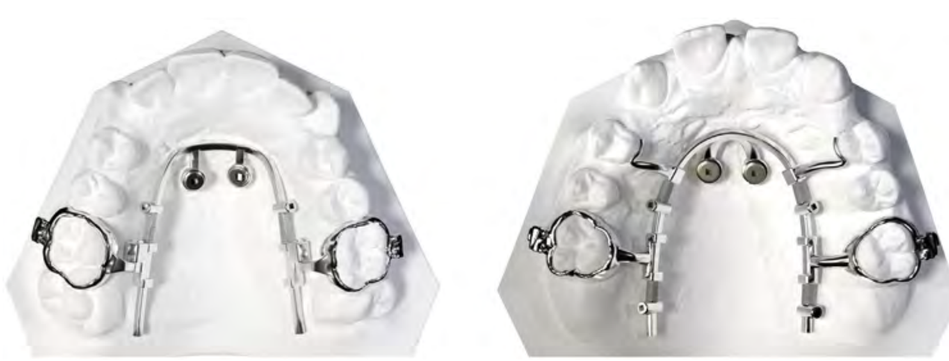

Fig. 7. CAD-CAM Beneslider (left, for distalization) and Mesialslider (right, for space closure).

Fig. 9. Rectangular slider rail

Fig. 10. Shell design for molars and a slider.

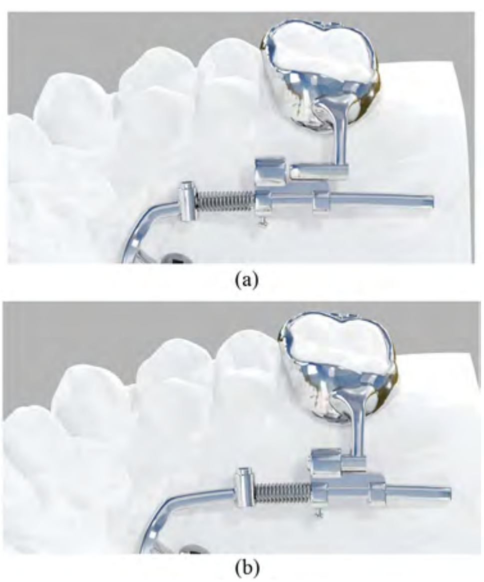

Fig. 11. “triple tube” connection for the digital Beneslider.

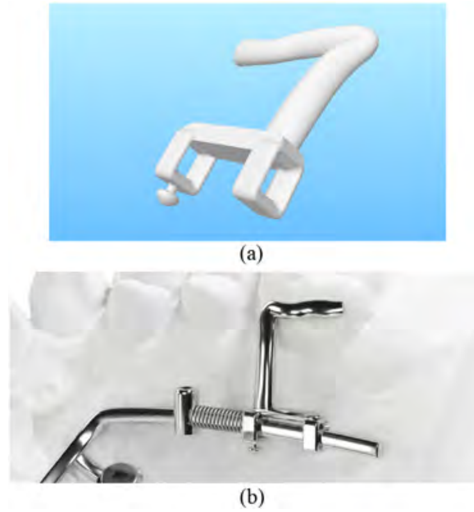

Fig. 12. Digital design of a bonded tube.

Fig. 13. Closing spring for a digital Mesialslider.

with the implants in place which is no longer a problem with current scanners. The appliance is designed and produced as described above and then inserted in a second appointment.

Clinical case 1: Upper molar distalization

Due to esthetic drawbacks and the length of time to be worn, molar distalization with a headgear is unpleasant for many patients.[37,38] Unfortunately, most of the conventional devices for non-compliance maxillary molar distalization show some unwanted side effects, such as anchorage loss, especially, when distalization forces are applied buccally.[39] The amount of the anchorage loss of conventional intraoral devices ranges between 24 to 55%.[40] To benefit from the advantages of *direct* anchorage mechanics and of the anterior palate as the most suitable mini-implant insertion site, the Beneslider[5,17,22,41,42] device has been designed to be mounted on top of mini-implants with exchangeable abutments. The Beneslider utilizes sliding mechanics and has proved to be a reliable distalization device.[42] After upper molar distalization, the cases can be finished using conventional brackets or aligners,[43] because pure bodily tooth movement with sequential plastic aligner therapy is challenging to achieve to a high degree of predictability. Following distalization of the maxillary molar teeth, the springs can be removed or steel ligatures can be used to modify the Beneslider from an active distalization device to a passive molar anchorage device. The primary objective is to stabilise the maxillary molar teeth during the retraction of the maxillary anterior teeth (Digital Beneslider case, Figs. 15-17).

Fig. 14. Guide and appliance are printed and ready to be inserted.

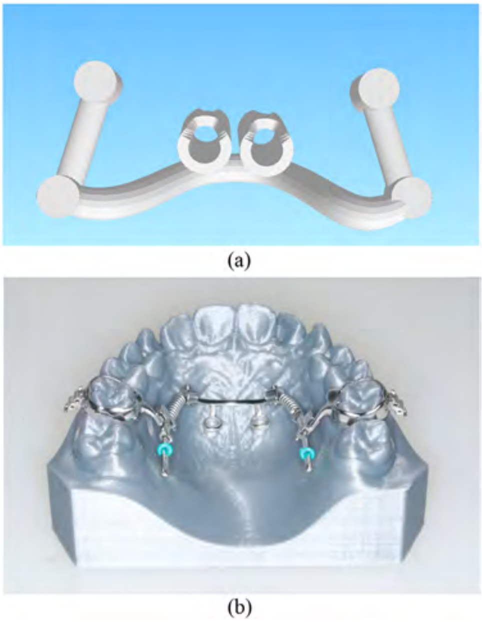

Fig. 15. 17-year-old patient: CAD-CAM made guide and upper molar distalization appliance (Beneslider).

Clinical case 2: Upper molar mesialization / space closure

The two major treatment approaches for missing teeth are space closure or space opening to allow prosthodontic replacements either with a fixed prosthesis or single-tooth implant. In many cases, space closure to the mesial seems to be the favourable treatment goal, since treatment already can be completed as soon as the dentition is complete.[44] As an alternative to the T-Bow (indirect anchorage), the Mesialslider[22,41,45] as a *direct anchorage* device can be used. The Mesialslider enables clinicians to mesialize upper molars unilaterally or bilaterally. Since the incisors are not fixed, a midline deviation can be corrected at the same time. The

Fig. 16. Insertion guide in situ.

Mesialslider can be used to close space in the upper arch from distal, e.g. for missing molars,[46] premolars, canines or even incisors. The Mesialslider can also be used for protrusion of the whole upper dentition to compensate a mild class III occlusion. Another indication of the Mesialslider is unilateral mesialization and contralateral distalization which is a combination of the Mesialslider and a Beneslider, the Mesial-Distal-Slider[47] (Digital Mesialslider case, Figs. 18-20).

Clinical case 3: Rapid Maxillary expansion (RME/MARPE)

Maxillary deficiency is a common orthodontic problem frequently associated with a Class III malocclusion. Conventional maxillary expansion and protraction appliances are tooth borne with many unwanted dental side effects such as buccal tipping of the teeth, root resorption,[48-50] decrease in buccal bone thickness[51] or dehiscence and gingival recession,[52] usually resulting from the heavy forces required for maxillary expansion and protraction. While the protraction forces from the facemask can lead to mesial migration of the dentition and anterior crowding.[53] More recently, mini-implants have been used to share the load of the expansion as well as the protraction with the anchorage teeth in order to reduce or eliminate the unwanted dental side effects. The Hybrid Hyrax expander was introduced in 2007 uses two mini-implants in the anterior palate and two (deciduous) molars.[5,19,22,54] Similar

Fig. 17. a: After insertion of 2 TADs, b: after installation of a Beneslider, c: upper molar distalization after 8 months, open spring is removed in the second quadrant; d: after the orthodontic treatment.

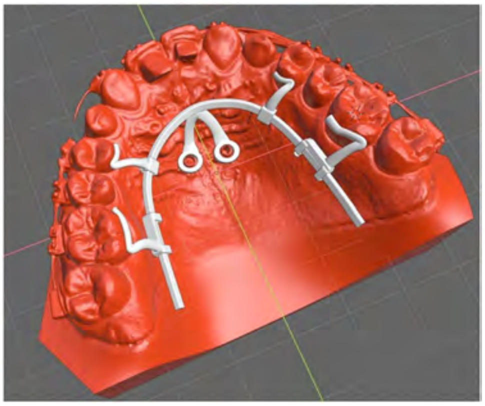

Fig 18. Digital design of upper molar mesialization appliance (Mesialslider) for a 13-year-old patient with missing lateral upper incisors.

Fig. 19. Guided insertion of palatal TADs.

hybrid expanders were published later by Garib[55] in 2008, Lee[56] in 2010 and Moon[57] in 2015 called MSE. Mini-implant supported expanders can also be used very successfully for the treatment of growing Class III patients[53,58-64] allowing skeletal maxillary protraction without the common dental side effects.[57,60,61,65] (Case Digital Hybrid Hyrax, Figs. 21-22).

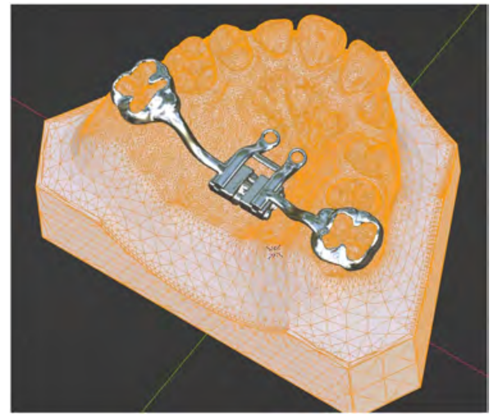

Fig. 21. Digital design of a RME appliance (Hybrid Hyrax) for a 9-year-old patient with a transverse deficiency.

Clinical case 4: Molar anchorage for alignment of impacted teeth / en-masse retraction

Conventional appliances designed to provide molar anchorage are headgear, Class II elastics, the transpalatal arch, the Nance button and the incorporation of additional bends in the archwire such as tip-back and buccal root torque. However, these anchorage mechanics are limited in their efficiency, which depends in part on patient compliance. As a consequence, mini-implants prove to be very useful if the molar mesial migration should be avoided during en masse retraction.[66,67] Another useful indication of a TAD-borne TPA is molar anchorage to avoid molar tipping during extrusion of impacted teeth. To control side effects in the transverse dimension and bending of the TPA, we found it advisable to design rigid connectors with a big diameter. (Case digital TPA Figs. 23-24).

Discussion - Pros and Cons of the CAD-CAM workflows

In both the conventional and digital workflows, TADs in the anterior palate are safe and efficacious and improve patient's care and comfort.

Fig. 20. a: After insertion of 2 TADs, b: after installation of a Mesialslider, c: upper molar mesialization after 10 months; d: after the orthodontic treatment.

Fig. 22. a: Design of the insertion guide; b: design of the Hybrid Hyrax; Hybrid Hyrax before (c) and after expansion (d).

As shown by Graf et al. the CAD/CAM workflow obviates the need for tooth separation and the uncomfortable step of band seating.[35] The full digital workflow offers the opportunity to insert mini-implants and CAD orthodontic appliances in a single appointment, making the process more economic for the patient and the doctor. De Gabriele et al. have initially described the implementation of a single appointment workflow. However, the orthodontic appliances were manufactured by conventional laboratory techniques.[25] Compared to the traditional laboratory manufacturing method of palatal min-implant borne mechanics, we experienced that the digital appliance design workflow enhanced appliance precision and fitting. The digital workflow eliminates possible sources of error such as:

- Band transfer from impression to a plaster model
- Incorrect transfer of implant position to the dental laboratory

The digital design process offers the perspective to improve and customize the appliance design, e.g., improve the rigidity of wires when rigidity is needed, for example for TPA's and RME appliances. The only disadvantage of the digitally designed shells in comparison to conventional bands seems to be a clinically observed higher failure rate.

Fig. 23. Digital design of a TAD-borne transpalatal arch.

Fig. 24. CAD-CAM TPA in situ, in this case for anchorage re-enforcement to extrude an impacted canine.

Conclusions

To summarize, the use of TADs in the anterior palate has expanded the options in orthodontic and orthopedic treatment significantly. Insertion and removal are minimally invasive procedures: orthodontists can place the screws by themselves and load them immediately. The anterior palate is the preferred insertion region because of its superior bone quality and low rates of mini-implant instability and failure. Nowadays, a complete digital workflow from virtual insertion to CAD/CAM design of insertion guides and orthodontic metallic appliances is possible. These new procedures allow mini-implant insertion and appliance fitting in one appointment. CAD/CAM design process may offer the opportunity to further improve orthodontic appliances biomechanically.

Patient consent

Patient consent was obtained.

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Author contributions

All authors attest that they meet the current ICMJE criteria for Authorship.

Declaration of competing interest

The authors reported no competing financial interests or personal relationships that could appear to influence the work reported in this paper.

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