Novel Arch Bar Fabricated With a Computer-Aided Design and Three-Dimensional Printing: A Feasibility Study

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Purpose: The aim of the present study was to evaluate the feasibility of the design and fabrication of a novel arch bar using 3-dimensional printing. Furthermore, the study assessed its use in a preliminary clinical study of intermaxillary fixation.

Patients and Methods: Seven patients who met the inclusion criteria were enrolled in the present study. Plaster dental casts were created of each patient and scanned using cone-beam computed tomography to obtain digital casts. Computer-aided design software was then used to complete the virtual building of the arch bars, which were manufactured using 3-dimensional printing and a cobalt-chrome alloy. The clinical results were observed after the arch bars were fixed to the dentition with steel wires.

Results: The arch bar contacted the dentition with a "surface-to-surface" pattern. The utility of these novel arch bars was verified by successfully fitting them to the dental arches of the patients. All the patients achieved their desired occlusion.

Conclusion: The results of the present study have illustrated that this digital method is feasible for constructing a novel arch bar, showing promise for clinical use.

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To reconstruct and adjust the occlusion and restore physiologic oral function, intermaxillary fixation (IMF) has generally been used in orthognathic surgery and in the treatment of jaw fractures. Although many methods have been used for IMF, including arch bars, brackets, and IMF screws, arch bars ligated to the dentition with stainless steel wires are currently the most common and preferred method.[1,2]

Currently, 2 types of wire-based arch bars are in widespread clinical use according to the published data and our clinical practice: commercially available arch bars and custom-made arch bars with 0.9-mm diameter steel wire. Commercial arch bars are inexpensive and easy to bend; however, these bars provide "multiple points to surface" contact to the dentition, making them easy to deform and difficult to stabilize

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for the application of orthodontic force to the teeth.[3] An individualized arch bar is made by a technician after taking an impression of the dentition with 0.9-mm diameter stainless steel wires. The contact pattern between this type of arch bar and the dentition gives "line-to-surface contact," which leads to better stability. However, because these arch bars lie along the gingival margin, it is typically difficult to maintain oral hygiene. Also, the production process is comparatively complicated and requires an experienced technician, limiting their use.

Computer-aided design (CAD) and 3-dimensional (3D) printing have been successfully introduced into the fields of oral and maxillofacial surgery, fixed prosthodontics, dental implantology, and the restoration of maxillofacial defects.[4,5] Williams et al[6] performed a series of studies on the virtual design of removable partial dentures (RPDs) and succeeded in using 3D printing to construct the clasps and framework of an RPD. No studies, however, have been published on the use of CAD and 3D printing for the fabrication of arch bars.

In the present study, we treated arch bars as a "continuous clasp" for the dentition and created a virtual design for their configuration. We also used the 3D printing technique to fabricate a novel arch bar and evaluated its preliminary clinical application.

Patients and Methods

The present study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the institutional review board of Peking University School and Hospital of Stomatology. All the participants provided written informed consent before their participation.

Seven patients were enrolled from the oral and maxillofacial surgery department at the Peking University School and Hospital of Stomatology. All the patients met the following inclusion criteria: *1)* orthognathic patients who had not received any preoperative orthodontic treatment; *2)* patients who had sustained maxillary and/or mandibular fractures; *3)* patients for whom arch bars were needed; and *4)* patients for whom a pair of dental casts could be created.

Dental casts of both the maxillary and the mandible dentition were created with plaster, and the CAD and 3D printing process was performed as follows. Dental casts from every patient were scanned using cone-beam computed tomography (CBCT) (NewTom VGi, Qualitative Radiology Srl, Verona, Italy) to obtain data in the Digital Imaging and Communications in Medicine format. Next, 3D digital models in STL format were calculated using Mimics software, version 10 (Materialise, Leuven, Belgium).

The FreeForm Modeling Plus software, version 11 (Geo Magics SensAble Group, Wilmington, MA) and Phantom Desktop arm (Geo Magics SensAble Group) used in our study have also been used to make removable partial denture framework. This system has the capability to design complex, well-defined shapes and is ideal for designing anatomically derived devices.[6-8]

In the FreeForm Modeling Plus program, a contoured cylinder with a diameter of 1.5 mm was created on the labial or buccal aspect of the maxillary dentition from the first right upper molar to the first left upper molar with an appropriate 1-mm distance from the gingival margin. This served as the central bar. A virtual material termed "clay" was added in some areas of the appliance to enhance strength, and the configuration of the appliance was smoothed (Fig 1).

Hooks that were 3 mm in height and 1.5 mm in diameter, with smooth ends, were attached to the central bar at the middle of each tooth. Angles were present between the hooks and the gingival surface, and

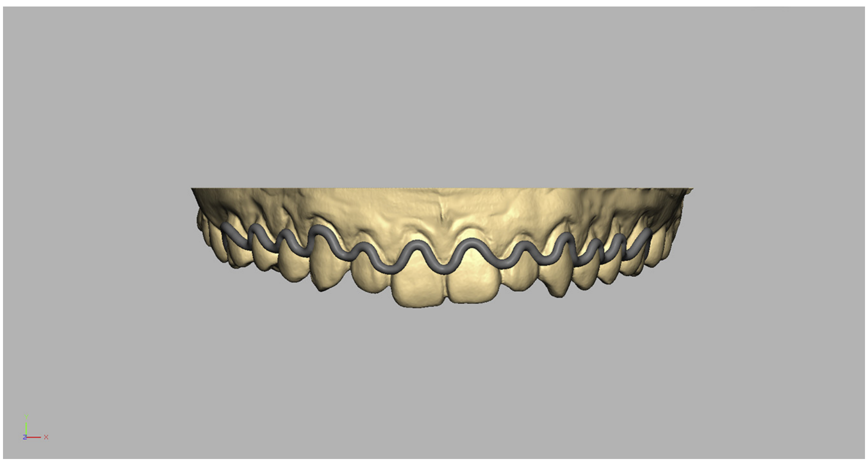

FIGURE 1. Virtual design of the central bar along the labial or buccal aspect of the dentition in FreeForm software.

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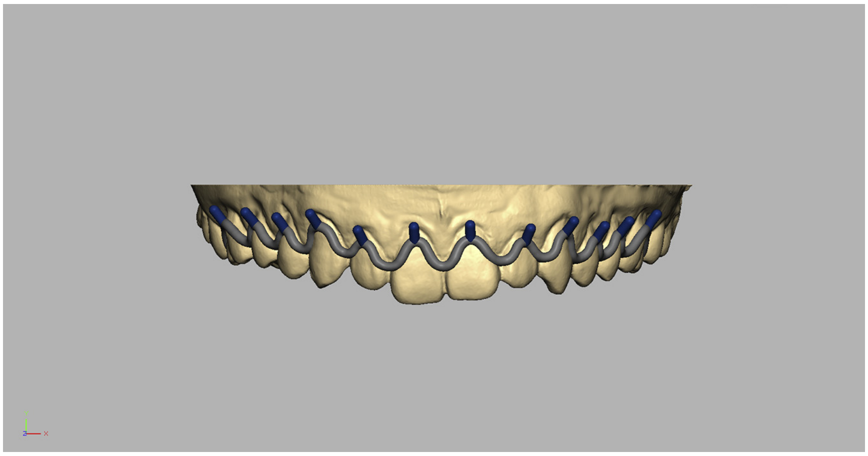

FIGURE 2. Hooks 3 mm in height and 1.5 mm in diameter were placed in the middle of each tooth.

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the distance between the ends of the hooks and the gingival surface was 1 mm for the use of more than 1 wire or elastic band (Fig 2). Angles were also created to avoid compressing the gingival surface. The appliance was cut from the virtual maxillary model using a subtraction Boolean operation to calculate the inner surface of the virtual arch bar. The arch bar contacted the dentition with a "surface to surface" pattern, such as is found in the clasps of removable partial dentures, to improve the stability of the arch bars after fixation. Adequate supports were created using FreeForm software to facilitate the selective laser melted (SLM) process. The supports conducted heat away from the arch bars during the melting process and helped to avoid deformation during the cooling process (Fig 3).

3D individualized arch bar data were imported into the SLM rapid prototype equipment (M280, Electro Optical System, Krailling, Germany), from which the arch bar was 3D-printed using a cobalt-chrome (Co-Cr) alloy (Fig 4). The arch bar was then subjected to a conventional polishing process (Figs 5, 6). Mandibular arch bars were designed and fabricated using the same process.

The individualized arch bars were tested on the original plaster casts to check for fit and then ligated to the teeth with bifilar, 0.25-mm diameter steel wires during surgery with the patient under general anesthesia by nasal intubation. Three-point fixation in each quadrant was performed on the patient with a mandible fracture, and the other 6 orthognathic patients received ligation to each tooth. IMF was performed 2 days after the surgeries. On days 1, 7, and 28 after fixation with the arch bar, we evaluated the subjective feelings and occlusal relationship of all 7 patients. The arch bars were removed on day 28.

Results

The arch bars fitted to the plaster model fit well and achieved a continuous "surface to surface" contact pattern with the dentin for all patients. Also, the arch bars had satisfactory contact with both the plaster

FIGURE 3. Virtual individual arch bar and supports.

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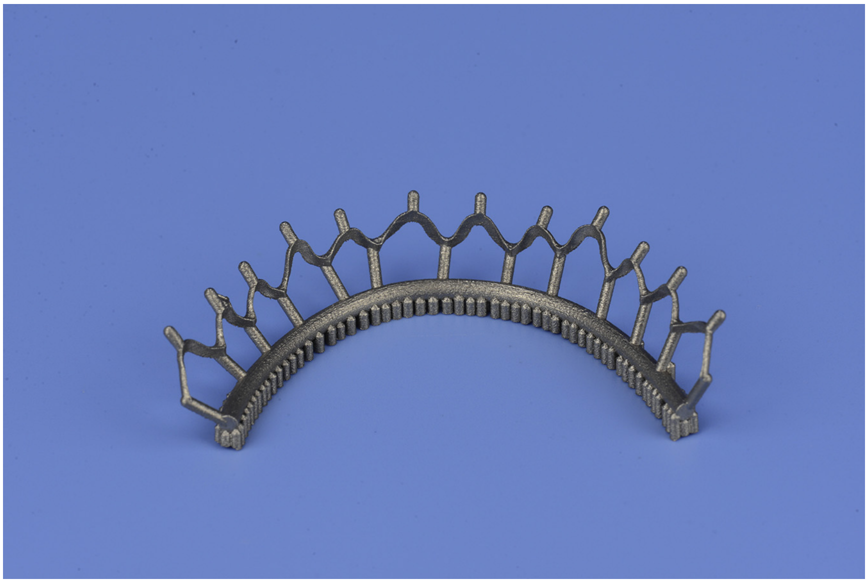

FIGURE 4. The final prototype of an individual arch bar after 3-dimensional printing.

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model and the dentition (Figs 7, 8). During the follow-up period, the patients had no obvious sensation of the presence of a foreign body. Two patients complained of dental pain 3 days after elastic traction was performed. No orthodontic extrusion was observed. All patients had satisfactory postoperative occlusion outcomes.

Discussion

Because intermaxillary elastic fixation with arch bars is a mature clinical technique, most studies regarding IMF and arch bars have focused on the clinical use and outcomes of IMF. Few have focused on improvements in configuration and fabrication.

Some researchers have made titanium arch bars using laser cutting technology with a wave-like configuration. This design could increase the contact area between the arch bar and dentition, providing good levels of stability from only 3 ligations.[3] The use of titanium IMF screws has emerged as a new method in recent years, and a commercial product is currently available. The advantages of this method include a good appearance, a straightforward surgical procedure, and the maintenance of good oral hygiene. The disadvantages include the high cost and the possibility of injury to the dental

FIGURE 5. Frontal view of the final individual arch bar after polishing.

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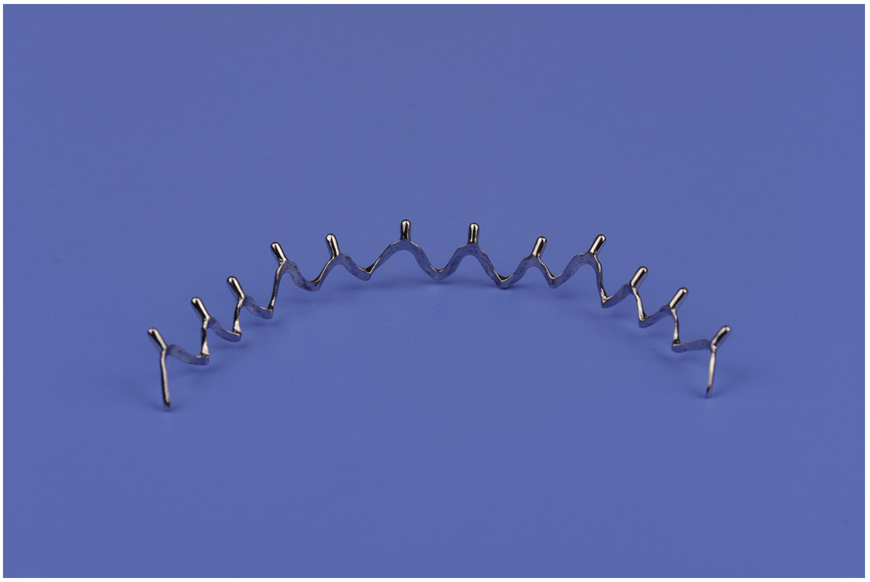

FIGURE 6. Lingual view of the final individual arch bar after polishing.

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germ tissue, nerves, and the maxillary sinus, which could lead to infection.[9] These problems have led to the limited use of this method in the clinic. Another type of IMF system, Rapid IMF (DuPuySynthes, Johnson & Johnson, West Chester, PA), sets 8 to 10 plastic appliances on the upper and lower dentition to act as an IMF. Although this system is easy to use, it is difficult to set the appliances when an overbite is present and crossing in the lower anterior teeth.[10] Bonded arch bars have also been reported. This method avoids the use of wires and minimizes periodontal injury and the threat of percutaneous injury to operators.[1]

In the present study, we scanned plaster models to create a digitized dental model and then used CAD and 3D printing to design and fabricate a novel individualized arch bar. This method was highly precise and formed close, continuous "surface to surface" contacts, which conferred increased levels of stability. We chose the same alloy used for RPD to fabricate the arch bars with the SLA method. The draw hook was made to be 3 mm in height, which enabled the introduction of 1 to 3 elastic ligation loops and avoided pricking the buccal tissues. The configuration of the bar was preformed to the dentition, thus saving the

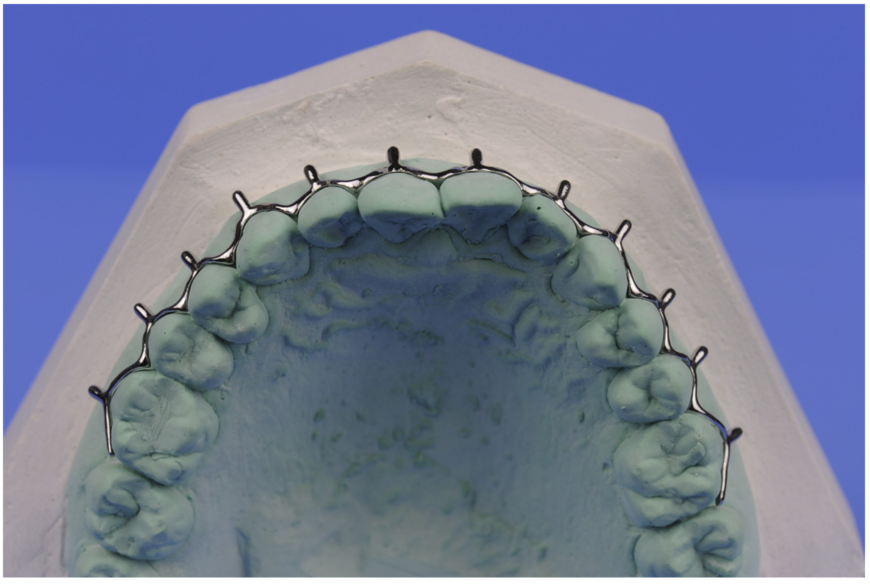

FIGURE 7. The individual arch bar fitted to the plaster cast.

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FIGURE 8. At 1 week after fixation, individual arch bars were attached to the dentition with stainless steel wires, and intermaxillary fixation was applied with elastic band.

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time needed to bend commercially available arch bars into the correct shape.

Steel wires should be used to fix arch bars to the dentition. Because the contact area of traditional commercially available arch bars is too small, operators usually need to ligate the arch bars to each tooth. During the operation, the ends of the ligation wires are likely to puncture the gloves and skin, leading to iatrogenic exposure for the surgeon. Recent studies have attempted to reduce the number of ligature wires needed.[10,11] Our individual arch bar has a larger contact area than that of traditional bars. We chose a patient with a mandible fracture with inconspicuous displacement and only ligated at a central incisor, canine, and premolar in each quarter. This allowed us to reduce the operative time and the trauma to the periodontal tissues. The clinical observations demonstrated that the arch bar was stable, which might have resulted from the special contact pattern, and no orthodontic extrusion was observed. Few reports have been published regarding how many teeth must be fixed, and the number of cases in the present study was relatively small. Therefore, we could not determine whether 3 teeth in each quarter were adequate for fixation. We agree with Iizuka et al,[3] who asserted that the number of teeth to be fixed is dependent on the specific condition of each patient, including the teeth, periodontal tissues, and intermaxillary traction force.

It is common for traditional arch bars to compress the gingival tissue, causing poor oral hygiene. In the present study, the arch bars were placed approximately 1 mm away from the gingival margin. The height of the hooks and the distance between the hooks and the gingiva was determined from previous studies.[12] Our design sought to reduce the harmful stimuli to the gingiva and protect periodontal health during IMF. The clinical observations demonstrated that, although swelling of gingiva was better relative to a traditional arch bar, significant amounts of food debris were still present. Furthermore, owing to the limited number of patients, the effects of our arch bars on periodontal health require additional study.

Dental pain can occur when 2 different metals come into contact causing a galvanic current. However, a previous study revealed low galvanic currents in the range of nanoamperes between stainless steel and Co-Cr alloy.[13] Both Co-Cr alloy and stainless steel have excellent levels of corrosion resistance. They have been used for orthodontic brackets, arch wires, orthopedic implants, and combined uses in the clinic.[14,15] Therefore, the dental pain experienced by the 2 patients in our study might have resulted primarily from the traction force imposed by the elastic bands and not from any galvanic current.

Other potential issues are present in the design and production of our individualized arch bar. Because these arch bars were smaller in size and longer in length, and the elasticity of the material was limited, a high level of precision was required during their fabrication. A pair of casts was needed; however, creating these casts was difficult for patients who experienced difficulty opening their mouth. Commercial arch bars or IMF screws might be more suitable for such patients. Finally, although crowded dentition did not affect the CAD process, an overbite might prevent the creation of the arch bar because of the inadequate space needed to place the arch bar in the mandibular dental arch.

The main limitations of the clinical application of the novel arch bars are currently the cost and time needed. The price of such a pair of novel arch bars is 800 Chinese Yuan (about $128.00). Although the cost is clinically acceptable, it is greater than that of commercial arch bars (60 Chinese Yuan [about $10.00]) and custom-made arch bars (750 Chinese Yuan [about $120.00]); however, this approach is inexpensive compared with IMF screws (1,200 to 2,400 Chinese Yuan [$192.00 to $384.00], depending on the number required per patient). The design and fabrication process of the novel arch bars required approximately 13.5 hours in total, and a pair of custom-made arch bars can be manufactured within 2 hours by an experienced technician.

The main disadvantage of the present study was that the evaluation of the clinical outcome was insufficient because the technique was only performed in 7 patients. In our future studies, outcomes from a greater number of cases will be collected and the occlusion outcomes, oral hygiene (plaque index and gingival index), mucosal ulceration, and orthodontic movement of the teeth, among others, will be evaluated and discussed.

In conclusion, the results of the present study have illustrated that the digital design and fabrication of a novel individual arch bar with greater levels of precision and better levels of stability is feasible. As digital technology is used more widely across medical fields, this type of arch bar could be promising for clinical use.

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