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CAD-CAM design and 3-dimensional printing of mini-implant retained orthodontic appliances

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The objective of this article was to illustrate the digital process in the custom fabrication of metallic mini-implant supported appliances. An implant-supported appliance was produced for a patient using a CAD-CAM procedure without a physical impression or a printed model. The work flow consisted of mini-implant insertion into the palate, recording an intraoral digital scan, digital design with incorporation of a scanned expansion mechanism, direct 3-dimensional metal printing via laser melting, laser welding of the hyrax mechanism, insertion, and activation of the appliance. The favorable clinical outcome demonstrated that this procedure is an efficient and viable method for constructing an implant-supported palatal metallic appliance. (Am J Orthod Dentofacial Orthop 2018;154:877-82)

The adjunctive use of mini-implants is considered a staple in contemporary orthodontic care due to their versatility, minimal invasiveness, and cost effectiveness.[1,2] They have enabled astute clinicians to bypass the need for extraoral appliances, support the biomechanical basis for selective tooth movement, and possibly avoid the need for adjunctive surgical intervention. The orthodontic specialty continues to make significant advances with the development and incorporation of various digital technologies including 3-dimensional (3D) digital casts, individual bracket setups, aligners, and customized archwires. The evolution of this progress is expected to naturally flow to the adaption of 3D printing of traditionally laboratory custom-made appliances. Graf et al[3] presented an innovative method of 3D metal printing (laser melting) for rapid palatal expanders.

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All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and none were reported.
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Submitted, December 2017; revised and accepted, July 2018.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2018.07.013

From the time when orthodontists first began to use palatal mini-implants in their treatment approaches, the method of connecting the orthodontic appliance with the implant has garnered little review and focus. Prefabricated appliances have been most commonly used (eg, Benefit system; PSM Medical Solutions; Tuttlingen, Germany), which can be directly adapted to the implants intraorally, or indirectly modified after recording an impression of the surgically positioned implants with the adjunctive use of impression caps.[4]

The introduction of intraoral scanning devices enables the recording of intraoral scans of the implants to be performed with a high degree of accuracy.[5] A scan body (analog to the impression caps) on the mini-implant can be used to enhance the precision of the scanning outcome, or the mini-implant can be scanned directly depending on the accuracy of the intraoral scanning device. Once the scan has been successfully procured, the clinician and laboratory technician can collaboratively design a customized appliance based on the individual treatment objectives and required biomechanical plan for the patient. The objective of this article was to illustrate a novel method for the digital CAD-CAM design and 3D printing of a mini-implant retained orthodontic appliance.

MATERIAL AND METHODS

The process commences with the surgical placement of 2 mini-implants (PSM Medical Solutions; diameter, 2 mm; length, 9 mm) in the anterior hard palate. A TRIOS intraoral scanner (3Shape, Copenhagen, Denmark) is used to record color images of the maxillary arch, including the 2 mini-implants without transmission caps. The 3D stereolithographic file is sent directly to the off-site dental laboratory, where the appliance is digitally designed with readily available appliance designer software from 3Shape. Additional proprietary components to the software include scanned stereolithographic files of the mini-implants and expansion-screw mechanism.

The molar bands of the designed appliance were substituted with a circumferential ring, consistent with the c-clasp design commonly used in removable prosthetic designs.

The circumferential ring is designed with a thickness of 0.7 mm and positioned 0.05 mm (bonding space) from the tooth surface, permitting application of the requisite bonding material between the appliance and the tooth. The molar bands were palatally extended with an arm to the second premolar and the second molar. The buccal surfaces of the maxillary posterior dentition were concomitantly bonded with multibracket edgewise appliances, while maintaining the implant-supported appliance to serve as anchorage and provide for stabilization. Small projection tips on the buccal and palatal extensions were incorporated to aid in the removal of the appliance, because the highly polished surfaces of the appliance are too smooth for the required frictional force with a debonding plier.

The connection on the neck of the implants was designed on the surgically positioned and digitally matched implants as a round flat ring with the same height and diameter as the neck of the implant. In patients with a high arched and narrow palate, it might be difficult to scan the implant head circumferentially because of the relatively large size of the scanner head. In such cases, it is prudent to use a virtual implant analog to achieve perfect fitting of the ring on the implant neck. Furthermore, some intraoral scanners cannot directly scan metal surfaces of mini-implants due to their highly reflective nature; this may necessitate the use of a digital implant analog. The analog is comparable with the classic cast implant analog for the laboratory process. When 3 points are clearly marked on the scanned implant head, superimposition with the digital implant analog is achievable, resulting in a precisely defined form to design the implant-neck surrounding ring. Another possible solution to improve the surface recording of the mini-implants is to use either a scan body (Fig 1), scan powder (eg, from 3M Unitek, Monrovia, Calif), or a prosthodontic occlusion spray. The expansion screw (Forestadent, Pforzheim, Germany; 12 mm expansion; 0.9 mm/turn) was digitized and inserted with the largest possible welding area to the designed wires. These wires are designed with a diameter of 1.2 mm, providing the connection between bonding site, implant head, and expansion screw.

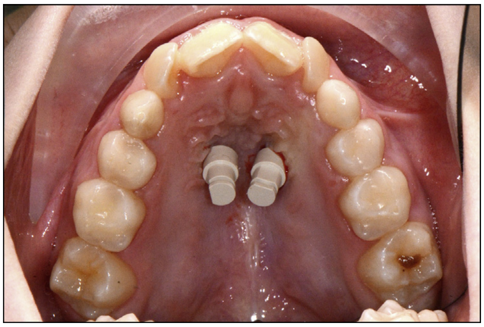

Fig 1. Scan bodies (analogous to the impression caps) on the mini-implants. They may be used to enhance the precision of the scanning outcome (only needed for some scanners).

The digital design goes to a laser-melting machine (Fig 2) (Concept Laser, Lichtenfels, Germany) where the primary structure of the appliance is printed 3 dimensionally with remanium star metal alloy (Dentaurum, Ispringen, Germany), commonly used in the fabrication of removable dental prostheses. The 3D metal printing process consists of 2 phases. Initially, the remanium star powder is spread in a layer of 25 μm (depending on the grain size of the metal-alloy powder) and laser melted in the required spots to construct a solid structure. The layering procedure is repeated until the whole structure is completed (Fig 3). The laser melting device from Concept Laser has the smallest melting volume of 9 × 9 × 8 cm with a 110-W laser and requires 11 hours for the fabrication of 4 appliances, each with a build volume of 6 × 3 × 2 cm. The time required for fabrication of the appliances could be further reduced with at least 1 of the following approaches: (1) a larger machine with a greater build volume, (2) use of 2 lasers instead of a single laser, and (3) a machine with higher power wattage.

The CAMbridge software (3Shape) controls the specific positioning of the appliances in the build-up volume. The precise bonding sites should not be covered with supporting sticks from the build-up process, because it would undermine the precision of that area. The supporting sticks are required, since the appliance would otherwise distort under its own weight with the accumulation of heat during the build process (Fig 3, *A*). The design of the stick can be varied to consist of small crosses, or thin solid or hollow columns connected to the appliance at a single spot. In this manner, they can be easily removed after the production for polishing.

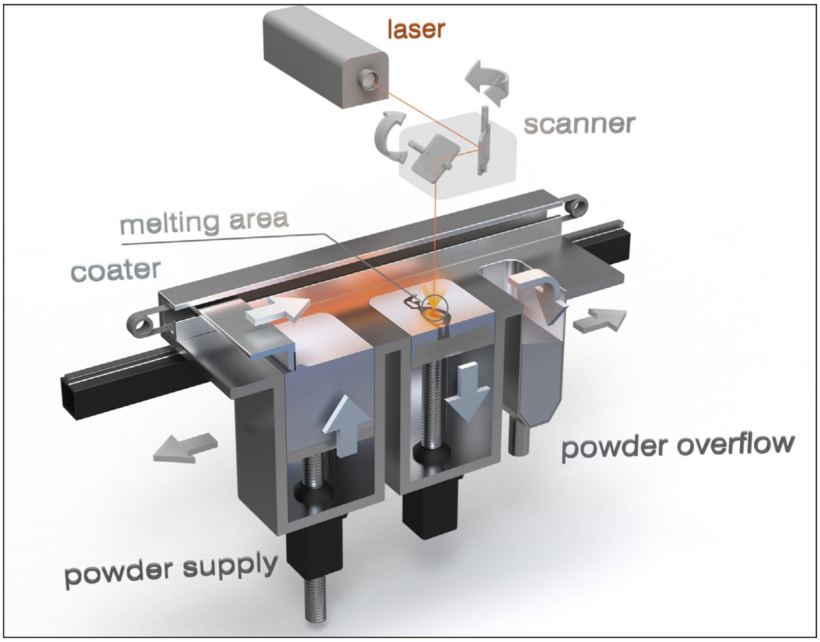

Fig 2. Principle of selective laser melting: The metal is applied in powder form in a thin layer by a coater. A laser locally melts the fine metal in powder form. The contour of the component is produced by redirecting the laser beam using a mirror deflecting unit (scanner). The component is built up incrementally layer by layer, applying more powder and then melting again (courtesy of Concept Laser, Lichtenfels, Germany).

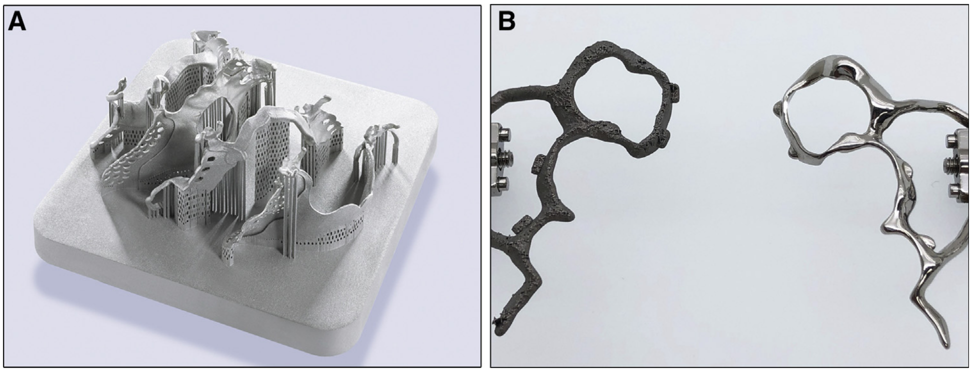

Fig 3. A, Appliances after laser melting with supporting sticks from the build-up process; **B,** hyrax expander before (*left*) and after (*right*) polishing.

The second phase, after removal of the unmelted powder, is the sintering process itself and removal of the accumulated stresses from melted spots (homogenization) in the construction. For the sintering process, the build-up platform is heated to 1150°C and held at this temperature for 1 hour. The entire duration including heating and cooling is approximately 5 hours.

Subsequently, the appliance with the support sticks needs to be removed from the building platform; the sticks need to be removed, and the whole appliance requires polishing. The principal advantage of laser melting over sintering is that there isn't a requirement to calculate the percentage of shrinkage, since the green body (in sintering) needs to be removed from the supporting material from within the structure itself. With laser melting, the basic structure already has the correct shape and size. The expansion screw is laser welded to the prepared site after the polishing procedure.

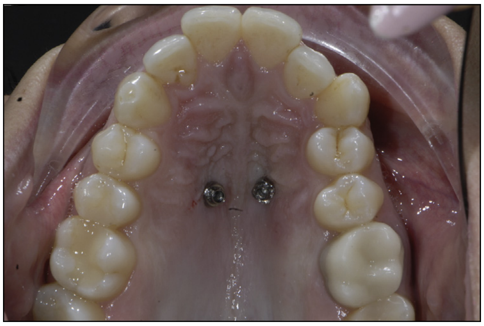

Fig 4. Two mini-implants positioned in a transverse configuration.

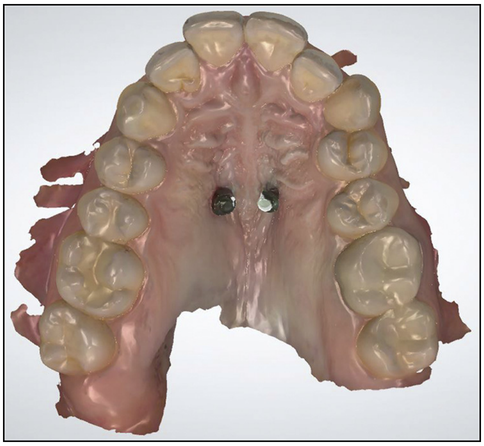

Fig 5. The intraoral scan after insertion of the temporary anchorage devices.

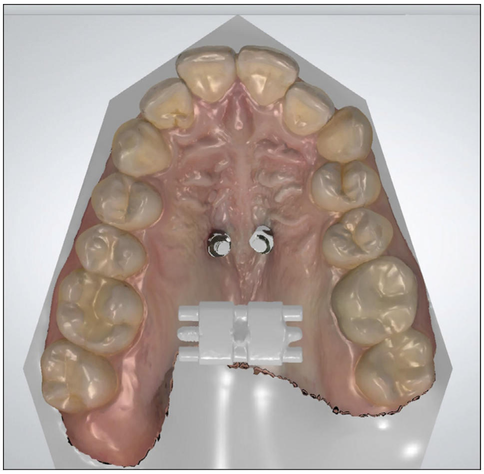

Fig 6. Virtual positioning of the digital implant analogs and the transverse expansion screw.

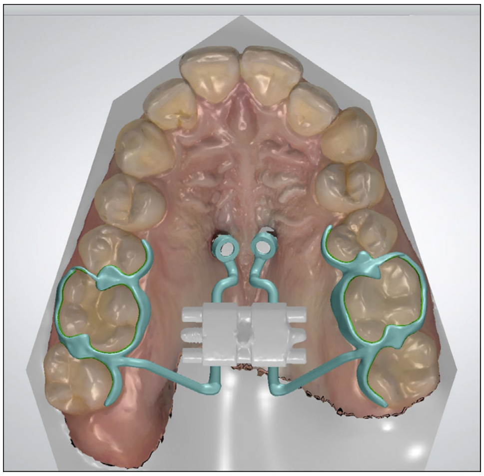

Fig 7. Virtual planning of a hybrid hyrax expander.

Clinical example

A 27-year-old fit and healthy woman attended the Belp clinic in Switzerland with a left unilateral skeletal crossbite, an Angle Class II Division 1 left-hand-side malocclusion on a skeletal Class II base. Transverse maxillary constriction was noted with a maxillomandibular deficiency of 7 mm. The maxillary incisors were excessively proclined. The treatment objective was correction of the left unilateral crossbite. The patient wanted to avoid the surgical procedures associated with surgically assisted expansion of the maxilla. The relative merits, shortcomings, and risks of each treatment modality were clearly presented to the patient, who made an informed decision to proceed with treatment using a partially tooth-borne and partially bone-borne expander (hybrid hyrax[6,7]).

After the application of topical or local anesthesia, 2 mini-implants (dimensions, 2 × 9 mm) were positioned adjacent to the midpalatal suture in a transverse configuration using a manual contra-angle driver (Fig 4). The thick lateral soft tissue limited the approximate distance between the mini-implants to 5 to 10 mm.[8] It is recommended that mini-implants positioned in a paramedian pattern should not be angulated anteriorly.[9] Rather, the mini-implants should be located directly perpendicular to the occlusal plane. The relatively reduced volume of bone in this region limits the use of a smaller mini-implant of 7 to 9 mm. The intraoral scan was recorded (Fig 5), and the stereolithographic file was sent to the orthodontic laboratory for the design and fabrication of the appliance as described previously (Figs 6-8). Approximately 10 days later, the hybrid-hyrax

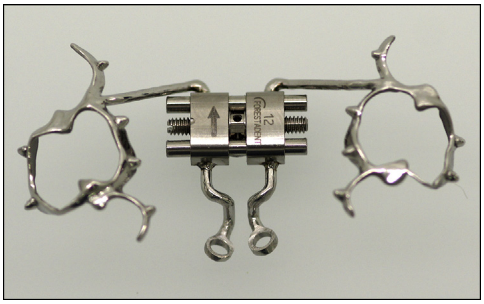

Fig 8. Laser-printed hybrid hyrax expander.

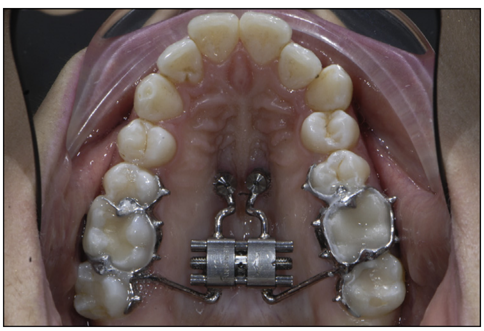

Fig 9. Intraoral fixed hybrid hyrax expander.

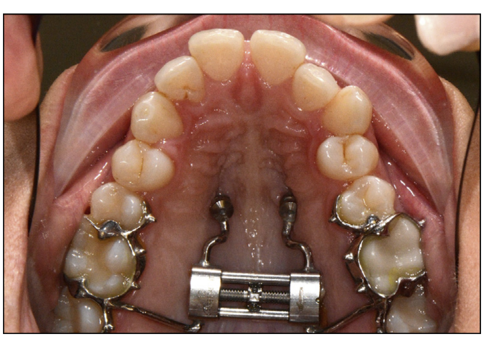

Fig 10. Intraoral situation after rapid maxillary expansion.

appliance was securely attached to the 2 mini-implants via fixation screws and bonded to the maxillary dentition (Fig 9) with Scotchbond Universal and Transbond XT (both, 3M Unitek). After the active phase of maxillary expansion was completed (Fig 10), the hybrid hyrax was left passively in situ for 6 months. The patient proceeded with the residual treatment recommendations involving full fixed orthodontic appliances bonded on the maxillary and mandibular dental arches (Fig 11). The maxilla was successfully expanded by 9 mm as planned (Fig 12).

Fig 11. After 6 months of retention, brackets were bonded.

Fig 12. Improvement of the smile corridor, before (*left*) and after (*right*) rapid maxillary expansion.

DISCUSSION

Advances in digital imaging have enabled modifications in the procurement of maxillary and mandibular dental arch records. Digital scanning has been reported to be accurate and simple to use, to cause minimal discomfort for patients, to eliminate the need to maintain the supplies for conventional impressions, to minimize disinfection and cross-contamination, and to provide a long-term storage option for dental casts.[5] The success of the procedures described here is underpinned with the adjunctive use of an accurate intraoral scanner. A learning curve must be expected for a scanner, the CAD-CAM work flow, and the interaction with a dental laboratory. Although it may not be considered mandatory, the 3D printing of the pretreatment study model may enable the fit and accuracy of the appliances to be verified. The adjunctive use of a scanning impression cap for the mini-implant may reduce the scan recording times for the implants.

Tooth-borne expanders are the commonly used treatment option to correct narrow maxillary arches. However, they often cause dental tipping, root resorption, and periodontal damage. Mommaerts[10] introduced a bone-borne technique to prevent these side effects (TPD distractor). However, some studies have reported that these distractors are associated with a high risk of root lesions or infections.[11] Mini-implants have attracted considerable attention in recent years, since they are less invasive, low in cost, and easy to use clinically.[1] More recently, expansion appliances have been developed that use palatal mini-implants, minimizing the forces that are placed on the teeth. Implant-supported rapid palatal expansion has been developed to maximize skeletal expansion and minimize the dental side effects.[7,12-14]

CONCLUSIONS

The CAD-CAM procedure for fabrication of 3D metal printed orthodontic appliances is an efficient and accurate method to fabricate palatal mini-implant borne appliances. The advantages for the patient are fewer clinical appointments and greater comfort during the scan recording process. Advantages of this technique over conventional impressions for mini-implant supported orthodontic appliances include elimination of impression trays and material while obtaining distortion-free images of the patient's dental arches. These can then be electronically transmitted to the laboratory for fabrication of the appliances.

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