PART B: THE USE OF PALATAL MINI-IMPLANT ANCHORAGE: CONVENTIONAL APPROACHES VERSUS COMPUTER-AIDED DESIGN AND COMPUTER-AIDED MANUFACTURING WORKFLOWS

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MINI-IMPLANTS IN THE ANTERIOR PALATE

TADs, especially mini-implants, are a routinely used staple in contemporary orthodontic care. The buccal aspect of the alveolar process continues to be the most preferred insertion site[274-278] for placement of mini-implants. However, orthodontists are confronted with an average loss rate of 10% to 30% of buccal mini-implants as reported in the literature.[279-283] In contrast, the failure rate of mini-implants in the anterior palate is reported to be 1% to 5%, which is significantly lower than in other regions.[283-287] In the anterior palate, a superior bone quantity and quality combined with thin attached mucosa and minimal risk of tooth-root injuries are observed.[283,285,288] Applications for the use of mini-implants in the anterior palate include molar distalization (Fig. 24.58A–B), space closure, rapid maxillary expansion (RME), and protraction, molar intrusion, and alignment of impacted teeth. To allow a stable connection between palatal mini-implants and orthodontic wires and to achieve integration into the orthodontic mechanics, mini-implants with interchangeable abutments are employed (Fig. 24.59).[289] More recently, computer-aided design/computer-aided manufacturing (CAD/CAM) techniques such as insertion guides and 3D metal printing have been integrated into palatal mini-implant workflow (see Fig. 24.58B).[290-292]

Mini-implant Placement

To adequately anaesthetize the area, we recommend the use of high-gauge needles (e.g., Citoject, Kulzer, South Bend, Indiana) with local infiltration in the intended two paramedian positions (Fig. 24.60). Customarily, palatal mini-implants can be inserted without the need for any predrilling. Based on our clinical experience, predrilling is required only if mini-implants are to be inserted in the palatal suture in adult patients (2–3 mm predrilling depth). A mini-implant of diameter of either 2 mm or 2.3 mm, and lengths of 9 mm or above, provide a high degree of stability and retention.[293-296] Palatal mini-implants can be inserted with or without an insertion guide, either manually using a contra-angle or an electrical implant-driver (Fig. 24.61). The ideal zone of placement with the lowest failure rates is directly posterior from the palatal rugae. Distally from the rugae, an area with sufficient bone volume and a thin soft-tissue layer can be detected (Fig. 24.62).[297,298] In this so-called T-zone, mini-implants can be inserted in a median

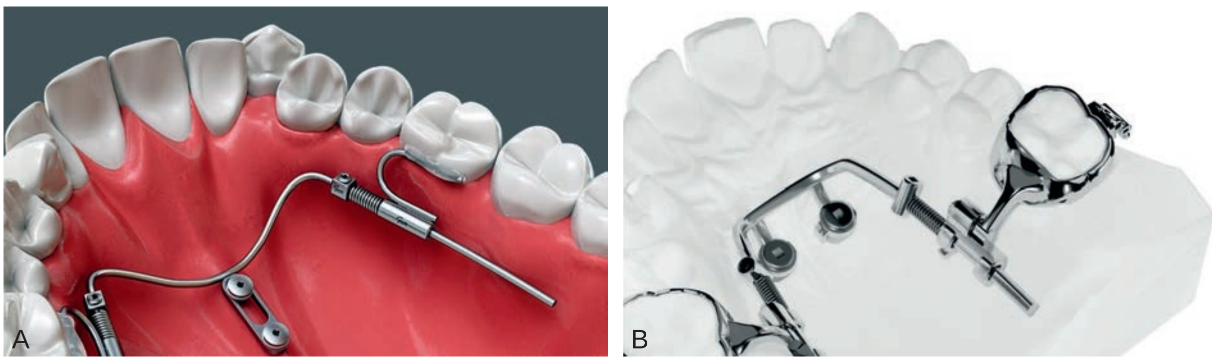

Fig. 24.58 Mini-implants in the Anterior Palate Used for Molar Distalization (Beneslider). A, Conventional framework on two median mini-implants employing a Beneplate and bonded tubes. B, Digital design on two paramedian mini-implants employing computer-aided design/computer-aided manufacturing–designed abutments, rails, and molar shells.

Fig. 24.59 Available mini-implants with interchangeable abutments to allow a stable connection between palatal mini-implants and orthodontic wires.

Fig. 24.60 Application of Local Anesthesia (Citoject, Kulzer, South Bend, Indiana) in the Anterior Palate.

Fig. 24.61 Insertion of Palatal Mini-implants with an Electrical Screwdriver (NSK, Japan).

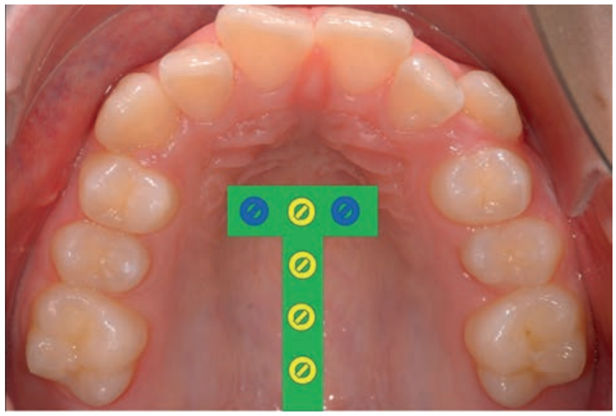

Fig. 24.62 Recommended Insertion Site T-Zone Distally from the Rugae.

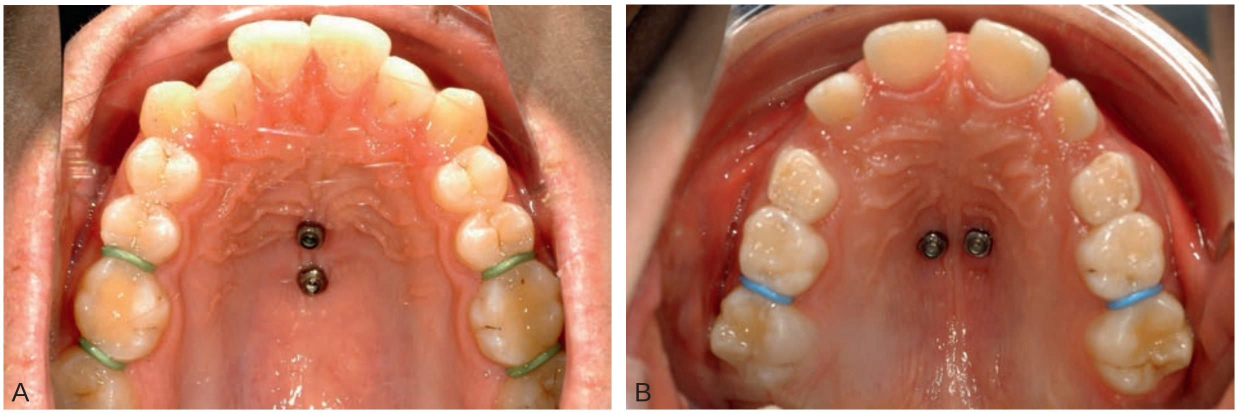

Fig. 24.63 **A,** Median insertion of mini-implants (in adults and adolescents). **B,** Paramedian insertion (in all patients).

Fig. 24.64 Lateral Radiograph Showing the Appropriate Insertion Site (Mini-implant Dimension: 2 × 9 mm).

configuration in adults and adolescents (Fig. 24.63A) or paramedian orientation for all patients (see Figs. 24.63B and 24.64). It is important to note that a paramedian configuration of insertion should be in the area of the bicuspids, as the bone quantity posterior to this area can become quite variable and usually of thinner quality.[298] Recently published studies have shown the advantage of paramedian over median insertion in the anterior palate, so we switched our preferred insertion site from median to paramedian.[299-301] The optimal area can be identified by intraoral clinical examination; a cephalogram or CBCT is required only in special circumstances.

Many practitioners are not immediately familiar with the placement of implants in the anterior palate and as such may be reluctant to use them. A mini-implant insertion guide potentially serves to assist clinicians to overcome their uncertainty, providing assurance that the optimal position, length, and angulation for the mini-implant has been predetermined for an individual patient using a CAD/CAM platform.[290,292] To this end, a digital stereolithographic (STL) file of the maxilla is generated. This can be performed directly using an intraoral scanner or indirectly by a laser scan of a plaster cast model. The STL file can be merged with either a CBCT or a lateral cephalometric radiograph (Fig. 24.65). The optimal sites for mini-implant placement in the anterior palate are identified, and a virtual planning software is used to confirm the precise anatomic positions. A rapid prototyping process produces the insertion guide, which locates the ideal position of the mini-implants within the anterior palate (Fig. 24.66A–B). Additionally, the orthodontic appliance can be fabricated in advance on a CAD/CAM 3D printed acrylic cast. Thus both the insertion guide and orthodontic appliance can be prefabricated before insertion of the

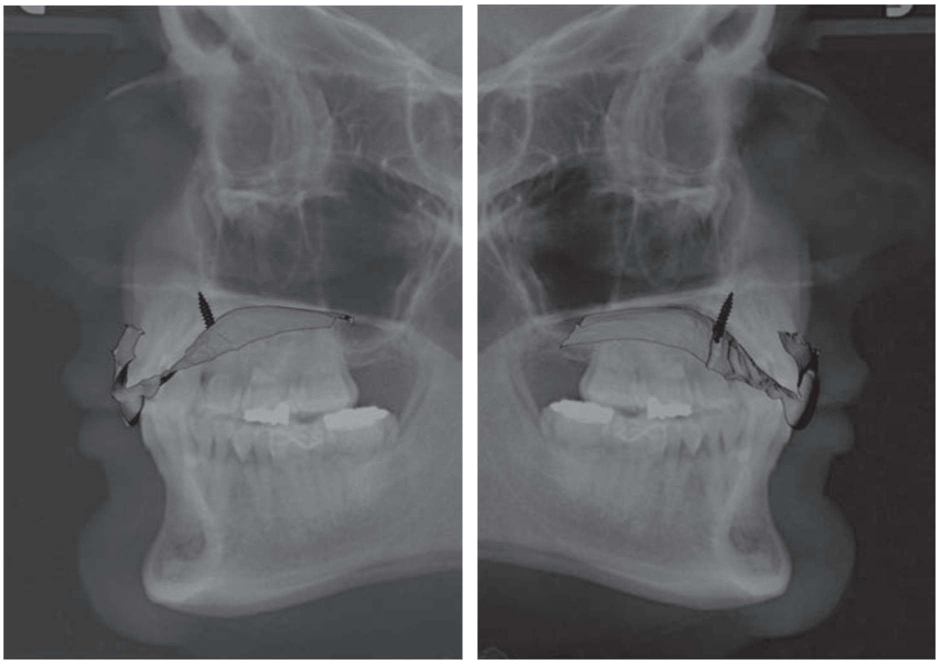

Fig. 24.65 Virtual Mini-implant Placement. The stereolithographic file of the upper jaw is merged with a lateral cephalometric radiograph.

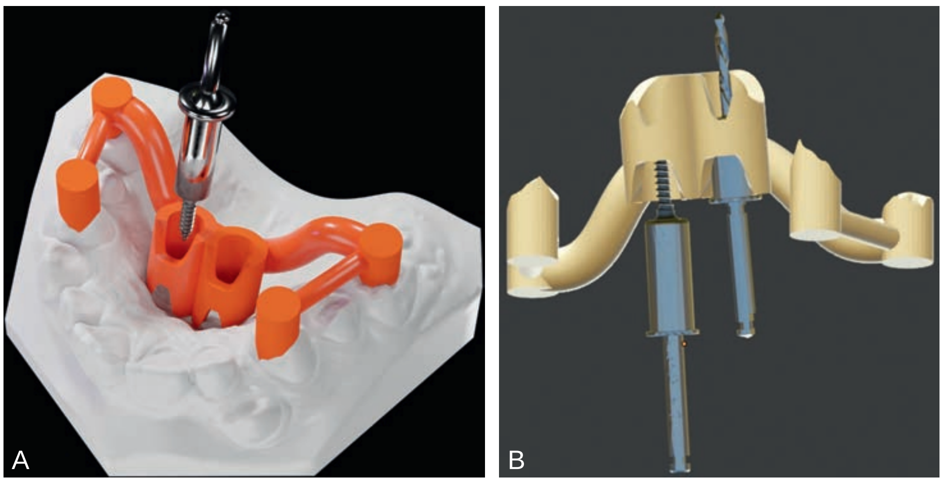

Fig. 24.66 A and B, Computer-aided design/computer-aided manufacturing insertion guides for ideal positioning of the mini-implants in the anterior palate. The guides can be used for mini-implant insertion and predrilling.

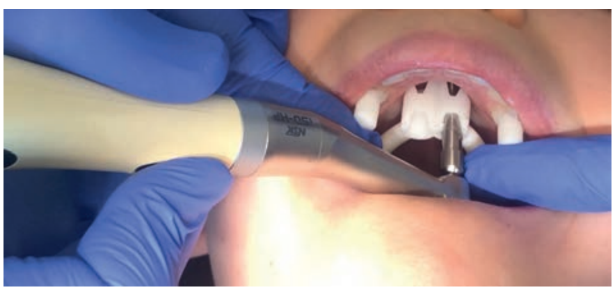

Fig. 24.67 Insertion of Palatal Mini-implants Using a Computer-Aided Design/Computer-Aided Manufacturing Guide. Insertion of both the mini-implants and the orthodontic appliance in a single office visit is now possible.

mini-implants. The described process allows for the insertion of both the mini-implants and the orthodontic appliance in a single office visit (Fig. 24.67).[290]

Appliance Installation: Conventional Workflow

From when orthodontists first began to use palatal mini-implants in their treatment approach, the method of connecting the orthodontic appliance with the mini-implants has garnered little review and focus. Prefabricated appliance products have been most commonly used (Figs. 24.68 through 24.71). In many cases the appliance could be adapted intraorally, which, of course, implies some chair time (see Fig. 24.70). The alternative is to adapt the mechanics in the laboratory by taking a silicon impression and transferring the intraoral setup to a plaster cast using the impression cap and the laboratory analog[289] (see

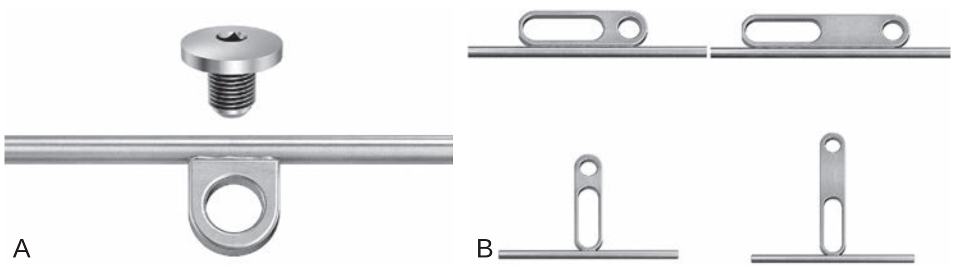

Fig. 24.68 Abutments for the Conventional Design of the Supraconstruction. **A,** Hyrax Ring abutment. **B,** Beneplates for median *(lower)* and paramedian *(upper)* insertion.

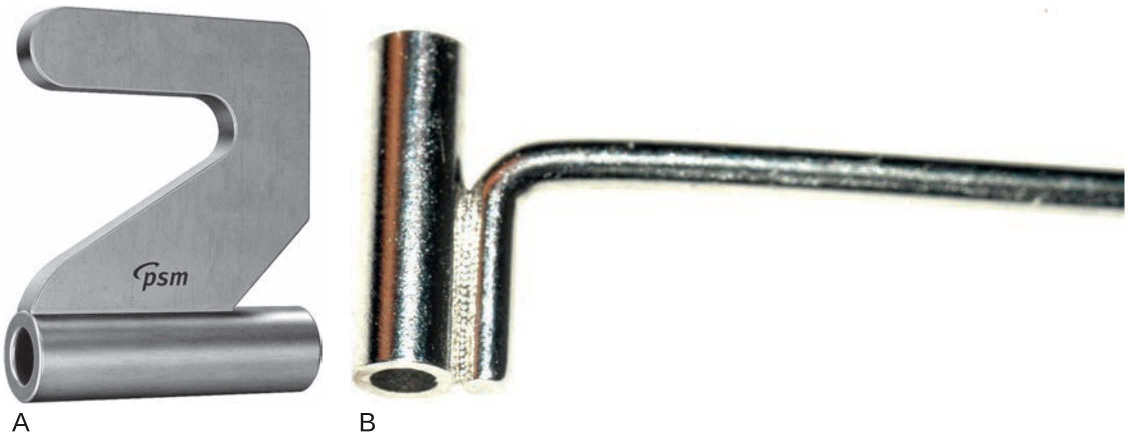

Fig. 24.69 Tubes for the Connection of Mini-implant–Borne Sliders with Molars. **A**, For bands with sheaths. **B**, For bonding to the palatal surface.

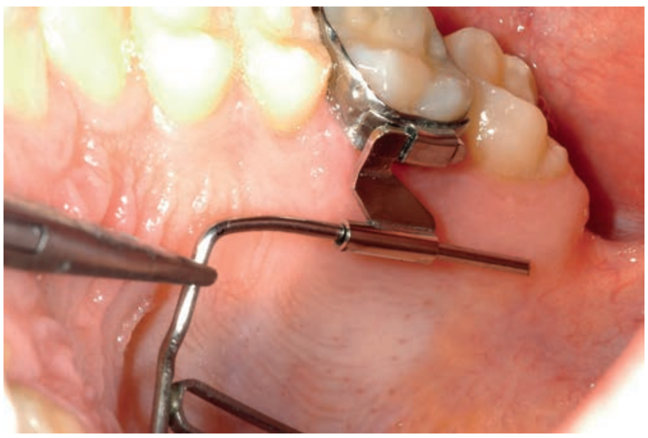

Fig. 24.70 Direct Intraoral Chairside Adaptation of the Framework.

Fig. 24.71B). For distalization and mesialization sliders, a miniplate[302] (Beneplate, 1.1 mm; see Figs. 24.68, 24.70, and 24.71) can be adapted to the mini-implants by bending of the miniplate body as well as the wire (see Fig. 24.70).

Clinical Procedure: Digital Workflow

Recently the feasibility of modern CAD/CAM workflows was described to manufacture appliances using a digital workflow.[291,303,304] A fully digital workflow is defined as follows:

1. Creating a virtual model of the dentition (intraoral scan)
2. If desired superimposition of the model with a lateral cephalogram or CBCT
3. Virtual implant placement
4. Digital appliance design on the virtually placed implants
5. Virtual design of a mini-implant insertion guide
6. 3D printing of the metal appliance and the mini-implant insertion guide

For the digital workflow, several software platforms are available from virtual mini-implant insertion to the design of the CAD/CAM appliances (Figs. 24.72 and 24.73). Digital Benesliders can be designed using virtual abutments, rails, connectors, sliding tubes, and shells (see Fig. 24.72). Molar shells are designed with a bonding gap of 0.05 mm.[303] To complete the digital workflow, insertion guides are designed to contain the information of mini-implant insertion site, angulation, and insertion depths. A minimalistic design is chosen comprising a four-point contact on the patient's dentition (see Fig. 24.72C). The final parts (slider framework, molar shells, sliding tube, insertion guide) are exported and materialized using advanced 3D printing techniques (see Fig. 24.72D). For production of the metallic components, selective laser melting using Remanium Star metal alloy (Dentaurum, Ispringen, Germany) is used. The insertion guide is printed using stereolithography and biocompatible resin. These CAD/CAM techniques have been successfully applied for the fabrication of numerous variations of maxillary anchorage devices—for example, maxillary expanders, such as the Hybrid Hyrax[291,305] (see Fig. 24.73).

Clinical Applications of Palatal Mini-implant Anchorage

Upper Molar Distalization

Class II malocclusions are frequently encountered in contemporary orthodontic practice. The distalization of the maxillary first permanent molar teeth may be considered as a treatment option for patients presenting with an increased overjet and anterior arch-length

Fig. 24.71 Transferring the intraoral setup to a plaster cast using an impression cap and a laboratory analog (A) and a silicon impression (B). Adaptation of a Beneplate on a plaster model (C).

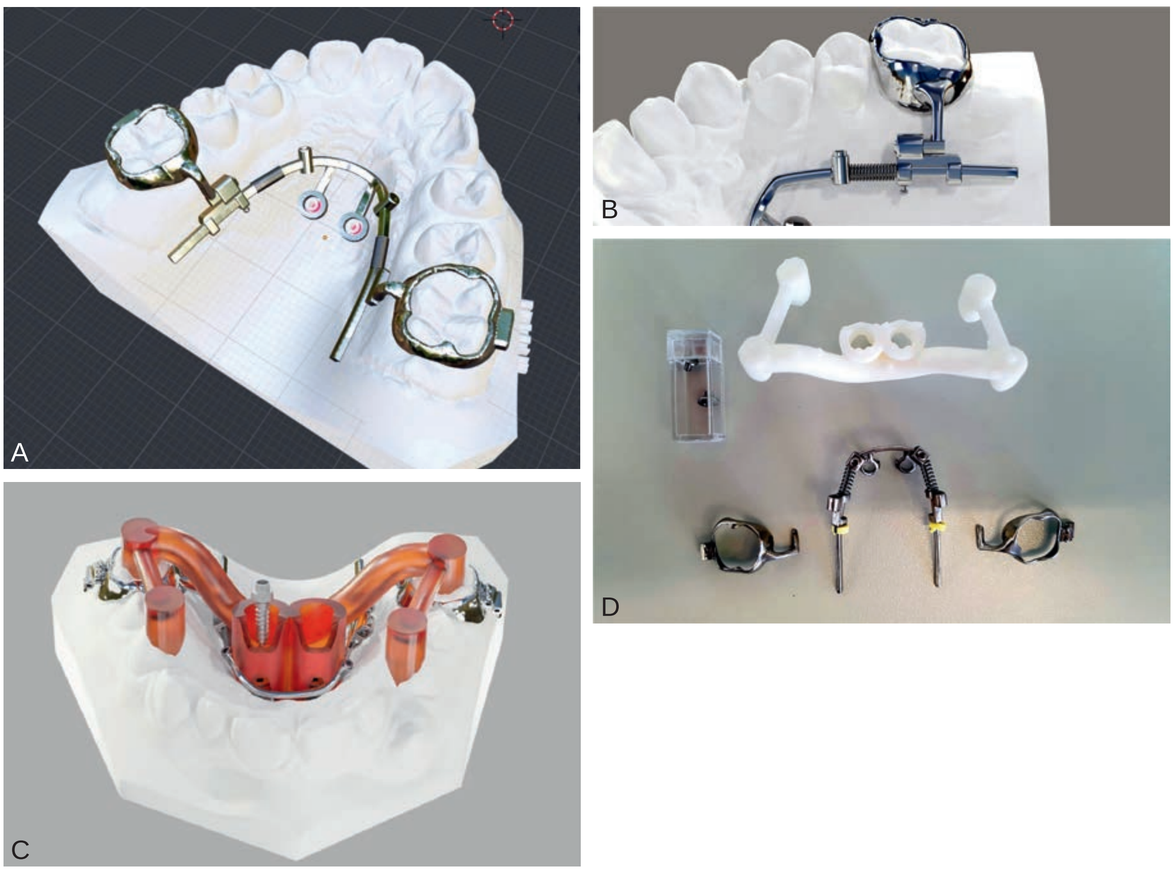

Fig. 24.72 A and B, Beneslider with digitally designed abutments, rails, connectors, sliding tubes, and molar shells. C and D, For a full digital workflow facilitating a one-appointment protocol, an insertion guide is produced.

insufficiency. Molar distalization can be performed with the use of intraoral or extraoral appliances. Potential issues arising with patient compliance may be associated with the prolonged use of headgear.[306,307] There has been an increasing trend in the clinical use of intraoral appliances that require minimal need for patient cooperation. However, most conventional tooth-borne appliances for maxillary molar distalization produce an unwanted side-effect of anchorage loss resulting in maxillary incisor proclination, especially when distalization forces are applied buccally.[308] The amount of anchorage loss with conventional intraoral devices ranges between 24% and 55%.[36]

Fig. 24.73 Computer-Aided Design/Computer-Aided Manufacturing–Designed Miniscrew-Assisted Rapid Palatal Expansion Appliance (Hybrid Hyrax). For Class III traction, an additional hook can be added (second quadrant).

To benefit from the advantages of *direct* anchorage mechanics and of the anterior palate as the most suitable mini-implant insertion site, the Beneslider[278,289,302,310,311] device has been designed to be fixed on top of mini-implants with exchangeable abutments. The Beneslider uses sliding mechanics and has proven to be a reliable distalization device.[311] After successful maxillary molar distalization, the cases can be finished using conventional brackets (Fig. 24.74) or sequential plastic aligners[312] (Fig. 24.75). Pure bodily tooth movement with sequential plastic aligner therapy is challenging to achieve to a high degree of predictability (see Chapter 22). Consequently, the realization of molar distalization as a treatment objective is limited when relying on aligner movement alone. Although there are limited reports of successful upper molar distalization of up to 2.5 mm in the literature,[313] an extended treatment time and high level of patient compliance is expected with requirement for intermaxillary Class II elastics to be worn during the long period of the sequential upper molar distalization.[314] Moreover, the potential side effects of Class II elastics must be considered in terms of mesial shift of the lower anchorage teeth. If clear sequential plastic aligner therapy is considered, the distalization forces from the Beneslider appliance are transferred to the molars using bonded tubes (Figs. 24.69B and 24.76). The advantages of a bonded tube are esthetics, and the adaptability and fit of the aligners is not undermined by the presence of stainless steel molar bands. The aligner material could cover this bonded connection (see Fig. 24.76A) or the aligner could be cut out in this connection area ("button cutout"; see Fig. 24.76B). After

Fig. 24.74 Distalization with a Conventional Beneslider. After molars are distalized in a Class I occlusion, the case was finished with brackets.

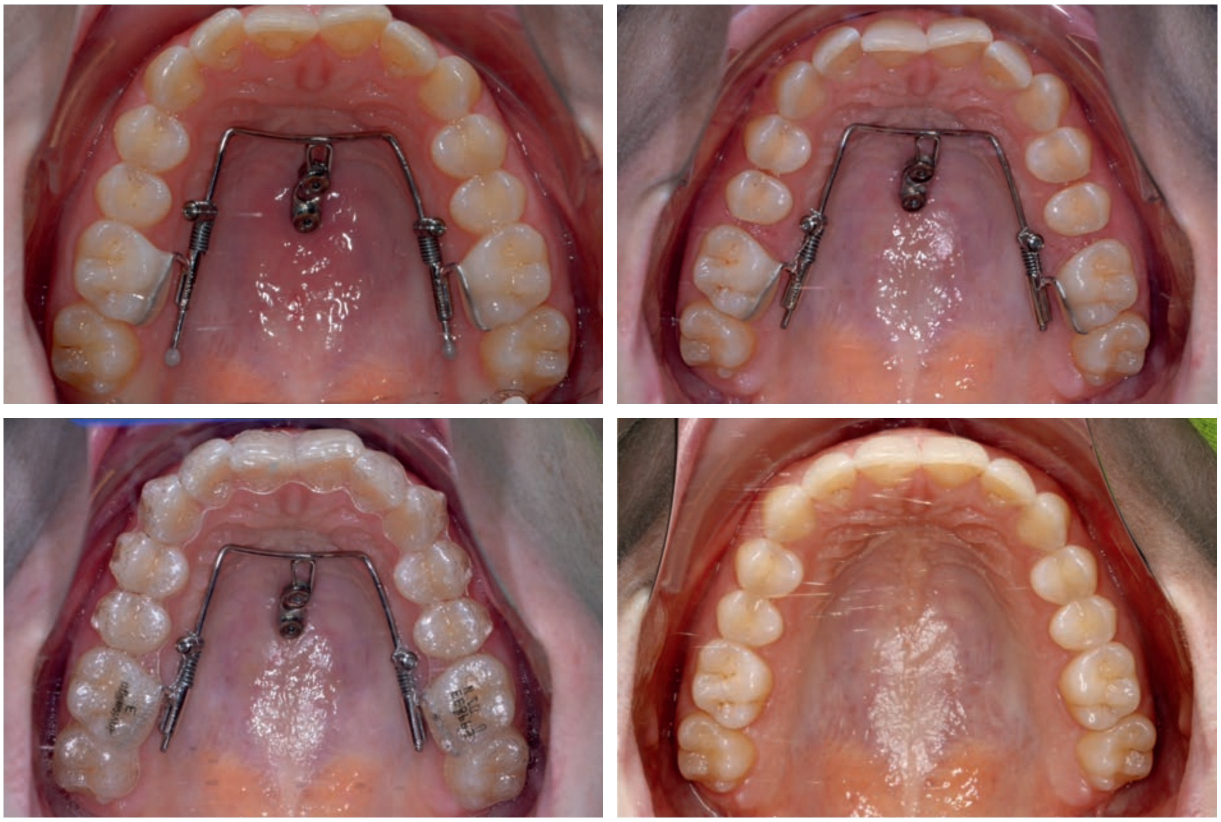

Fig. 24.75 Distalization with a Conventional Beneslider. After molars are distalized in a Class I occlusion, the case was finished with aligners.

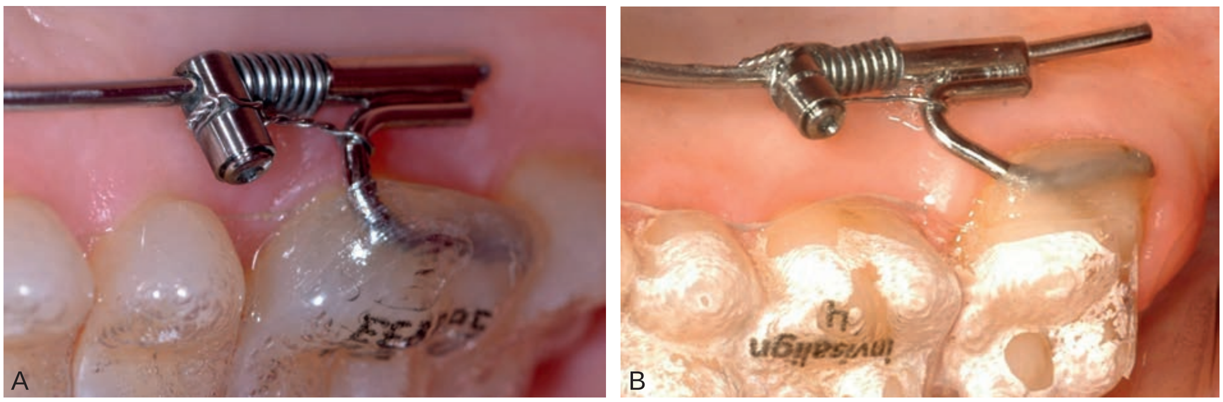

Fig. 24.76 Clinical Tips. The aligner material could cover this bonded connection **(A)**, or the aligner could be cutout in this connection area ("button cut out," **B**). After distalization of the maxillary molar teeth, steel ligatures can be used to modify the active Beneslider into a passive molar anchorage device.

distalization of the maxillary molar teeth, steel ligatures can be used (see Fig. 24.76) to modify the Beneslider from an active distalization device to a passive molar anchorage device. The primary objective is to stabilize the maxillary molar teeth during the retraction of the maxillary anterior teeth.

If frictionless mechanics is preferred and/or the molars are to be uprighted or derotated simultaneously during distalization, Pendulum mechanics can be employed.[315] Several authors have introduced bone-supported Pendulum mechanics to avoid anchorage loss.[316-319] However, all described appliances require additional laboratory work. The Pendulum B[47] was designed to have the ability to adapt a skeletal-borne Pendulum device chairside immediately after mini-implant insertion without a laboratory procedure (Fig. 24.77).

Maxillary Space Closure

A unique clinical challenge presents when faced with a congenitally absent anterior maxillary tooth in an adolescent patient. The two major treatment approaches for consideration are space closure or space opening to allow prosthodontic replacements with either a fixed prosthesis or single-tooth implant. In many cases, space closure to the mesial

Fig. 24.77 Distalization with Pendulum mechanics fixed on two mini-implants (Beneplate with flexible 0.8-mm wire). After molar distalization in a Class I occlusion, the case was finished with brackets.

seems to be a favorable treatment goal because treatment can be completed as soon as the dentition is complete.[321] As an alternative to the T-Bow (indirect anchorage) the Mesialslider,[289,302,322] a *direct anchorage* device can be used. The Mesialslider enables clinicians to mesialize upper molars unilaterally or bilaterally. The maxillary incisor teeth are not fixed, and a midline deviation can be corrected at the same time. The Mesialslider can be used to close space in the upper arch from the distal, such as for missing molars,[323] premolars (Fig. 24.78), canines, or even incisors (Figs. 24.79 and 24.80). The Mesialslider also can be used for protrusion of the whole upper dentition to compensate a mild Class III occlusion. A deviated maxillary midline is often observed in many cases of unilateral congenital tooth absence. The favored appliance to correct the midline, to close the space on one side and to distalize the contralateral segment, is a combination of the Mesialslider and a Beneslider: the Mesial-Distal-Slider[324] (Fig. 24.80).

Molar Anchorage, En Masse Retraction

Conventional appliances designed to provide molar anchorage are headgear, Class II elastics, the transpalatal arch (TPA), 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.[325-327] A mean of 1.6- to 4-mm anchorage loss can be anticipated using conventional dental unit anchorage.[328,329] As a consequence, mini-implants prove to be very useful if molar mesial migration should be avoided during en masse retraction.[327,328] To avoid the risk of root damage, mini-implant fracture, and the high failure rate of mini-implants in the alveolar process, bigger mini-implants in the anterior palate instead of small mini-implants between the second premolars and first molars seem advantageous.[330] It is feasible to anchor the molars with a Beneslider appliance. The second alternative is to adapt a Beneplate or similar abutment with a 1.1-mm steel wire in place and to connect it to lingual surfaces of the molar bands (Fig. 24.81). To control side effects in the transverse dimension, we found it advisable to carry out corresponding additional posterior transversal reinforcement, resulting in the Triangle-TPA (see Fig. 24.81).

Alignment of Impacted Teeth

Ectopic and impacted teeth are frequently encountered in contemporary orthodontic practice, with epidemiologic studies reporting an incidence of impacted teeth of up to 39% for lower third molars, 0.92% to 3% for upper canines, and 0.2% for upper central incisors.[331,332] The treatment of impacted teeth usually comprises three phases: (1) surgical exposure and bonding of an attachment, (2) eruption of the impacted tooth by application of an extrusive force, and (3) three-dimensional orthodontic alignment.[333] The force needed to conventionally extrude an impacted tooth very often produces side effects on the surrounding dentition.[334] Intrusion of the adjacent teeth or even the development of a cant of the occlusal plane may be encountered. Consequently, stable anchorage is essential to minimize these side effects. Using palatal mini-implant anchorage, new solutions to provide sufficient anchorage have become feasible without any side effect on anchorage teeth (Fig. 24.82).

Molar Intrusion

To avoid tipping of the molars as intrusion occurs, forces must be applied consistently from the buccal and palatal aspects, or a TPA placed to support the teeth. Skeletal fixation plates may be surgically inserted into the zygomatic buttress, to apply a buccal force to achieve molar intrusion.[335-339] However, their placement necessitates a surgical procedure

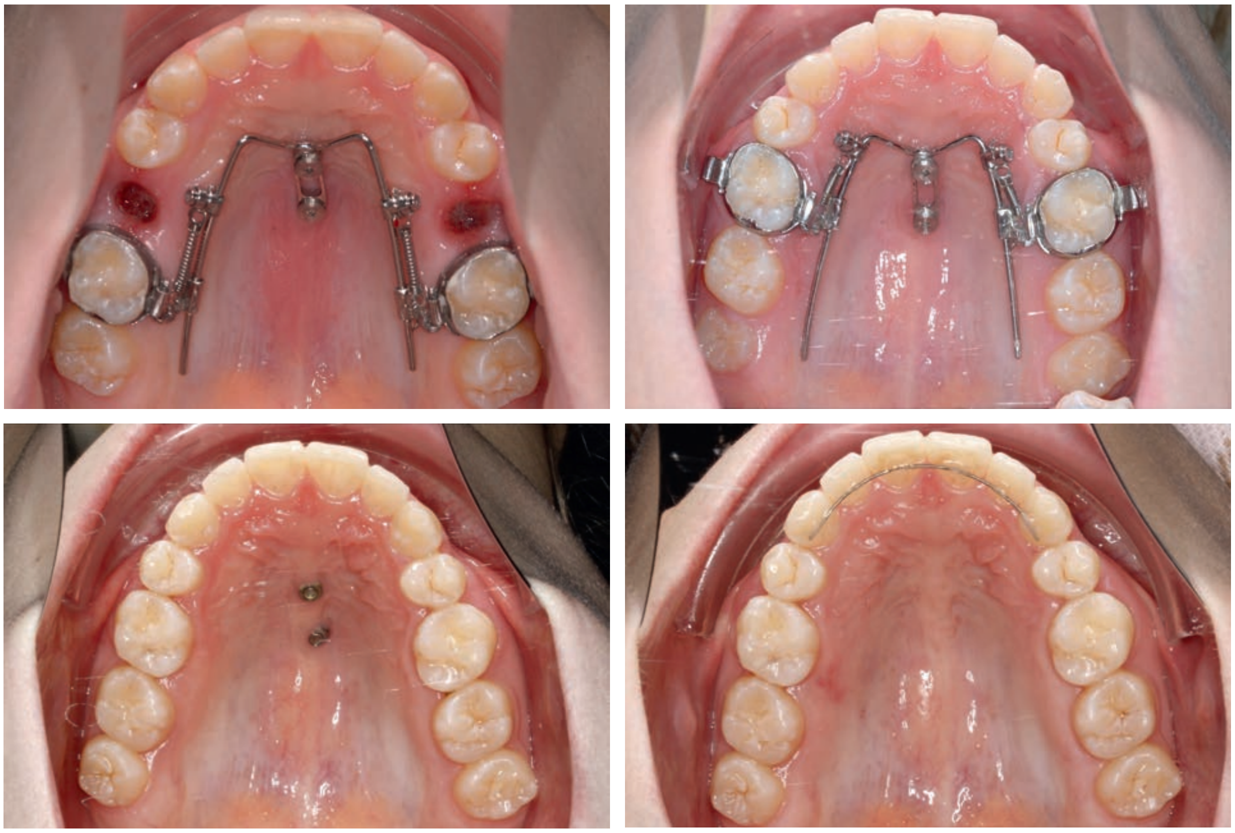

Fig. 24.78 Space closure in the upper arch (missing second bicuspids) using a Mesialslider. The case was finished with brackets.

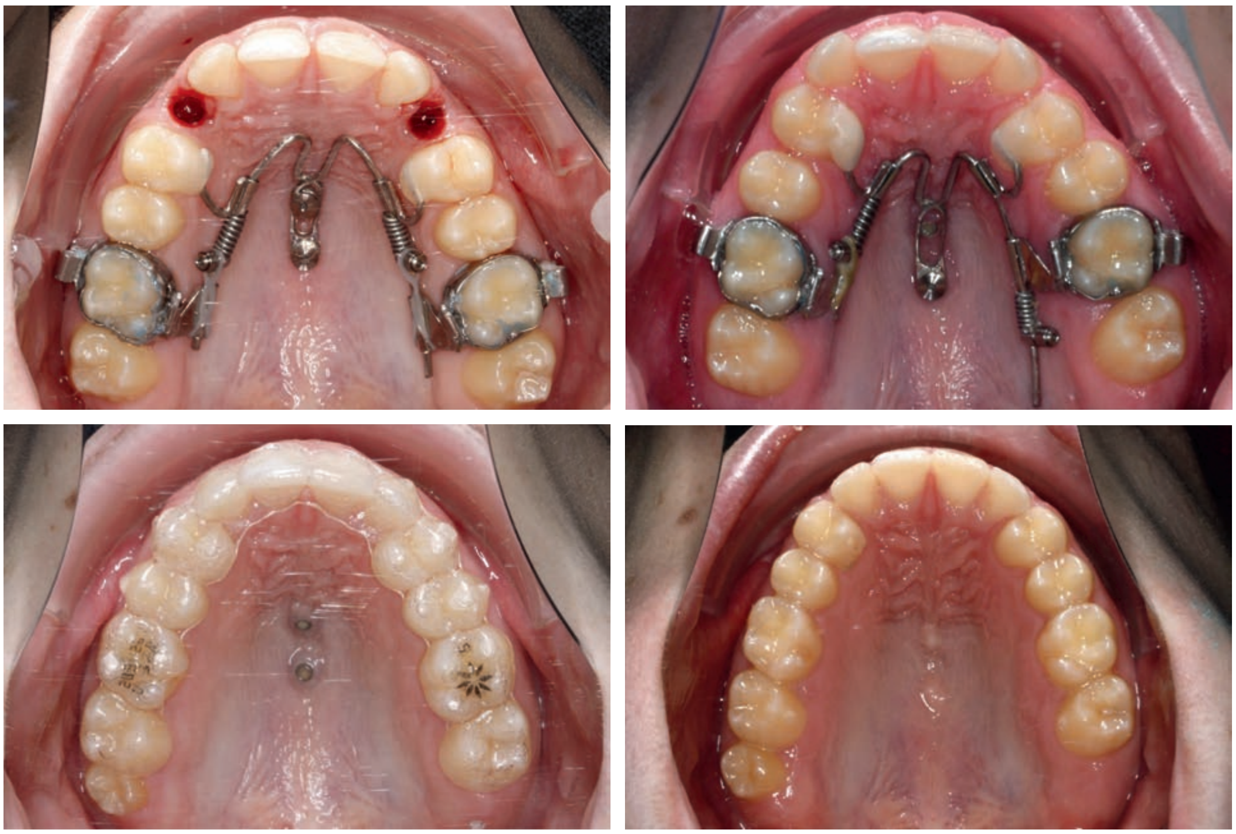

Fig. 24.79 Space closure in the upper arch (missing lateral incisors, canines in the position of the lateral incisors) using a Mesialslider. The case was finished with aligners.

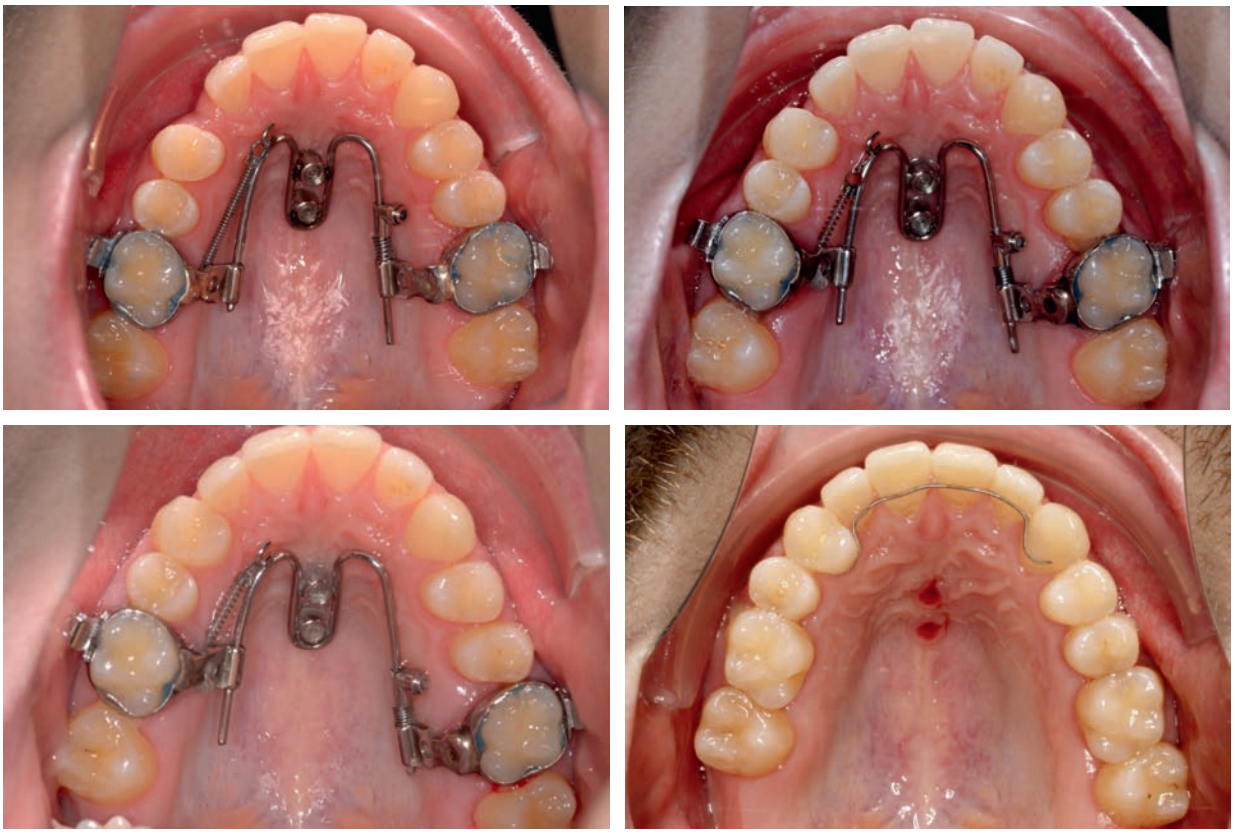

Fig. 24.80 Space closure in the upper right quadrant (missing canine), distalization in the second quadrant to correct a midline shift using a Mesial-Distalslider. The case was finished with multibracket therapy.

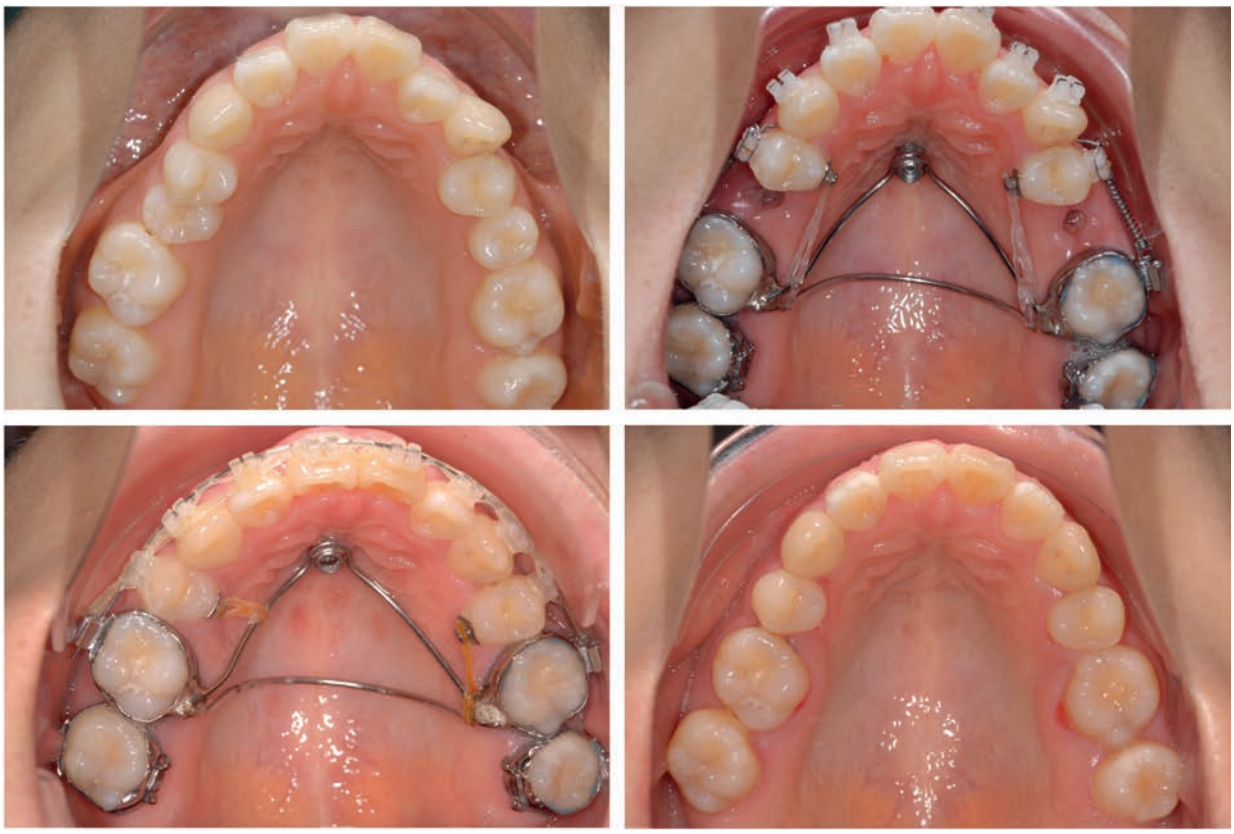

Fig. 24.81 Maximum upper molar anchorage for en masse retraction using one palatal mini-implant and a triangle transpalatal arch.

Fig. 24.82 Alignment of an impacted left central incisor using a 16 × 22 titanium-molybdenum alloy wire fixed on a Beneslider for simultaneous upper molar distalization (multipurpose use[114]).

and the exposure of bone. The insertion of larger mini-implants in the infrazygomatic crest is a considered alternative, but carries the risk of screw failure and soft-tissue irritation given the quantum of movable mucosa at the insertion site.[280,340] A third alternative is to insert mini-implants in the alveolar process,[341-344] but the disadvantages of placement between the roots of the upper molars include:

- In many cases, there is insufficient space on the buccal aspect to insert a mini-implant safely between the molar roots.[345-347] Narrower implants carry a higher risk of fracture[348] and failure.[349,350]
- The soft tissue is often thicker on the palatal side of the alveolar process,[288] necessitating a longer lever arm that increases the likelihood of mini-implant tipping and failure.[349]
- Contact between a mini-implant and a dental root may cause damage to periodontal structures and possibly lead to failure.[282,351]
- A molar moved against a mini-implant during intrusion will cease to move, and the root surface may be damaged.[352,353]
- When a mini-implant is inserted in the posterior area of the upper alveolar process, there is a risk of penetration into the maxillary sinus.[354]

In consideration of these problems, it is preferable to insert mini-implants away from the roots of the teeth likely to be moved. The anterior palate offers a location of high bone quality, thin soft tissues, and nearly no risk of dental interference or root damage, which allows the insertion of mini-implants with a very high success rate.[287] Mini-implants have been used in the anterior palate in combination with a lever arm.[355,356] Aptly named a Mousetrap, this appliance generates upper-molar intrusion and is combined with a TPA to avoid palatal molar tipping (Fig. 24.83). Because the placement of a TPA may reduce patient comfort, a down-sized palatal appliance named the Mini-Mousetrap may be used as well (Fig. 24.84). The design of the Mini-Mousetrap is less bulky compared with the original Mousetrap appliance, which incorporated a TPA. However, movement of the molars should be monitored carefully, and the lever arm must be adjusted as necessary.

Rapid Maxillary Expansion

Maxillary hypoplasia is commonly encountered with a Class III malocclusion. Maxillary transverse deficiency is often associated with unilateral or bilateral posterior crossbite,[357] whereas anteroposterior deficiency can be associated with an anterior crossbite or edge-to-edge relationship.[358] RME has been considered the optimal approach to manage transverse maxillary deficiency in preadolescent individuals,[359-361] and when combined with a protraction facemask, can stimulate downward and forward growth of the maxilla while redirecting mandibular growth downward and backward.[362–364] In conventional maxillary expansion and protraction tooth-borne appliances, unwanted dental side effects such as buccal tipping of the teeth, root resorption,[365-367] decrease in buccal bone thickness,[368] or dehiscence and gingival recession,[369] usually resulting from the heavy forces required for maxillary expansion und protraction is observed. The protraction forces from the facemask can lead to mesial migration of the dentition and the development of anterior crowding.[362]

More recently, mini-implants have been used for expansion as well as the protraction with the anchorage teeth to reduce or eliminate the unwanted dental side effects. Wilmes et al.[278,289,305,370] introduced the Hybrid Hyrax expander in 2007 using two mini-implants in the anterior palate and two molars (Fig. 24.85). Similar hybrid expanders were published in the following years by Garib[371]

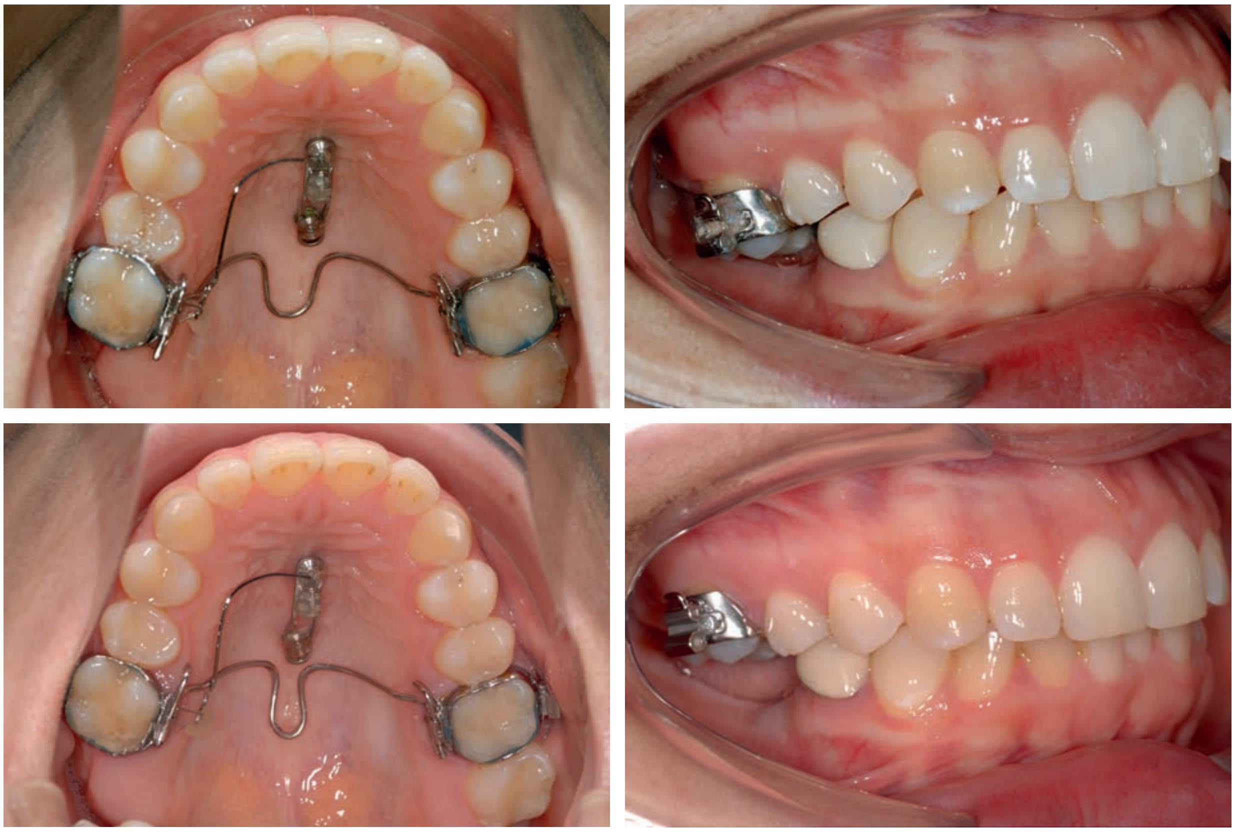

Fig. 24.83 Upper molar intrusion using the "mousetrap" appliance. The transpalatal arch aids in maintaining molar axial inclination.

Fig. 24.84 Upper molar intrusion using the "mini-mousetrap" appliance.

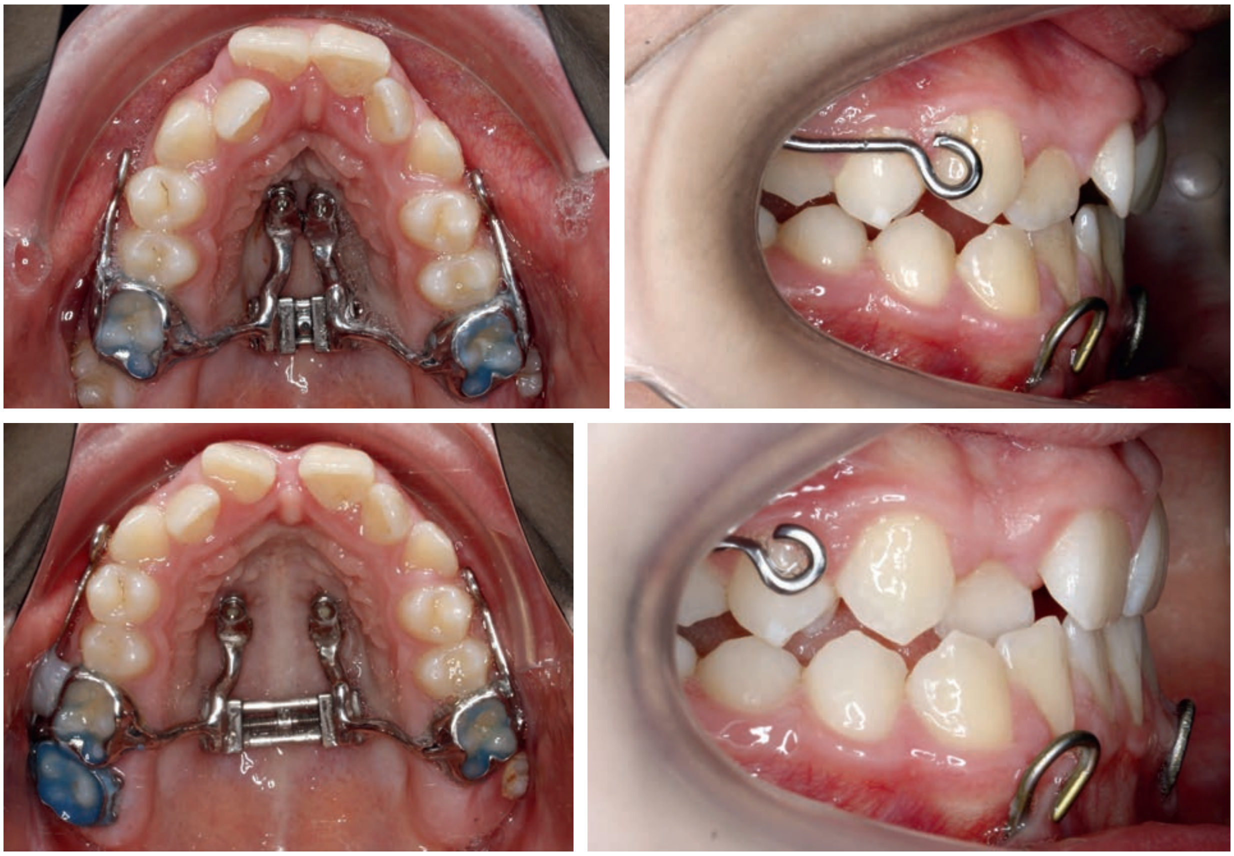

Fig. 24.85 Rapid maxillary expansion and protraction using a digitally designed Hybrid Hyrax for expansion and a miniplate in the mental area (Mentoplate) for Class III traction.

in 2008, Lee[372] in 2010, and Moon[373] in 2015 called mini-implant assisted rapid palatal expansion (MARPE) (see Chapter 25) . Mini-implant–supported expanders also can be used very successfully for the treatment of growing Class III patients,[362,374-380] allowing skeletal maxillary protraction without the commonly observed dental side effects.[373,376,377,381] Furthermore, the introduction of miniplates offered an alternative to the facemasks with improved patient acceptance, given ability to wear the protraction elastics full-time as well as better vertical control of the mandible. Additionally, alternating expansion and constriction of the maxilla Alt-RAMEC[380,382] over a period of 9 weeks can enhance the response of the maxilla to the protraction forces and confer an improved response in children with more sutural maturation.[383-385]

In some clinical scenarios, there may be an additional need for subsequent molar distalization following maxillary expansion. The use of a headgear for maxillary molar distalization may result in a perhaps unwanted orthopedic maxillary growth inhibition. Additionally, there may be an instinctive problem with compliance with headgear. Consequently, it seems reasonable to use the mini-implants that were used for rapid palatal expansion and maybe for sagittal anchorage for the facemask (Hybrid Hyrax) phase for the molar distalization phase. This multipurpose appliance is called the "Hybrid Hyrax Distalizer" and is used for the following three purposes:

1. To relieve the premolars/deciduous molars of side-effects (no tipping, no periodontal damages, no loosening of teeth) when expanding the maxilla[305]
2. To avoid mesial migration of the upper molars when using a facemask[386]
3. To distalize the upper molars without anchorage loss and a need for additional patient compliance

In summary, the orthopedic advancement of the maxilla and the simultaneous orthodontic distalization of the upper molars is feasible with the Hybrid Hyrax Distalizer (Fig. 24.86).

Conventional Versus Digital Techniques?

Both conventional and digital workflows are safe and efficacious and improve patient care and comfort. As shown by Graf et al.[303] the CAD/CAM workflow obviates the need for tooth separation and the potentially uncomfortable procedure of fitting of orthodontic circumferential stainless steel bands. The full digital workflow offers the opportunity to insert mini-implants and CAD orthodontic appliances in a single appointment, making the process more economical for the patient and the doctor. De Gabriele et al.[292] have initially described the implementation of a single appointment workflow. However, the orthodontic appliances were manufactured by conventional laboratory techniques.[292] Compared to the traditional laboratory manufacturing method of palatal min-implant borne mechanics, we experienced that the digital appliance design workflow enhanced appliance fitting greatly. The digital workflow eliminates possible sources of error such as:

1. Band transfer from impression to a plaster model
2. 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 maxillary expansion appliances).

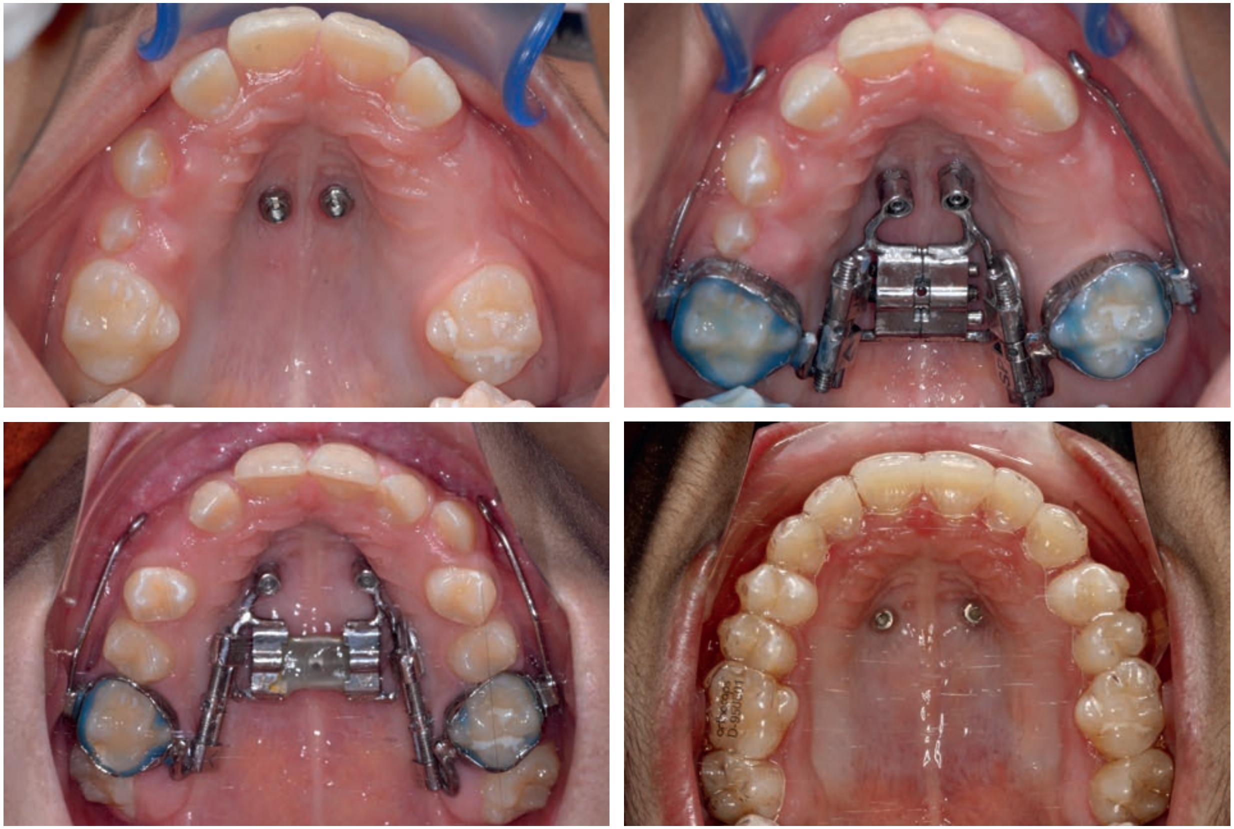

Fig. 24.86 Rapid maxillary expansion and subsequent upper molar distalization using the Hybrid Hyrax distalizer, the case was finished with aligners.

CONCLUSION

The use of palatal TADs with abutments is expanding the options in orthodontic and orthopedic treatment significantly. Insertion and removal are minimally invasive procedures; orthodontists can position the implants 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. The attached mucosa has a better prognosis than other areas, and there is no risk of tooth damage. Today, a complete digital workflow from virtual insertion to CAD/CAM design of orthodontic metallic appliances is possible. These new procedures allow mini-implant insertion and appliance fit in one appointment. CAD/CAM design processes offer the opportunity to further improve the biomechanics of orthodontic appliances.

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