Maxillary space closure using a CAD/CAM manufactured Mesialslider in a single appointment workflow

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Acknowledgement: The authors Willmann, Wilmes and Drescher are co-partners of the dental laboratory "TADMAN", which uses CAD/CAM designing technique for manufacturing orthodontic appliances. This case report did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Abstract

New digital technologies, many involving 3D printing, bring benefits for clinical applications. This article reports on the clinical procedure and CAD/CAM fabrication of a skeletally anchored mesialization appliance ("Mesialslider") used for the space closure of a congenitally missing lateral incisor in a 12-year-old female patient. The insertion of the mini-implants and of the appliance was done in a single appointment workflow. The case report showed that bodily movement of the molars was achieved with the Mesialslider. Anchorage loss, such as a deviation of the anterior midline or palatal tilting of the anterior teeth was completely avoided. The CAD/CAM procedure facilitates the safe and precise insertion of mini-implants. Furthermore, they can improve patients comfort by reducing office visits and avoiding the placement of orthodontic bands or the taking of physical impressions.

Keywords: Agenesis, Orthodontic mini-implant, tooth movement, CAD/CAM

Introduction

Congenitally missing maxillary lateral incisors and traumatic tooth loss are the most frequent reasons for spaces in the maxillary anterior region in adolescents.[1] The absence of these teeth can be either uni- or bilateral. When planning the therapy, each practitioner has to decide how to treat these spaces in the long-term as there are two major treatment approaches.[2,3] One option is to maintain or to open the space in order to allow a later prosthodontic replacement with a single-tooth implant or fixed prosthesis.[4] However, single-tooth implants may potentially compromise long-term aesthetics of the maxillary anterior region due to ongoing alveolar ridge growth and bone remodeling resulting in an increasing infraposition.[5,6] Therefore, in many cases orthodontic space closure seems desirable and treatment can be started as soon as the dentition is complete.[7-9] The demands for anchorage quality will be higher compared to space opening.[10] Maintaining the sagittal overbite and avoiding a deviation of the anterior midline requires excellent anchorage, especially in asymmetrical spacing and the more mesial the position of the missing tooth is. Intraoral anchorage by means of intermaxillary elastics is frequently used, but the success highly depends on patient compliance. A further disadvantage is the distally directed force on the mandibular dentition, which will result in retrusion of the mandibular anterior teeth.

A compliance-independent appliance that anchors itself exclusively in the maxillary dentition would therefore be desirable for space closure to avoid retrusion of the mandibular teeth. The use of skeletal anchorage has increased in recent years not only because of its independence from patient compliance but also due to the need to provide more reliable anchorage.[11] For mesialization in the maxillary jaw, the Mesialslider in particular has become increasingly well established.[12-17] Three-dimensional evaluation of space closure using the Mesialslider have shown that the anterior tooth position was not adversely changed after space closure with an average molar movement of 6.3 mm.[18] The advantages of mini-implants in the anterior palate (T-zone) are the good bone quality, the high success rate without the risk of tooth injury and the ability to move all teeth in the dental arch without any interference with the TADs.[19]

New digital technologies are increasingly being incorporated into the practice of orthodontics. Multiple examples show that many workflows have already been successfully digitalized, including the digital workflow for the use of mini-implants and the production of superstructures.[20] Until recently, the manufacturing involved a classical laboratory process with band fitting, physical impression taking, production of a study model and subsequent construction of the appliance using some prefabricated components.[12] Due to the improvements in intraoral scanners and their increasing reliability as well as the emerging developments in the field of additive manufacturing, digital CAD/CAM workflows have been successfully applied in the production of orthodontic appliances such maxillary expanders and fixed retainers.[21,22] This article reports on the application of these technologies for the manufacturing of a mini-implant-supported Mesialslider.

Diagnosis and Etiology

A 12-year-old healthy female patient in the permanent dentition presented with a Class I malocclusion, agenesis of the maxillary right lateral incisor, a retained right deciduous canine and a high smile line (Fig. 1). The maxillary left lateral incisor was diminutive with generalized microdontia resulting in generalized spaces in both arches. Radiographs (OPG and dental film) showed presence of all wisdom teeth and advanced root resorption of the deciduous canine (Fig. 2).

Treatment Objectives

Treatment objectives were to level and align both arches, extract the deciduous canine, space closure by mesialization of the right quadrant and finishing with a therapeutic unilateral Class II molar relationship.

Treatment Alternatives

The treatment alternative involved preserving the deciduous canine and keeping the space open for an implant later. Given the questionable prognosis of the tooth, which was likely to be lost soon and considering the young age of the patient, it would be too early for space opening as the alveolar ridge would probably atrophy to a significant degree due to the lack of function by the time implantation is possible. The patient and family agreed to a treatment plan to mesialize the maxillary posterior teeth unilaterally for orthodontic space closure. For aesthetic reasons, restorative enhancement of the diminutive left lateral incisor with composite build-ups, as well as remodeling of the maxillary right canine and first premolar according to the "camouflage concept" of Zachrisson[23] were planned. The first premolar was remodeled into a canine and the canine into a lateral incisor. In addition, intrusion of the first premolar and extrusion of the canine were planned in order to harmonize the gingival line along with reshaping the canine by inter-proximal and incisal grinding.

Treatment progress (CAD-CAM manufacturing and clinical procedure)

The maxillary arch and palate were recorded with a TRIOS intraoral scanner (3Shape, Copenhagen, Denmark) and the resulting STL file uploaded to Blender (open-source software, Blender Foundation, Amsterdam, Netherlands), where the options were to merge it either with a CBCT or with a lateral cephalometric radiograph. In this case, we used the available cephalometric radiograph. The superimposition of the patient scan and the patient X-ray was based on a positioning of the central incisors on top of each other: The 3D model is split along the raphe median plane, and then moved and rotated in transparent mode on the lateral ceph until the axis inclination and width of the upper incisors of the position are matched. The matching can be made by Blender or by commercial software (for example "TADmatch" by OrthoLox, PROMEDIA, Siegen, Germany).

Our blender database maintains previously scanned STL files of different lengths mini-implants on file. The optimal selection of the implant length and sites for placement was identified according to the superimposition of the x-ray with the scanned maxillary arch (Fig. 3). In this clinical case, two 2 x 9 mm mini-implants with exchangeable abutments (Benefit system, PSM Medical Solutions, Gunningen, Germany) were selected and placed in the midline of the anterior hard palate. Based on that implant positioning, the insertion guide was digitally designed using Blender and printed with a 3D printer, in this case with Formlabs® (Formlabs, Somerville, Massachusetts, USA). The printing material used was Formlabs Form 2, Dental SG Resin, which is sterilizable. Any deviations in this step or in the final fabrication or positioning of the insertion guide may lead to inaccuracies that could make insertion of the appliance difficult or even impossible. Therefore, the lumen of the guide was checked by the dental technician for freedom of movement and further polished with a coarse diamond cylinder to reduce any resistance to sliding (Fig. 4). A resulting minimal deviation in the accuracy of the surgical guide is neglectable, as the subsequent superstructure also has a certain tolerance due to the hyrax rings, compared to rigid implant abutments.

The whole appliance was designed with Blender. There was no other add-on module needed except the implant library with implant details, which was shared by the implant producer (Benefit system, PSM Medical Solutions, Gunningen, Germany). The CAD/CAM Mesialslider consisted of a rectangular sliding arch (1.2 x 1.4 mm) for precise guidance control and semicircular rings, so-called shells, functioning as orthodontic bands, which in this example were attached to the maxillary first molars and the right first premolar (Fig. 5). Each shell was positioned 0.05 mm from the tooth surface to allow space for the application of the bonding adhesive. Coupling between tooth and slider was achieved using Versalock tubes (TADMAN, Gunningen, Germany) (Fig. 6).[24] The appliance was attached to the implants using round, flat rings (hyrax rings) of the same height and diameter as the mini-implant neck.

The final digital design was sent to a lab with a laser-melting machine, in which the main portion of the appliance was 3D printed with a Concept Laser (Concept Laser GmbH, Lichtenfeld, Germany) with Cobalt-Chrome-Remanium star metal alloy (Dentaurum GmbH and Co. KG, Ispringen, Germany). The laser-melting process involved the application of metal powder in several thin layers by the coater and subsequent laser melting until the entire structure was finished. Finally, the structures of the Mesialslider were polished by a dental technician and the bonding bases were roughened by sand-blasting (Fig. 7).

The insertion of the mini-implants and of the appliance was done in a single appointment workflow: After surface and local anesthesia, the self-drilling mini-implants were placed using the insertion guide. Usually predrilling is not necessary, but if an insertion guide is used, especially in adult patients with high bone density, it is recommended in order to reduce the possibility of axial implant deviations. A screwdriver with a stop function is recommended for inserting the mini-implants using a surgical guide, so that the screwdriver automatically stops at the upper edge of the guide (Benefit system, Screwholder with stop, 33-10903, PSM Medical Solutions, Gunningen, Germany). This prevents the implants from being inserted too deeply.

The Mesialslider was securely attached to the mini-implants with fixation screws and the shells were adhesively bonded to the palatal surfaces of the teeth with Transbond (3M Unitek). The appliance was then activated with NiTi closing springs (240g) (Fig. 8). Follow-up appointments were scheduled every four to six weeks. After five months of treatment, space closure in the anterior region was almost completed (Fig. 9) and the composite restoration of the diminutive maxillary left lateral incisor was finalized.

The multibracket appliance (Discovery Brackets, 0.018-in slot Roth system, Dentaurum) was inserted eight months after the start of treatment. In accordance with the "camouflage concept" a canine bracket was bonded to the right first premolar and a lateral incisor bracket to the right canine for the appropriate torque values[4,8,23]. The brackets were positioned so that intrusion of the premolar and extrusion of the canine could occur during leveling to ensure correct gingival alignment (Fig. 10). The canine was reshaped by approximal and incisal grinding in two sessions and the intruded premolar was built up with composite. To facilitate final occlusal settling, short vertical elastics were worn while finishing on a 0.017 * 0.025-in

TMA archwire. The brackets were debonded after a total treatment time of less than 24 months; an appropriate overjet and overbite were achieved (Fig. 11, 12).

Results

The virtual superimposition of the pre-treatment situation (blue) with the final outcome (white) showed a bodily mesialization of the posterior teeth in the first quadrant (Fig. 13, 14). The sliding friction or binding in the archwire-slot interplay of the fixed appliance led to a mild proclination of the maxillary anterior teeth, a so-called reverse anchorage loss. The position of the mini-implants remained unchanged. The torque of the maxillary right canine and first premolar was not fully corrected to the normal torque of lateral incisor and canine. In order to achieve further torque, additional treatment time for finishing or aesthetic porcelain restorations with veneers would have been necessary. However, the patient and the family were very satisfied with the result and wished no further treatment.

Discussion

The treatment of anterior spaces is a challenge for every dentist, since both treatment options, orthodontic space closure or prosthetic rehabilitation, have their pros and cons.[5,6,25] Due to vertical alveolar ridge growth and bone remodeling that continues long into adulthood, it is often observed that single-tooth implants develop an infraposition that compromises aesthetics, especially in the maxillary anterior region.[5,6] However, orthodontic closure also has its disadvantages: Treatment usually takes longer than space opening. In addition, there are usually high anchorage demands to prevent undesirable tooth movements such as excessive retraction or palatal tilting of the anterior teeth or midline deviation in the case of unilateral space closure. The use of TADs guarantees better anchorage making one-sided space closure possible and predictable. The virtual superimposition of the pre-treatment situation with the final outcome in this case report showed a bodily mesialization of the posterior teeth in the first quadrant (Fig. 13, 14). However, in order to evaluate that there wasn't any anchorage loss after posterior mesialization, it would be important to compare the pre-treatment situation with the immediate outcome after the space closure. Otherwise, possible anchorage loss could have been corrected by the use of the fixed appliance. In the presented case report we didn't have any recordings at hand before braces were inserted, so this is a limitation of the case report.

The anterior hard palate and direct anchoring by means of Mesialsliders have proven to be highly reliable in everyday clinical practice due to its high success rate and compliance-independence.[18] After complete space closure, detailed finishing is a key factor in achieving an aesthetic outcome. Harmonized gingival contours can be obtained by vertical leveling of the anterior teeth.[4] The canine can be extruded and the first premolar can be intruded to mimic the natural gingival line.[26]

Studies have shown that occlusal function and periodontal status after orthodontic space closure and vertical adjustment showed excellent long-term stability even after many years.[8] A further advantage of space closure is that new bone can be generated in the area of the missing teeth through tooth movement. The clinical impression is that the teeth "take their bone with them". Bone atrophy that has developed in toothless alveolar regions can therefore be corrected.[27-33] Last but not least, existing wisdom teeth often drift mesially after mesialization of the molars due to the interdental fibers and subsequently find sufficient space in the dental arch.

The complete digital workflow, from TAD insertion planning to appliance design, could be implemented in orthodontic implantology. The simultaneous digital manufacturing of insertion guide and superstructures (in this case Mesialslider) allows the insertion of mini-implants and skeletal appliances in only one session (single appointment workflow). Practitioners seeking a safe introduction to treatment with mini-implants often prefer insertion with an insertion guide based on radiographic diagnostics (CBCT or lateral cephalometric radiograph) (Fig. 3). Further potential applications would be for patients presenting with a cleft palate, where bone availability in the anterior palate is unpredictable without guidance from a CBCT. In the single appointment workflow, specific attention must be paid to a precise insertion of the mini-implants, since small axial deviations of the implants can make insertion of the orthodontic appliance difficult if not impossible.

It is already evident that the new digital technologies are bringing significant benefits for clinical applications.

The CAD/CAM designed mesialslider features an enlarged rectangular cross-section to optimize tooth movement and controlled guidance of the molars through the alveolar process. In addition to the change in cross-section, the Cobalt-Chrome-Remanium star metal alloy used for manufacturing (E-modulus: 220 GPa) also ensures a significant increase in the dimensional stability of the 3D-printed mesialslider compared to spring-hard steel (E-modulus: 180 GPa), which is used in conventional manufactured sliders.

The coupling between the guiding bar and the tooth is achieved by means of the newly developed Versalock tubes.[24] This new development is based on the clinical experience that conventional palatal locks easily deform during use and therefore no longer offer sufficient torque control after only a short time. The coupling between tooth and appliance takes place at the level of the resistance center and thus supports a physical tooth movement. The flexible design allows the distalization or mesialization distance to be extended if the guiding bar does not allow sufficient movement distance.

Some studies indicate that implants close to the third rugae or even further anterior may have a higher risk of penetrating the canalis incisivus which could damage the nasopalatine bundle.[34,35] In general, the further posterior the insertion, the less the risk of penetration. Previous publications have shown, that the risk penetrating the incisive canal and accompanying loss of the mini-implants is neglectable when the mini-implants are positioned paramedially or posterior the third palatal rugae within the “T-Zone”. [19] The CAD/CAM appliance described in this article fulfilled both criteria.

However, literature only reports on a very low number of sequelae from possible penetration, such as numbness of the palatal mucosa, which indicate that even penetrating the canalis incisivus often has no negative effects. One idea is that the canalis incisivus has a high anatomic variability and consists of easily slipping fibres within the lumen, so that the risk of injury is very low.[36-38] The described CAD/CAM slider anchors on paramedially placed mini-implants with individually fabricated abutments, which facilitates oral cleaning of the peri-implant region.

It is already evident that the new digital technologies are bringing significant benefits for clinical applications: the devices can be safely inserted in only one defined position and the digital workflow is extremely well received by our patients. The fact, that placement of molar bands including separation and the taking of a physical silicone impression can be avoided, is perceived very positively and increases patients’ comfort by reducing office visits.

Conclusion

CAD/CAM procedures now make it possible to fabricate orthodontic appliances using 3D metal printing. As this article demonstrates, the combination of digital intraoral scanning and direct metal printing of the framework for a molar mesializer can be used to successfully resolve space closure and reduce office visits by achieving a single-appointment workflow. The mesialization appliance is virtually invisible, and fixed orthodontic appliances are needed for only a short period to finish and detail the occlusion.

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Figure:

Figure 1: Pretreatment photographs. Maxillary left lateral incisor was congenitally missing.
Figure 2: Pretreatment radiographs.
Figure 3: Merging of the STL file with the lateral cephalometric radiograph for implant positioning.
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