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A digital CAD/CAM configurator for the production of orthodontic appliances − Going new ways

Christoph J. Roser[a,*], Vincenzo D'Anto[b], Chrisopher J. Lux[a], Cristiano Segnini[b,c]

[a] Department of Orthodontics and Dentofacial Orthopedics, Heidelberg University Hospital, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany
[b] Department of Neurosciences, Reproductive Sciences and Oral Sciences, University of Naples Federico II, Via Pansini, 5, 80131, Naples, Italy
[c] Private Practice of Orthodontics Studio Associato Segnini, Via liberta181, 80055 Portici, Naples Italy

A R T I C L E I N F O

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A B S T R A C T

Functional therapy in growing patients is a highly relevant area in orthodontics. With the increasing integration of computer-aided design and manufacturing technology (CAD/CAM) in orthodontics, we are witnessing significant advancements in the design of orthodontic appliances. Modern 3D printing technologies allow for the creation of complex, customized equipment in a cost-effective and time-efficient manner, using robust and durable resins. Additionally, the creative input of dental CAD design programs has led to the development of new designs.

The aim of this report is to present a novel digital orthodontic prescription that aligns with the concept of a "full digital workflow". This prescription utilizes a digital virtual configurator, enabling effective communication between the clinician, the technician and the patient.

Using this prescription system, clinicians can easily configurate an orthodontic appliance before sending it to a dental technician for individualisation. 3D printing of the final design can then be performed directly within the dental office or by the technician. This approach allows the clinician to explore different orthodontic equipment options and modules, without the requirement for a demanding and sophisticated design process and without any knowledge of CAD. The availability of the present configurator might represent a fundamental advancement in the field of the CAD/CAM production of removable appliance linked to economic and ecological benefits.

Introduction

Digitalisation has opened up more and more possibilities in orthodontics in recent years, both in diagnostics and therapy. Diagnostic tools for the analysis of digital models or cephalograms are now standard in orthodontic diagnostics, whereby a higher degree of accuracy and precision has been achieved.[1,2] In some fields digital technology has progressed to a point whereby orthodontic analysis can even be carried out autonomously. Likewise, the use of digital techniques has also become established in many fields of therapy. A range of appliances which were produced manually are now produced by Computer Aided Design/Manufacturing technology (CAD/CAM) using 3D printers or milling devices. Also, at least partial replacement of long-established appliances such as the multibracket appliance with aligners arrived with the introduction of digital technology in orthodontics.[3,4] To be precise, however, as long as aligners are produced the conventional way, they represent a rather hybrid form of CAD/CAM and manual production since aligners themselves have to be produced manually. However with the rising possibilities of direct printing also the production of aligners will become increasingly automatic since they now can be printed directly by a 3D-printer.[5] Apart from aligners, fixed orthodontic CAD/CAM appliances have also become established in everyday practice for many. First and foremost are anchorage appliances, have also become established planned and purchased from several manufacturers.[6] The same applies to retainers, which are produced by different CAD/CAM techniques like milling, laser melting or laser cutting from a variety of materials such as cobalt-chromium, titanium, nickel-titanium or even zirconia.[7,8] Moreover, 3D-printed have also become established or even produced in-office fully individualized for the respective patients[9-11] and positioned precisely by the use of a 3D-printed bonding tray.[12-15]

In contrast, the CAD/CAM production of functional orthodontic or other removable orthodontic appliances has been limited to a few individual reports. Recently we have presented the CAD/CAM production of the functional regulator III (FR3),[16] the functional regulator II (FR2) and the Sander II appliance[17] and various other removable CAD/CAM appliances.[18] Others presented the CAD/CAM production of the Twinblock,[19] the activator[20] or active plates.[21,22] However, despite numerous advantages, the digital production of functional orthodontic CAD/CAM appliances has not become routine clinical practice. This might primarily because of a demanding and sophisticated design process, which has required a certain affinity for

* Corresponding author at: Department of Orthodontics and Dentofacial Orthopaedics, Heidelberg University Hospital, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany.
E-mail address: christoph.roser@med.uni-heidelberg.de (C.J. Roser).

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working digitally with different programmes like Exocad (exocad GmbH, Darmstadt, Germany), Meshmixer (Autodesk, San Francisco, USA), Blender (Blender Institute B.V., Amsterdam, Netherlands), Blue Sky Plan (Blue Sky Plan, Libertyville, USA), OnyxCeph (Image Instruments, Chemnitz, Germany) or OrthoAnalyzer (3Shape, Copenhagen, Denmark). Yet, despite the sophisticated design part, manufacturing removable appliances from polymers in a 3D-printer might have considerable potential for an in-office production. This is in contrast to other CAD/CAM devices like anchorage appliances whose production process seems not suitable for a dental office to date. Therefore, new concepts are required to facilitate the design process of functional orthodontic CAD/CAM appliances to incorporate the advantages of these appliances into clinical practice. This encouraged to work on a solution that would involve the clinician in the design process but would not require a time-consuming and complex design procedure. Against this background, we present a new digital planning concept, which enables an easy and feasible communication between the clinician and the technician. Using this concept, relieves the clinician from CAD work but offers the opportunity to provide the technician with highly precise specifications for the desired appliance. The clinician just has to choose from several elements, which first automatically fuse to a non-individual appliance. The technician can then use this blueprint to customize the requested appliance in shape, size and position. The aim is to improve the integration of removable orthodontic CAD appliances into everyday clinical practice.

Materials and methods

Scanning the patient

A digital model serves as the basis for a digital construction of the respective CAD/CAM appliance. The clinician has various options to choose from. An intraoral scan can be performed (Fig. 1 b), whereby there are no restrictions in scanner type for the appliance production. For the production of soft tissue worn appliances like the FR3, care should be taken that the soft tissue is properly visualised. For multiple scanners this can be ensured by switching the artificial intelligence function on the scanner off so that important information of the soft tissue is not subtracted. As an alternative a conventional impression can be performed and then digitised by an intraoral scanner or a desktop scanner. In addition to scanning or taking the conventional impression, a construction bite must be taken to capture the therapeutically aimed occlusion. This construction bite in wax corresponds to the conventional fabrication and has to be scanned in mouth to adjust the digital models. If conventional impressions were taken, the plaster models can be scanned with the construction bite on them (Fig. 1 a).

Uploading the STL-files and choosing different elements

After uploading the models as a Standard Triangle Language- (STL-) file, the clinician can start creating the appliance in a software-based configurator (3DO, Naples, Italy). To date, this design process is not yet based on the individual patient model but on a standard model which is already stored within the configurator and which the technician uses as a prescription when designing the patient version accordingly later on the individual patient model.

When creating the appliance, the clinician can choose from a library with a wide range of elements. These include basic elements which are part of the main appliance structure and additional elements which are required for individual purposes. Both location and dimensions are self-determinable. Examples include vertical bite stops in different dimensions which can be located on the upper or lower front teeth or on the posterior teeth (Fig. 2 d). According to the therapy requirements these can be chosen with an impression or with a flat surface to control eruption of individual or multiple teeth. Other elements include sagittal anchorage elements. If required, these can also be combined with attachments, which then must be bonded on to the teeth (Fig. 2 e). Using attachments with functional removable appliances can be useful to transfer the soft tissue pressure on to individual teeth in order to distalize or to uprightening them.

Moreover, it is possible to incorporate metal-based active elements, which can be used for several purposes (Fig. 2 g). The variety includes all elements which have been used for decades for the manufacture of conventional appliance. For example, springs can be integrated to procline anterior teeth or for a buccal movement of the premolars and molars. Other examples include screws which can be used to expand the maxilla or to move individual segments. After all elements have been selected, the software fuses everything together to a final design (Fig. 3). Fig. 4 shows individual final designs of different appliances.

Manufacturing the appliance in-office or by the technician

The final design requested by the clinician serves as the blueprint for the technician's subsequent work, which involves recreating the design for the patient's individual situation. Essentially, the same elements are used but must be individually customized in size, shape, and position. For this purpose, the technician can utilize multiple CAD programs, such as Exocad (Align Technology, San José, USA), Meshmixer (Autodesk Inc., San Francisco, USA), Blender (Blender Institute, Amsterdam, Netherlands), BlueSkyPlan (Blue Sky Bio, Libertyville, USA), OnyxCeph (Image Instruments, Chemnitz, Germany), among others.

The individual appliance design can then be sent to the clinician digitally to print it in-office or can be manufactured by the technician and then send physically to the dental office. When printing the appliance, care should be taken that a biocompatible resin (Class IIa) is used. Class IIa resins are permitted for use of appliances which remain over 30 days intraorally. Examples include Dental LT Clear, Biomed Clear (both Formlabs, Somerville, USA) or Keysoft (Keystone Industries, Singen, Germany), Freesplint (Detax, Ettlingen, Germany), Dima Print (Kulzer, Hanau, Germany) or recently released more flexible resins Freeprint

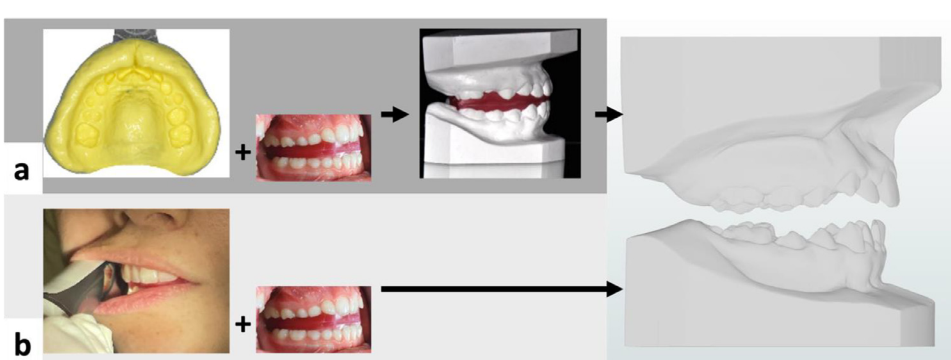

Fig. 1. Models for construction − a digital model serves as the basis for the later construction of the appliance. The clinician has different options: a) doing a conventional impression and digitising it with a desktop or intraoral scanner or b) doing an intraoral scan on the patient.

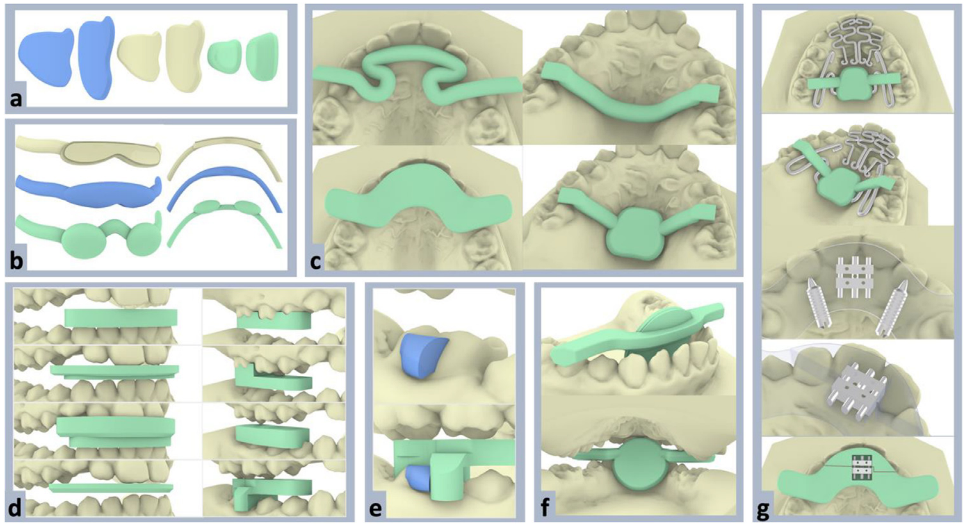

Fig. 2. Examples of elements for construction. a) buccal-retraction shields, b) Lip-retraction shields, c) palatinal elements, d) frontal and posterior bite and sagittal anchoring element, e) sagittal anchoring element combined with attachments, f) tongue pressure shield, g) metal-based elements.

Splintmaster taff or flex (both Detax). After 3D printing, post-processing should be carried out according to the manufacturer's instructions. This normally involves washing in isopropanol and subsequent light curing. Milling the appliance from a plastic block is also possible but to the authoŕs opinion should be critically considered because of economic and ecological reasons.

If metal-based elements are required, they have to be bend and incorporated into the appliance after the 3D printing process. This is done by planning small recesses into the appliance base, in which the metal-based elements can be placed. The same resin that is used to print the appliance is then used to attach the metal-based elements. Bending of the metal-based elements can be done manually or by using a bending robot like the "Micro Bender MB1" (Advanced Orthodontic Solutions, Tampa, USA), which can bend wires with a diameter from 0.5 to 1.2 mm (0.020 to 0.045"). Overall, constructing the customized appliance of the requested design is easy and takes only a few minutes, as the elements are usually already stored and only need to be adapted to the individual situation. This also applies to the insertion of the metal-based elements, especially if they are bent by a bending robot.

Then the appliance can be inserted. During insertion usually no adjustments of the appliance are required, as the digital production provides a particularly high accuracy of fit. This is mainly because in contrast to conventional manufacture there is no risk of material deforming of both the impression or the construction bite material as both are immediately digitised,[23] (Fig. 5, and Fig. 6)

Fig. 3. Final design within software interface.

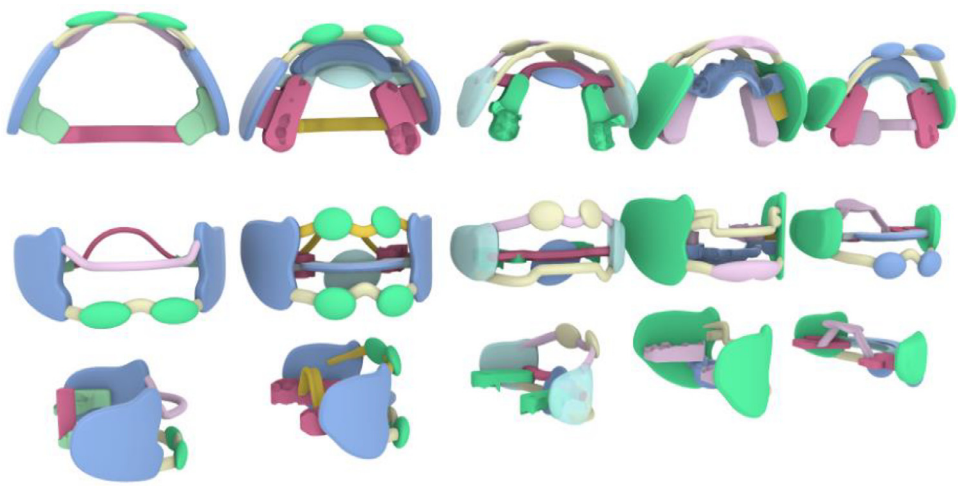

Fig. 4. Examples of configured appliances.

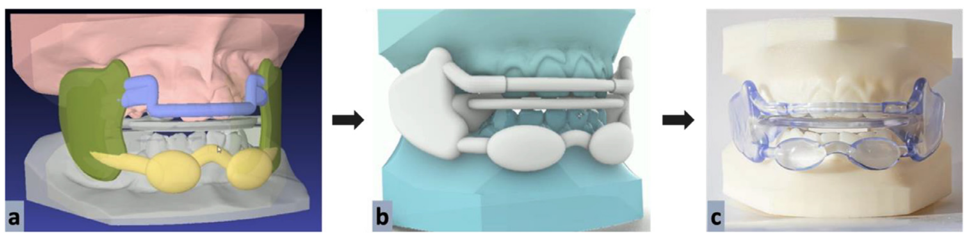

Fig. 5. Final production steps − After transferring the final design to the individual patient situation (a), the technician can send the appliance digitally (b) to the clinician for an in-office production or already manufactured (c) if no in-office production is requested.

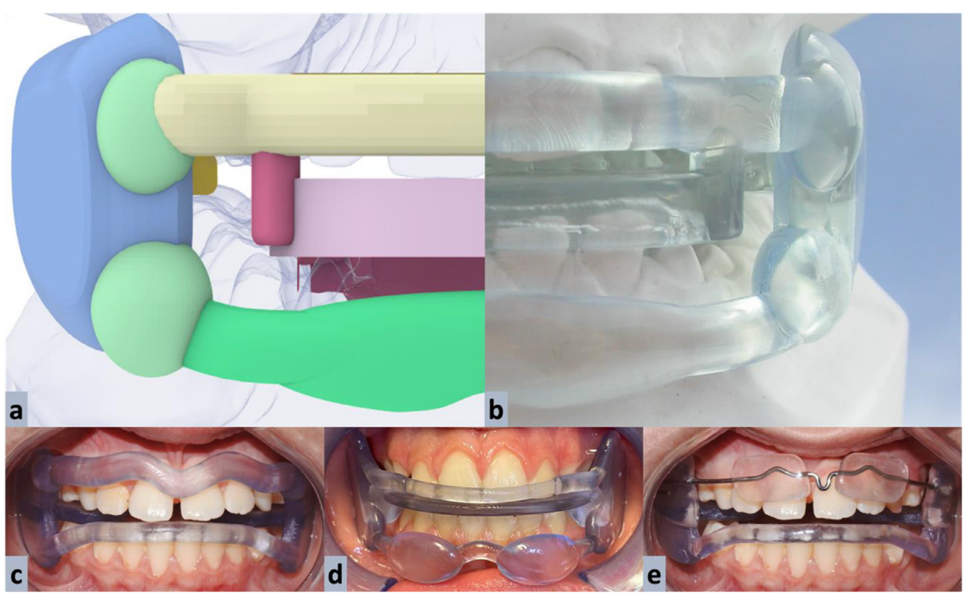

Fig. 6. Final appliance in CAD-Design (a), printed (b) and three different appliances inserted (c-e), one of them with metal-based elements (e).

Discussion

The article presents a fully new digital approach for the CAD/CAM based production of functional orthodontic appliances. This concept aims to overcome the limitations which have impeded an integration of CAD/CAM functional orthodontic appliances into daily clinical practice. So far designing functional orthodontic CAD/CAM appliances has been a sophisticated process, requiring a high level of expertise in CAD/CAM techniques. This might be one of the main reasons, why this promising field has never got any further than individual reports.[16-22] This contrasts with the wide range of options for ordering other orthodontic CAD/CAM appliances like retainers, brackets, anchoring devices or aligners from various commercial suppliers. However, one should keep in mind that a facilitated CAD/CAM production might be particularly usable for functional orthodontic CAD/CAM appliances due to numerous reasons. Storing both the design and the corresponding models might one of the most important benefits of working digitally. Apart from economic and ecological aspects, which are becoming increasingly relevant, there are further aspects which might be beneficial in everyday clinical practice. A fully digital workflow does not lead to any damage of the patient́s models. Rather, the models can be used for various proposals like for the comparison of different therapeutical steps or for matching them into cephalograms to facilitate a precise planning of the orthodontic appliance.[24,25] The same applies to the appliance design. Once it has been stored, it can be replicated infinitely. This seems to be particularly advantageous in the field of functional orthodontic appliances since they are worn by particular young patients, which is increasing the risk of loss or damage. Complication rates during the orthodontic therapy with removable appliance have been described of up to 25%.[26,27] It seems mandatory to mention that these can negatively affect the therapeutic progress.[28,29] Building a new appliance after it was lost or damaged, has required a certain amount of time, therefore causing an interruption of therapy. Especially in younger patients who have become accustomed to wear their appliance continuously, an interruption of therapy often leads to a decrease in compliance. Easier and faster reintegration of the appliance might be facilitated through the digital storage. Taking digital impressions instead of conventional impressions might be another important benefit for functional orthodontic CAD/CAM appliances. This seems especially relevant for patients with an increased gag reflex or patients which suffer from a physical or mental disability.

Despite its numerous benefits the CAD/CAM production of functional orthodontic appliances has not become a part of daily clinical practice. Apart from a sophisticated design process which has been addressed through the present digital solution, lacking flexibility or adaptability of the material still represents a challenge for the future. Lacking flexibility of currently available biocompatible resins is particularly limiting the implementation of CAD/CAM archwires and active elements with a small diameter. We addressed this by incorporating metal-based elements within the appliance design. Consequently, this still requires manual work from the technician after the basic appliance has been printed. Therefore, there is a need for further developments in the field of materials or simplified approaches to integrate metal-based elements within the printed appliance. Providing resins with the required flexibility is often demanding, since they also have to be biocompatible (class IIa), permitting them to be used intraorally for over 30 days. Newly released printable thermoplastic resins might offer higher flexibility by remaining the required stability. One should consider, however, that, when using flexible resins, active CAD/CAM elements have to be planned within the digital design process and cannot be bend chairside. In addition, other concepts like the use of a click system, through which non-plastic elements can be implemented into the 3D-printed appliance or attaching elastics to the appliances in order to bring active forces onto the teeth are conceivable and might therefore represent at least a temporary solution.[22] However, since functional orthodontic appliances are intended to provide sufficient growth control with rather rare requirement for activation, lacking adaptability might be no considerable drawback for them. Our clinical experience to date and preclinical studies[16] show that the appliances are highly stable, so that the complication rate is comparably low to that of conventional appliances. Furthermore, the mostly young patients show great interest in the new 3D-printing approach, which in turn increases the compliance.

As a limitation, the appliance design created by the clinician is not yet individualized to the patient situation but must be rebuild accordingly by a technician before manufacturing it. To benefit from a faster production, this challenge must be overcome in the future. Artificial intelligence might provide a remedy here but still needs a large amount of data. As another limitation, so far this configurator concentrates on the functional regulator or the Cervera appliances with all the numerous customisation options included. This is because both appliances are particular demanding to produce manually. However, the configurator will continuously be updated with new designs and elements in order to incorporate all removable orthodontic appliances in the future. Summarized, this new concept paves the way for a facilitated and feasible new concept in the CAD/CAM fabrication of orthodontic appliances, which might become urgently relevant due to economic and ecological reasons in the future.

Conclusions

This report presents a digital configurator for the construction of functional orthodontic CAD/CAM appliances. It is intended to relieve the clinician from a sophisticated and time-consuming production process which might be one of the most considerable drawbacks for functional orthodontic CAD/CAM appliances to date. This new concept might represent an effective way for enabling both patients and clinicians to benefit from the numerous advantages of functional orthodontic CAD/CAM appliances such as indefinite reproduction, digital impressions, digital data transfer, more individualised design options and better therapy monitoring in the long term.

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Patient consent

Patient consent was obtained.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Christoph J. Roser: Writing – review & editing, Writing – original draft. **Vincenzo D'Anto:** Supervision, Software, Conceptualization. **Chrisopher J. Lux:** Supervision. **Cristiano Segnini:** Visualization, Software, Methodology, Conceptualization.

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