THE INTERNATIONAL JOURNAL OF MEDICAL ROBOTICS AND COMPUTER ASSISTED SURGERY
Int J Med Robotics Comput Assist Surg 2009; **5**: 198–206.
Published online 2 March 2009 in Wiley InterScience (www.interscience.wiley.com). **DOI:** 10.1002/rcs.251

ORIGINAL ARTICLE

The role of computer-aided 3D surgery and stereolithographic modelling for vector orientation in premaxillary and trans-sinusoidal maxillary distraction osteogenesis

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Accepted: 27 January 2009

Abstract

Background Maxillary distraction osteogenesis is a challenging procedure when it is performed with internal submerged distractors due to obligation of setting accurate distraction vectors.

Methods Five patients with severe maxillary retrognathy were planned with Mimics 10.01 CMF and Simplant 10.01 software. Distraction vectors and rods of distractors were arranged in 3D environment and on STL models. All patients were operated under general anaesthesia and complete Le Fort I downfracture was performed.

Results All distractions were performed according to orientated vectors. All patients achieved stable occlusion and satisfactory aesthetic outcome at the end of the treatment period.

Conclusion Preoperative bending of internal maxillary distractors prevents significant loss of operation time. 3D computer-aided surgical simulation and model surgery provide accurate orientation of distraction vectors for premaxillary and internal trans-sinusoidal maxillary distraction. Combination of virtual surgical simulation and stereolithographic models surgery can be validated as an effective method of preoperative planning for complicated maxillofacial surgery cases. Copyright © 2009 John Wiley & Sons, Ltd.

Keywords computer-aided surgery; vector; 3D; premaxilla; maxilla; trans-sinusoidal; distraction osteogenesis

Introduction

Software programs simulating maxillofacial surgery have become important evaluation and presentation tools (1–5). Softwares providing computer-aided surgery have progressed from simple comparison programs of two-dimensional (2D) preoperative/postoperative facial profiles to sophisticated surgical simulation covering profile adjustments and intraoperative procedures such as virtual reality osteotomies, distraction osteogenesis and placement of dental implant (6,7). Stereolithographic modelling (STL) is a very useful method to justify skeletal properties of maxillofacial deformity and determine surgical technique on printed solid models (8).

Mid-face distraction offers comparatively stable and convenient period for reconstruction (9–15). It is a promising technique for patients with severe maxillary hypoplasia who are at higher risk of postoperative relapse (10–13). The rigid systems used for mid-face distraction include extra-oral and intra-oral devices which confer many advantages upon each other (10–13). The negative social/psychological impact of the cranial halos of extraoral devices have forced maxillofacial surgeons to use rigid smaller and patient-compliant intraoral distractors (12,13).

Indications for maxillary distraction are moderate and severe maxillary retrusion that requires large advancement, forward and downward lengthening of the maxilla and the need for early treatment in growing patients (11,12). The rationale to prefer mid-face distraction versus traditional maxillary osteotomies for large mid-face advancements is prevention from skeletal relapses in long-term period by performing overcorrection at the end of the active distraction period (11).

The trans-sinusoidal maxillary distractor (TS-MD; Gebrüder Martin GmbH & Co. KG, Tuttlingen, Germany) is an intra-oral distractor introduced by Nadjmi (13). This system consists of a rod that resides completely within the maxillary sinus, placed through a small hole in the anterior antral wall and secured *in situ* by two plates positioned superior and inferior to Le Fort I osteotomy cuts.

The main disadvantage of TS-MD is the difficulty of arranging the distraction vectors and adaptation of a device for the maxilla (13). We investigated the role of Mimics CMF 10.01 (Materialise, Leuven, Belgium), a virtual reality surgical simulation software, and surgery on STL models for the adjustment of distraction vectors for patients who have undergone trans-sinusoidal maxillary distraction osteogenesis.

Materials and Methods

Patients

Five patients with severe maxillary retrognathy (two patients with cleft palate (CLP), two posttrauma patients with Le Fort level I and II fractures) underwent maxillary advancement with trans-sinusoidal intraoral Le Fort I distractors (Figure 1). The 5th patient was operated by premaxillary distraction osteogenesis using a custom made three-directional premaxillary/palatal expander. All patients were adult males with a mean age of 19. One of the CLP patients had undergone failed Le Fort I osteotomy for maxillary advancement several times, performed by another surgical team. Ethical approval was obtained from the local committee of the Health Institute.

Preoperative set-up: performing 3D virtual surgery

Axial CT scans were obtained at 1 mm slice thickness, using a GE Lightspeed Plus CT Scanner System. Once the scans were acquired, the data were saved on CD-ROMs for transfer to the Mimics 10.01 (Materialise, Leuven, Belgium) software, using the Digital Imaging and Communication in Medicine (DICOM 3) format. Mimics was used to read and reconstruct the data into 3D images. In one case, treatment planning was completed using Simplant (Materialise) software to confirm whether dental implantation would be possible after fan-type segmental distraction. All the segmented patient data was sent to 4C Medical Modelling (Istanbul, Turkey) for printing of the STL models, with 1 : 1 anatomical resemblance. Spectrum Z510 (ZCorporation) was used as a scanner.

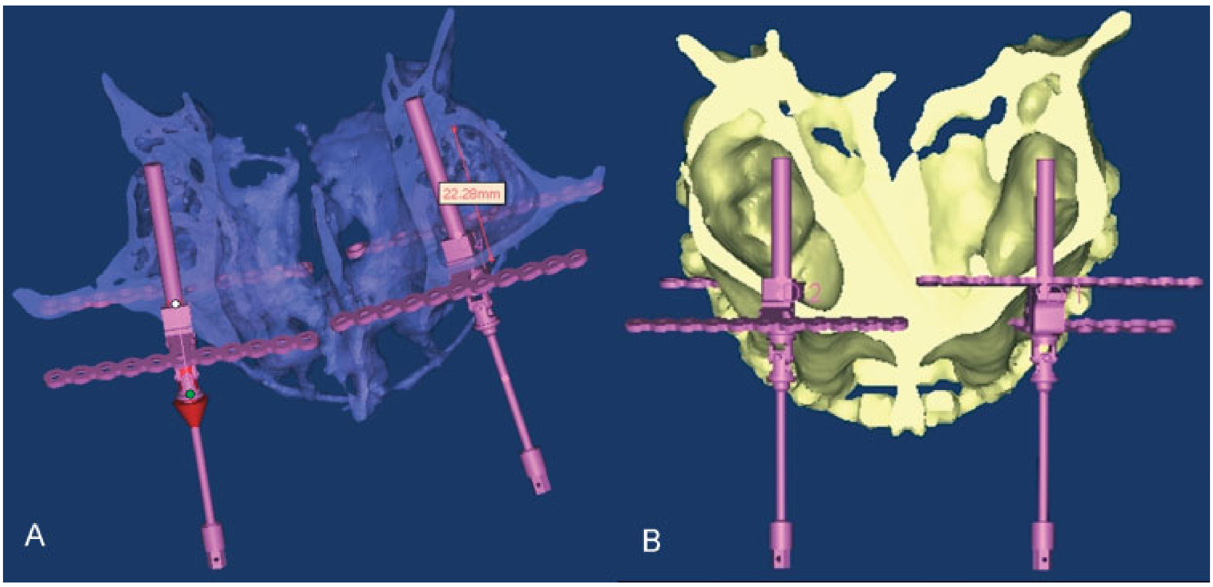

Figure 1. (A) Selecting the appropriate length of a distractor by measuring the anteroposterior dimension of the maxillary antrum. The depth of sinus was measured at 22.3 mm, which necessitated the placement of a distractor 20 mm in length. (B) The anatomical differences of the maxillary sinuses and parallelism may cause asymmetrical positioning of the distractors with regard to the axial plane of the maxillary antrum

DOI: 10.1002/rcs

Arrangement of distraction vectors

The mandible, maxilla and cranium were segmented and separated from each other, using a Boolean operation. Traditional Le Fort I osteotomy was performed virtually on the 3D reconstruction mask, using the osteotomy wizard facility of Mimics software. The TS-MD was explored in the distractor library of the software. The distractor rod is produced in three different lengths, 20, 25 and 30 mm. The length of the distractor can be chosen by virtually measuring the anteroposterior depth of the maxillary sinus (Figure 1A, B).The intraoral distractor was adapted on the 3D mask of maxilla (Figures 2, 3A) and the osteotomized 3D object was repositioned with anterior and downward translation to diagnose the course of maxillary motion (Figure 3A, B). Parallel placement of both distractors inside the maxillary sinus is very important, otherwise advancement of the maxilla would not occur (Figure 4A, B).

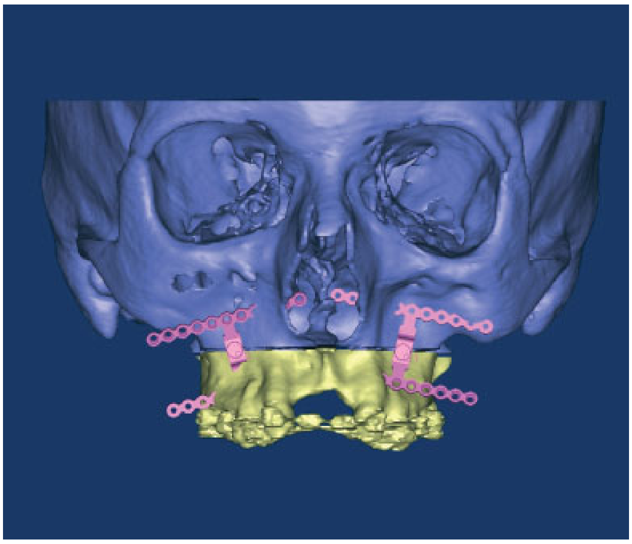

Figure 2. 3D simulation of Le Fort I osteotomy (yellow mask) and bilateral placement of TS-MD

Surgery on STL models

Virtual simulation is repeated on STL models (Figure 5A, B). Le Fort I osteotomy was performed on STL models in the laboratory (Figure 5C). A hole was opened in the mid-osteotomy line on the anterior wall of the maxillary sinus to enable the entrance of the distraction rod into the sinus. The upper mini-plates of the distractor were bent and secured by a few screws to the infraorbital rim. The rod bound to the turning mechanism of the device was pushed through the antral hole and the inferior plate was fixed to dentoalveolar segment. The rods were arranged very precisely to allow parallel movement of the maxillary halves (Figure 5C). Parallel placement of the two rods is of great importance, since advancement of the maxillary segment could stop after several activations. Inferior inclination of the device was done by bending the upper mini-plates. The rods should not be placed at wide or narrow angles; a set-square must be used whenever possible to arrange parallelism. As the distractors were fixed to the STL models, the rods were activated to advance the maxilla through a planned vector until it overlapped the mandibular teeth (Figure 5D).

Anterior segmental osteotomy and corticotomy were drawn virtually in the Mimics CMF platform (Figure 6A). The surgical simulation was prepared and the processed data were transmitted to the Simplant 10.01 platform (Figure 6B) to determine whether it was possible to bilaterally place two implants in the distracted alveolar sites (Figure 6C).

Maxillary corticotomy and segmental osteotomy was done on the STL model of the patient with narrow maxillary arch and teeth crowding (Figure 7A). The three-directional premaxillary/palatal expander was placed and mode of movement was checked out (Figure 7B).

Maxillary distraction osteogenesis

Surgery for total maxillary distraction

Circumvestibular incision was performed from the left to the right first molar region at the maxillary vestibule. The

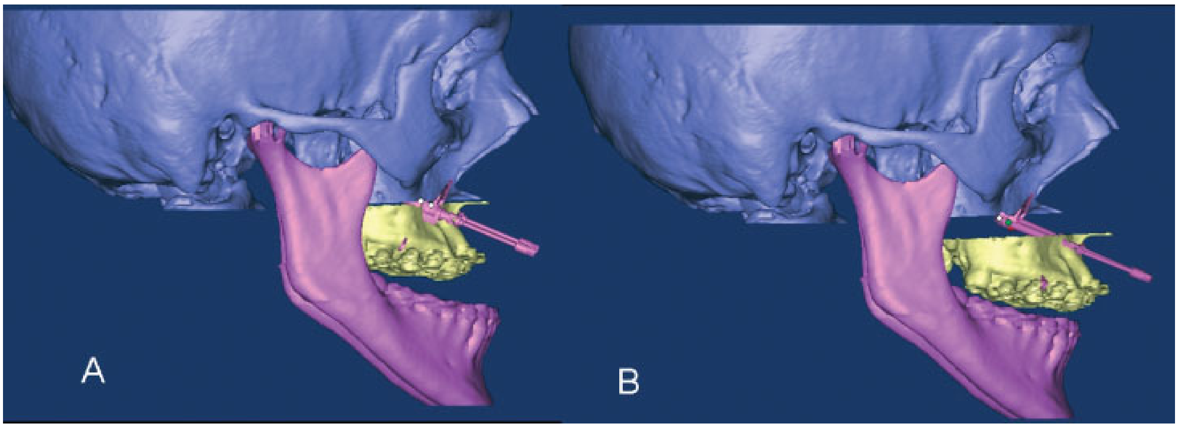

Figure 3. (A) Orientation of distraction vectors in the sagittal plane in a 3D environment. (B) Repositioning the maxillary segment (yellow mask) by virtual reality distraction osteogenesis

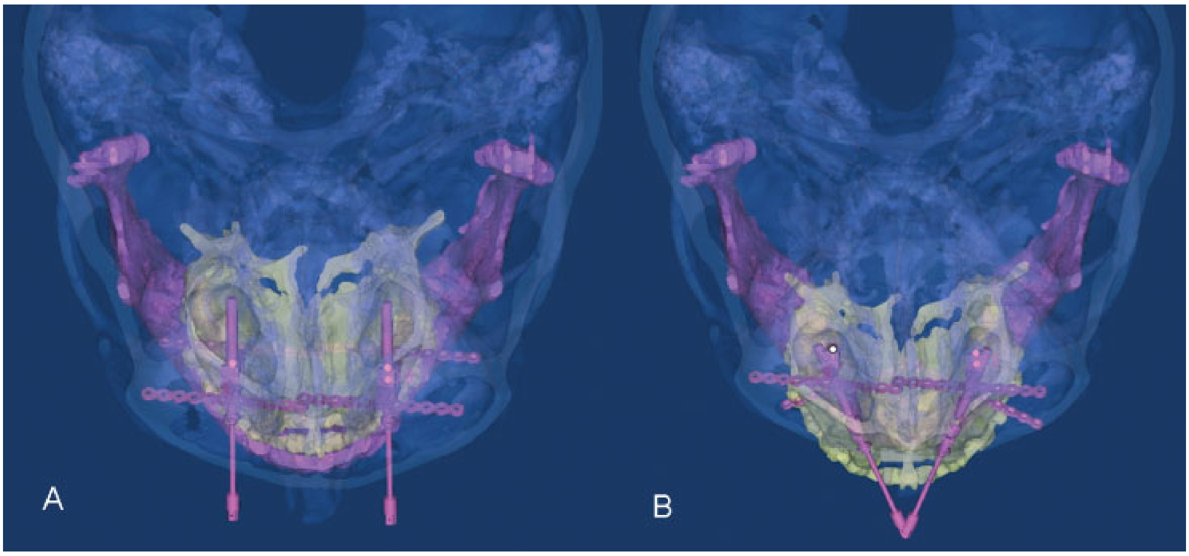

Figure 4. (A) Parallel placement of both distractors is mandatory to achieve anterior advancement. (B) Convergent or divergent placement of distractors would not allow anterior maxillary movement

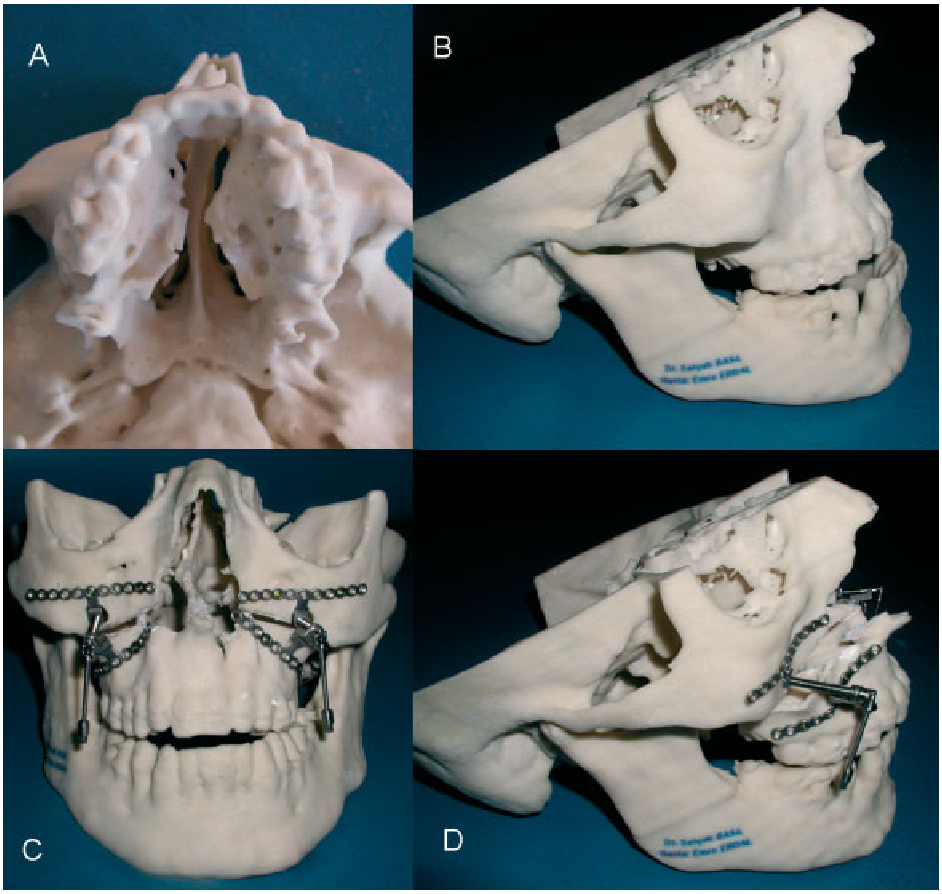

Figure 5. (A) STL model of a patient with maxillary retrusion and cleft palate. (B) Lateral view of the STL model. (C) Placement of TS-MD on the STL model at the laboratory. (D) Vector orientation and checking out the distraction path by repositioning Le Fort I osteotomy

mucoperiostal flap was elevated to the infraorbital region and dissection continued with exposure of the infraorbital nerves. The nasal floor was dissected to prevent any tear during downfracture of the maxilla. A complete Le Fort I cut was made using a reciprocating saw (TPS Stryker, USA) and downfracture of the maxilla was performed in all operations to achieve full mobilization, in order to prevent any relapse by an incomplete osteotomy. The distractors were positioned on the anterior faces of the maxillary walls and penetrated the maxillary

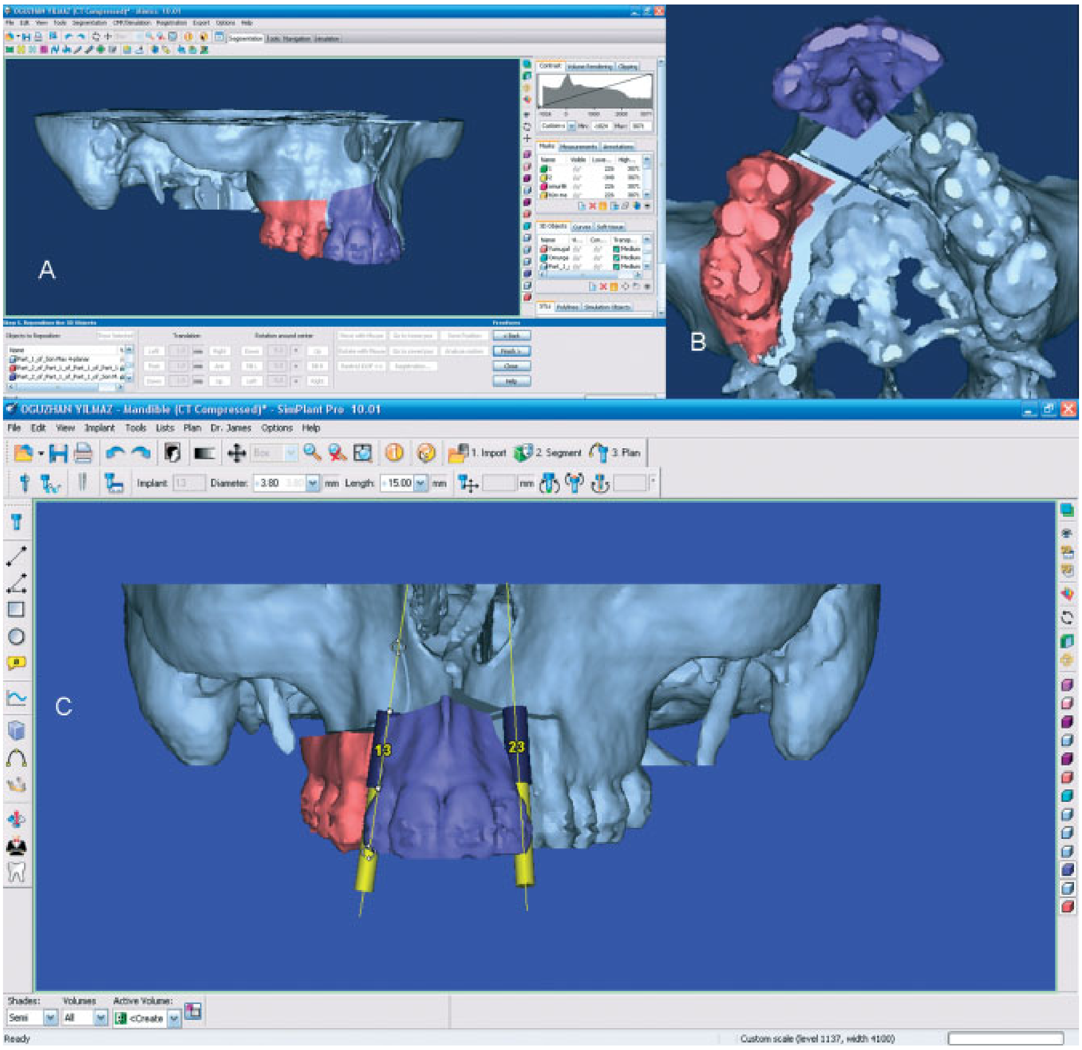

Figure 6. (A) Virtual reality segmental maxillary osteotomies. (B) Virtual reality simulation of anterior segmental osteotomy and unilateral maxillary expansion. (C) Placement of implants into a 3D surgical mask to endorse the efficiency of the distraction

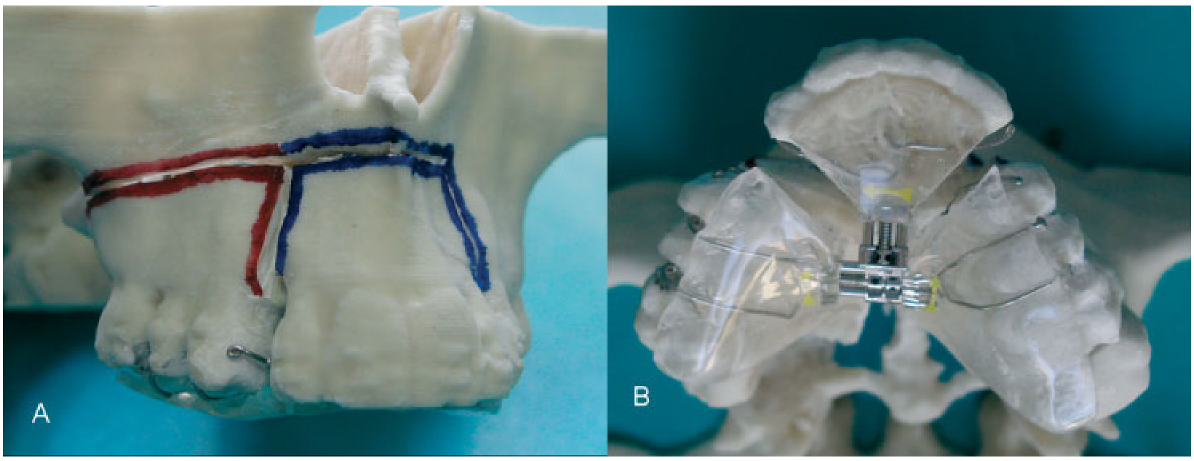

Figure 7. (A) Model surgery for the patient undergoing segmental osteotomy and corticotomy. (B) A three-directional premaxillary/palatal expander is adapted to the palate and checked out

antrum from anterior to posterior with its screw-type rod (Figure 8).

The internal trans-sinusoidal distractors were adapted and fixed with titanium screws (TS-MD, Gebrüder Martin GmbH & Co. KG, Tuttlingen, Germany), 5–7 mm in length and of diameter 1.5 mm (Figure 8). The distractors were checked for correct functioning and the flap was closed back with resorbable running sutures.

DOI: 10.1002/rcs

None of the patients required intraoperative blood transfusion.

Surgery for segmental maxillary distraction

An anterior segmental osteotomy was performed between the first premolars to widen the narrow maxilla and allow the placement of dental implants at the canines (Figure 9A). To prevent flattening of the nasal projection, the nasal base was excluded from the osteotomy. Maxillary corticotomy was performed on the right half to solve cross-bite. The fan-type distractor was secured to the maxillary teeth and activated (Figure 9B).

After active distraction, the consolidation period was determined to be 3 months (Figure 9C) to allow ossification of the distracted sites, which received two dental implants (Xive,Dentsply-Friadent, Mannheim, Germany) at the end of procedure (Figure 9D). An aesthetic smile was achieved by a fixed ceramic restoration (Figure 10).

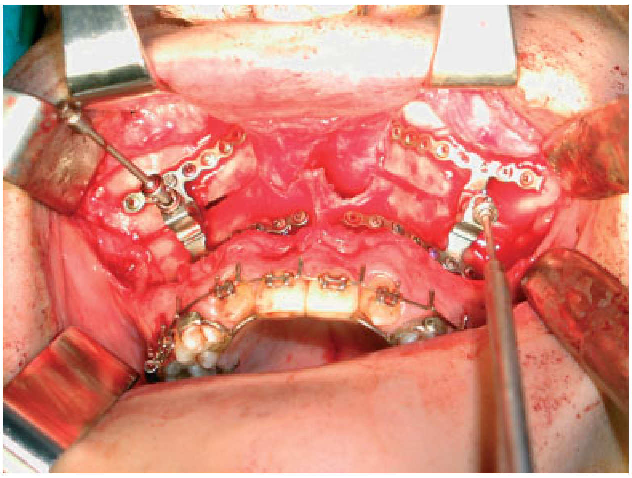

Figure 8. Intraoperative view of a TS-MD system fixed to the maxilla and Le Fort I osteotomy. The device is activated with a wrench

Distraction phase

Distraction protocol was same for all patients. After a week of latency, the distractors were activated. The rhythm of distraction was 1 mm/day until the desired amount of advancement had been achieved. At least 3 mm overcorrection was done to overcome any relapse. The retention or consolidation period was 3 months for all patients. The distractors were removed again under general anaesthesia and the treatment was finished by orthodontics or prosthetic fixed restorations (Figures 11, 12).

Figure 10. Final ceramic fixed restorations were fabricated to restore occlusion

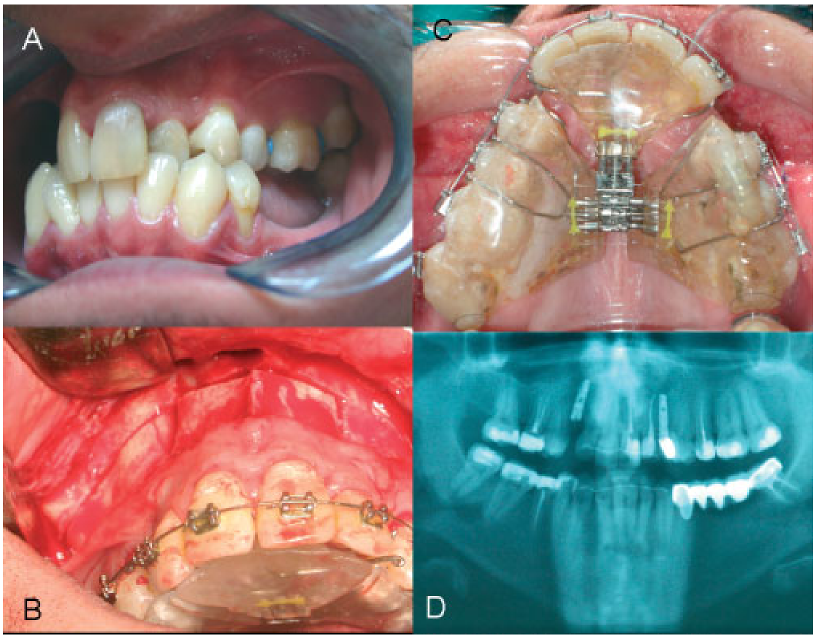

Figure 9. (A) Teeth crowding and narrow maxillary arch. (B) Anterior subapical segmental osteotomy and unilateral corticotomy. (C) Gradual advancement of the anterior maxillary segment and formation of gaps for the future implant placement segment. (D) Panoramic radiograph, revealing placement of two dental implants into the distracted sites

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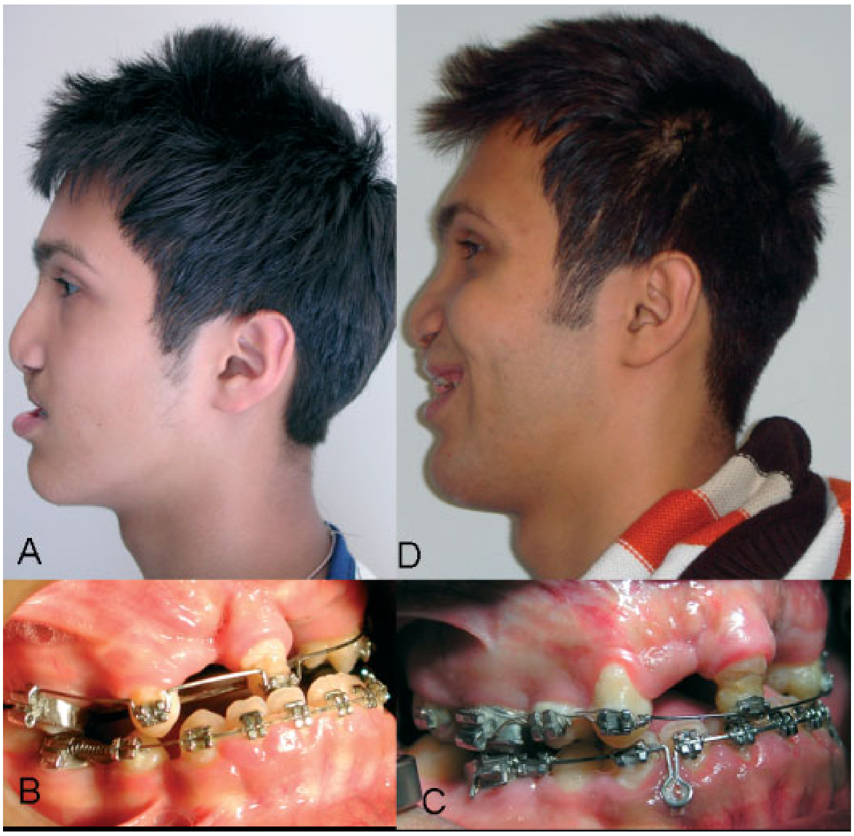

Figure 11. (A) Pre-operative facial view of a patient with CLP. (B) Pre-operative intraoral view. (C) Postoperative intraoral view after maxillary distraction. (D) Postoperative facial profile

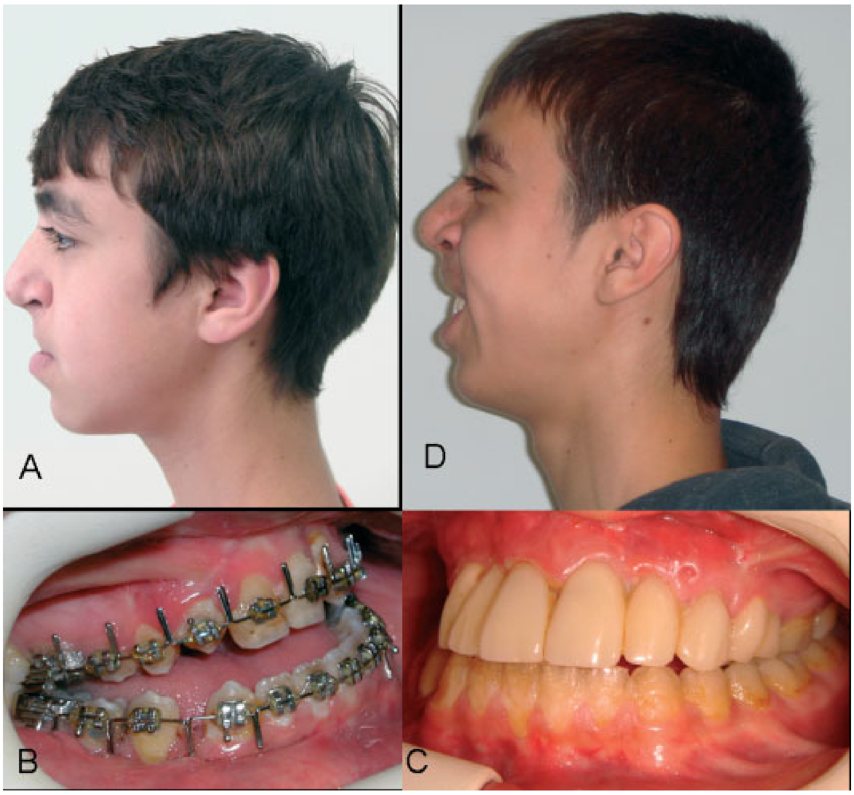

Figure 12. (A) Pre-operative facial view of a patient with CLP. (B) Pre-operative intraoral view. (C) Postoperative intraoral view after maxillary distraction. (D) Postoperative facial profile

Results

No complications were encountered in the postoperative period. All distractors followed preoperative planned vectors. Soft tissue ulceration, attributed to poor hygiene, occurred around the rods and labial mucosa in two patients. During the removal of the devices in three patients, bony impaction of the superior plates into infraorbital rim was observed, which was considered to occur by bone-stimulation forces on the plates caused by tension during the distraction period. All distracted patients achieved stable occlusion at the end of the treatment period.

Discussion

Treatment of CLP or trauma patients with severe maxillary hypoplasia requires a combination of bone grafting, orthognathic surgery or distraction osteogenesis (9,11,14, 16,17). Acute skeletal advancements of the mid-face often results in postoperative relapses when the maxilla is advanced more than 10 mm or the procedure is performed at puberty (18). Skeletal relapses were reported to occur following Le Fort I advancement within the range 22–40% in the horizontal plane and 19–70% in the vertical plane (16–19). To overcome such relapses, distraction osteogenesis is indicated, with gradual advancement of a retruded maxilla by intraoral or extraoral devices (9,10,12,14).

The foremost disadvantages of intraoral devices are: (a) it is not possible to perform 3D advancement; (b) there is no control over the distraction vector during active stretching, which is why the vector must be arranged preoperatively; (c) only limited distraction can be achieved and there is a need for a second surgery to remove the distractors (11,13). Adaptation of the distractors to the complicated anatomy of syndromic or hypoplastic maxillae may be difficult; even setting proper vectors in such situations turns out to be a time-consuming procedure (15). Therefore, pre-bending on 3D models is logical when submerged internal distractors are used (3).

It is very probable that predictable final occlusion can be achieved at the first surgery if careful planning, proper vector orientation and prebending of the distractors on 3D models is performed. Gateno *et al.* (4) benefited from computer-aided simulation and used stereolithographic modelling for 3D mid-face distraction with optimal results. Nadjmi *et al.* (13) fabricated a methyl-methacrylate template on stereolithographic models to position TS-MD devices. They adjusted the vectors virtually, placed the distractors on 3D models, waxed them onto the models to register their positions, and reproduced a methyl-methacrylate template that was used for intraoperative distractor positioning (13). Nakagawa *et al.* (15) fabricated an appliance from Roger Anderson pins for positioning intraoral Zürich Paediatric Maxillary Distractors (KLS Martin, Germany) parallel to the direction of lengthening.

A 3D simulated distraction surgery allows orientation of the distraction vectors in three planes (13). Besides the vector of straight anterior movement, it is also possible to give anteroinferior inclination to provide anterior and downward positioning of the distracted maxilla. Consequently, a combination of STL and 3D computer-aided surgery provides the full range for vector alignment. In our study, the vector of distraction was tuned on STL models. The vectors were adjusted accordingly by fitting the distractors several times to the STL models until the desired final occlusion was achieved by controlled activation of the devices. We did not fabricate resin templates as others had done, in view of the fact that anterior parallel movement of the distracted maxillary halves could not be justified without full activation of the system on the solid head models. The model surgery is a primary step to reshape or cut plates of distractors, which provides an easy intraoperative fit (3).

The rod of TS-MD is positioned completely into the maxillary sinus. Preoperative selection of the rod's length and arrangement of its x axis in the maxillary antrum in a 3D environment is important to overcome complications related to device adaptation that are likely to occur by underestimated contacts of the rod with the inner aspect of the posterior antral wall.

It is possible to combine both platforms, Mimics CMF and Simplant, to simulate complicated cases, such as the patent treated by segmental anterior distraction. Editing processed Mimics data in the Simplant platform allows surgeons the chance to consider whether placement of the dental implant could be possible after reconstructive bony surgery. This specific feature is very valuable for both patients and surgeons, because 3D surgical simulation determines the necessity for operation and reveals success preoperatively, thus obviating unnecessary surgery.

Virtual reality surgery offers a low-cost profile and repeatable planning, thus eliminating malpractice, and helps surgeons to perform surgeries with minimal drawbacks (3). STL models have been very important for simulating operations and validating the accuracy of virtual reality surgeries. However, surgery on the STL model could not be repeated, since rapid prototyping is expensive and models often become useless after primary model surgery. Therefore, computer-assisted surgery becomes invaluable for the planning of complex maxillofacial deformities. This new technology improves safety and precision in surgical vector planning. Soft tissue predictions are another developing part of surgical simulation software that gives important perception to postoperative facial profiles.

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