Mandibular surgery planning and 3D printed splint design.

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Abstract.
Purpose: Sagittal Split Ramus Osteotomy (SSRO) of the mandible is a very common osteotomy procedure used to correct jaw deformities. A recurrent problem is to maintain the position of the mandibular condyle as SSRO separates the anterior mandible and the condylar process. Alteration of condylar position can lead to malocclusion with a risk of relapse and temporo-mandibular disorders. The quality of the procedure depends on the operators experience. The purpose of this cadaveric and clinical study is to present splint and Condylar Positioning Devices (CPDs) produced using 3D Computed Aided Design/Computed Aided Manufacturing (CAD/CAM) technology. The aim is to keep condyles the closest to their preoperative position with postoperative planned occlusal position using 3D printed splint and CPDs during SSRO.
Materials and methods: External surface of 3D CT scan of craniofacial skeleton was extracted as a 3D mesh. SSRO was planned virtually. On one cadaver, occlusal splint and right and left anatomic maxillo-mandibular plates for condylar positioning were designed and manufactured. For one patient, latero-mandibular plates were fixed on the occlusal splint. A postoperative CT scan was performed after bilateral SSRO. We compared the virtual final position and the real postoperative position of occlusion and condyles.
Results: In cadaver and patient, the final occlusion was good and condylar movement was minimal. In anteroposterior plane comparison be-

tween planed condyle position and post-operative position show an infra-millimeter precision.

Conclusion: This new splint allows to obtain a good precision of the occlusal and condylar movements during SSRO. It is also simple and easy for surgeons who use CPDs. Here are presented first surgical results using the complete processing chain. Future works will focus on the automation of each process.

Keywords: Orthognathic Surgery, Surgery Computer-assisted, Mandibular Condyle, Occlusal Splints, Printing

1 Introduction

Sagittal split ramus osteotomy (SSRO) of the mandible is a very common osteotomy procedure used to correct jaw deformities. Occlusal splints are necessary for positioning the bone after SSRO. There were limitations of orthognathic models during : occlusal plane transfer, preparation of plaster models, simulation of operations and splints production [OR04].

Another problem is the preoperative position of the condyle. SSRO separates the anterior mandible and the condylar process. With a large review, Costa concluded that most authors rely on manual repositioning after SSRO to obtain the best relationship with the condylar fossa [CRT+08]. But the quality of the procedure depends on the operators experience. Alteration of condylar position can lead to malocclusion with a risk of relapse and temporo-mandibular disorders (TMDs) [EW86]. Ellis recommended the use of condylar positioning device [Ell94]. Uekei with a large review concluded that the most favorable post operative condylar position, including the disk position and horizontal condylar angle may not match the preoperative one, but would not be dramatically different except for cases with TMD (temporo mandibular disorder) or asymmetry [UMS+12]. Beziat reported very interesting results after sagittal split osteotomies peroperative splints and condylar positioning devices (CPDs) [BBFG09]. The disadvantage of the latero-maxillo-mandibular plates is the necessity of plates modeling and maxillary incision.

Recently, several articles highlighted the use of three-dimensionnal (3D) planning in orthognathic surgery [AHCHA12]. Computed aided design/computed aided manufacturing (CAD/CAM) approach allows preoperative planning and production of 3D printed splints using a 3D printer [MHMS+08].

The purpose of this cadaveric and clinical study is to present splints and CPDs produced using 3D CAD/CAM technology. The aim is to keep the condyles the closest to their preoperative position with postoperative planned occlusal position using our 3D printed splints and CPDs during SSRO. Splints designed have to be of simple and effective use.

2 Materials and methods

From imagery to surgery and quality assessment, the proposed method consists in the followings steps :

1. A head from a non-embalmed cadaver specimen was studied. It was a 61 years old woman with almost all her teeth, well fixed and none treated (metal free).
2. Dental impressions of maxillo-mandibular occlusion in centric relation were made to produce initial dental guide (G0). G0 was recorded to determine the initial occlusal position.
3. Computed tomography (STOMATOM Sensation 16, Siemens, Forchheim Germany) was realized. Acquisition protocol: X-Ray tube current of 177 mA, voltage of 120 kV. The slice thickness was 1mm with no gapes. The field of view was from the skull base to hyoid bone and CT images were stored in Digital Imaging and Communication in Medicine (DICOM) format. The images were obtained positioning the head with Frankfurt plane perpendicular to the horizontal plane. Mouth was opened during the scan.
4. A surface extraction using an isocontour method was carried out on the DICOM images. The method used is called "Neighbourhood Based Marching Cubes" [GD05]. While based on the classical "Marching Cube" method [LC87], this algorithm leads to a more precise surface extraction. The external surface of the cranio-facial skeleton is reconstructed as a 3D mesh (figure 1).

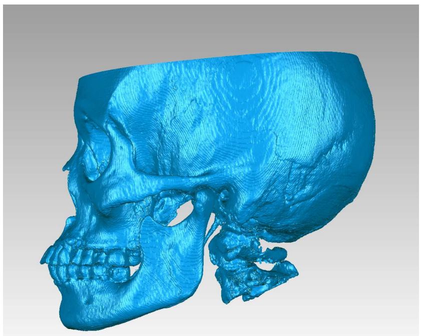
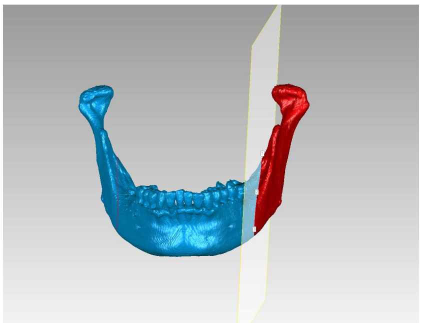


Fig. 1. Segmentation and external surface extraction. 3D mesh

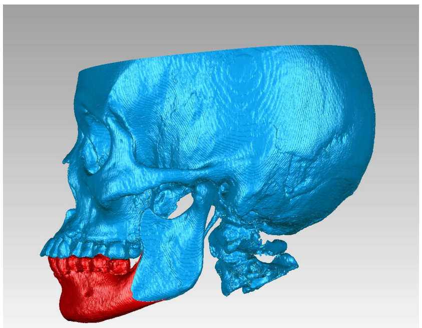
5. Planning was performed:
   – G0 was scanned using a surface scanner (Aquilon, Kreon Technology, Limoges, France). The point cloud was stored in ASC file and the mesh was reconstructed using Geomagic® Studio® 12. First we aligned G0 to the 3D maxilla reconstructed using 3 anatomical points in maxillary teeth to obtain a precise overlap in teeth. Subsequently, we aligned

G0 to the 3D mandible reconstructed using 4 others anatomical points in mandibular teeth. The 3D mandible and maxilla were automatically moved to the primary position according to G0.

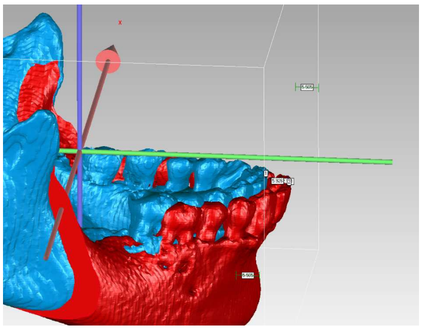
- Then, we performed virtual osteotomies of the mandible (SSRO) with Geomagic (figure 2(a), figure 2(b)). We moved the distal segment of the mandible using a multiplanar view to the final position. It was determined that the mandible required 5,5 mm advancement and 2 mm mouth opening (figure 2(c), figure 2(d)).



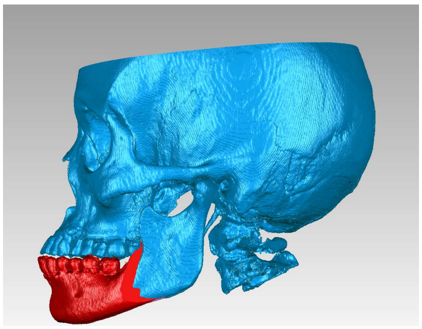
(a) Osteotomies of the mandible (SSRO) performed with Geomagic® Studio® 12



(b) Lateral view of the virtual SSRO



(c) Mandible required 5,5 mm advancement and 2 mm mouth opening

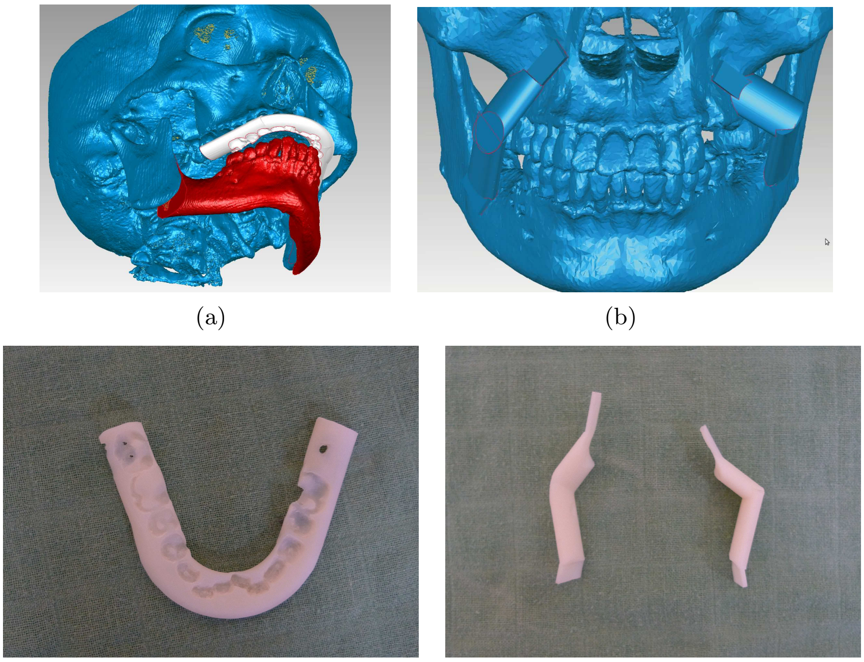


(d) Lateral view of the virtual SSRO with mandible advancement

Fig. 2. Virtual SSRO planning

6. We designed 3D printed surgical splints
   - To produce the first splint (S1, primary position), the original mandible and maxilla in primary position were used. We designed a splint and placed it between the teeth. The software (GEOMAGIC) performed a Boolean operation by subtracting the impressions of the teeth from this splint resulting in S1.
   - The second splint (S2, final mandibular position) was produced using the maxilla and the mandible in final position (figure 3(a)).

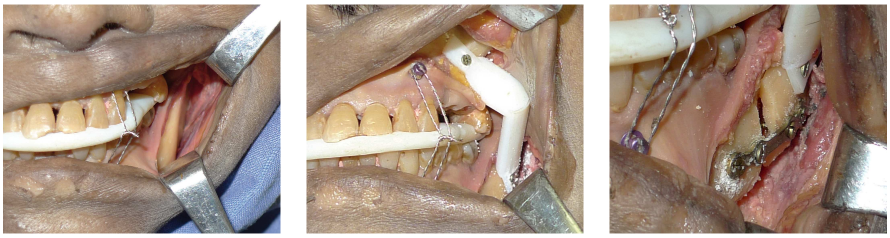
- Right and left latero-maxillo-mandibular plates were designed. A Boolean operation by subtracting the impressions of bone surface from the ends of the plates resulting in right and left anatomic maxillo-mandibular plates (Pr, Pl) (figure 3(b)).
- S1, S2 Pr and Pl were exported to a 3D printer (Objet Eden250$^{\text{TM}}$) to produce the splints (figure 3(c), figure 3(d)).



(c) (d)

Fig. 3. Splint design and 3D printing
(a) Second splint (S2, final mandibular position) was produced using the maxilla and the mandible in final position. On the picture, the mandible was moved down **(b)** Right and left latero-maxillo-mandibular plates were designed **(c)** Occlusal splints were produced in a 3D print **(d)** Pr and Pl were exported to a 3D printer to produce the splints

7. Surgery was performed. The maxilla and the mandible were fixed in primary position with the first 3D printed splint S1 and maxillo-mandibular fixation (MMF) was performed (figure 4(a)). Lateral maxillo-mandibular plates (Pr, Pl) were drilled and fixed by 2 screws at each ends of them (figure 4(b)). Then plates and MMF were removed. Bilateral sagittal split ramus osteotomy of the mandible was performed. MMF was performed in final position with the second splint (S2). Lateral anatomic plates (Pr, Pl) were fixed again to po-



(a) (b) (c)

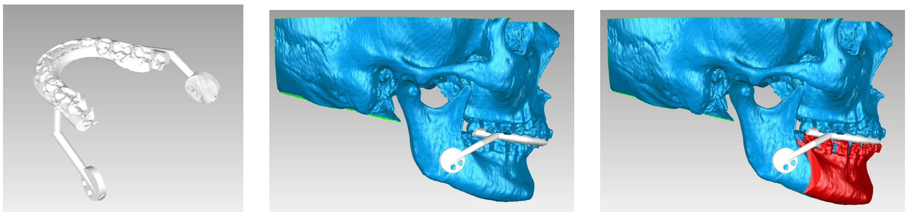
Fig. 4. Cadaver surgery
(a) The maxilla and the mandible were fixed in primary position with the first 3D printed splint S1 and maxillo-mandibular fixation (MMF) was performed **(b)** Lateral maxillo-mandibular plates (Pr, Pl) were drilled and fixed by 2 screws at each ends of them **(c)** MMF was performed in final position with second splint (S2). Lateral anatomic plates (Pr, Pl) were fixed again to position the condyles in primary position. Then osteosynthesis was performed bilaterally with titanium plates

sition the condyles in primary position. Then osteosynthesis was performed bilaterally with titanium plates (figure 4(c)).

8. A postoperative CT scan was performed (same protocol).
9. Image fusion procedure: the preoperative position, the virtual final position and the real postoperative position were compared.
10. Analysis:
    - Comparisons : G0-S1 pre operatively on cadaver : initial positions evaluation found on cadaver with S1 comparisons.
    - A postoperative CT scan was performed with the final splint and segmentation of images was carried out. Maxillo-zygomatic complex of the planning was aligned with the maxilla-zygomatic complex of the postoperative segmentation using 4 points of registration. The preoperative planning situation and the postoperative situation of the condyles have been be evaluated.
11. We propose a latero mandibular plate fixed on the occlusal splint (figure 5(a)). The production method was the same. A 40-year-old patient with squelettal class 2 malocclusion but without TMD underwent a SSRO. The mandible required 5 mm advancement (figures 5(b), 5(c), 6). Evaluation method was the same than in cadaver.

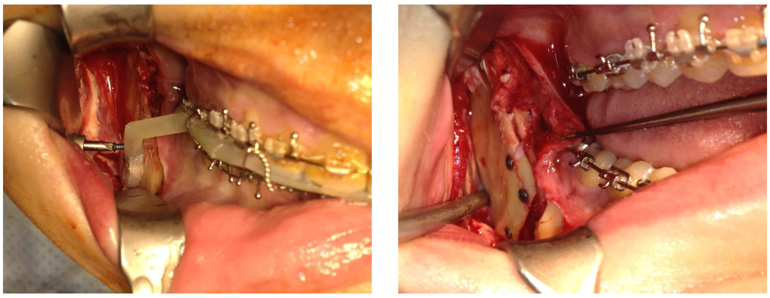
3 Results

On the cadaver, maxillary and mandibular teeth fitted perfectly in S1. Condylar movement was minimal (figure 7). For the class 2 malocclusion patient, the surgery was easy and final occlusion was perfect. The CT comparison showed minimal condylar movement (figure 8).



(a) (b) (c)

Fig. 5. Latero mandibular plate fixed on the occlusal splint
(a) 3D occlusal and condylar splint **(b)** in primary occlusal and condylar positions
(c) with 5mm mandibular advancement and condyle in primary position



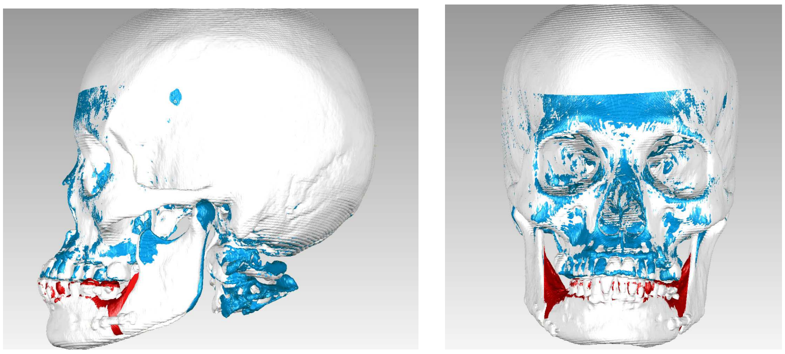
(a) (b)

Fig. 6. Patient surgery
(a) Occlusal and condylar positioning splint in place with MMF. Latero mandibular plate of the splint were fixed by 2 screws on the right and left proximal segments **(b)** Osteosynthesis of the mandibular segments

4 Discussion

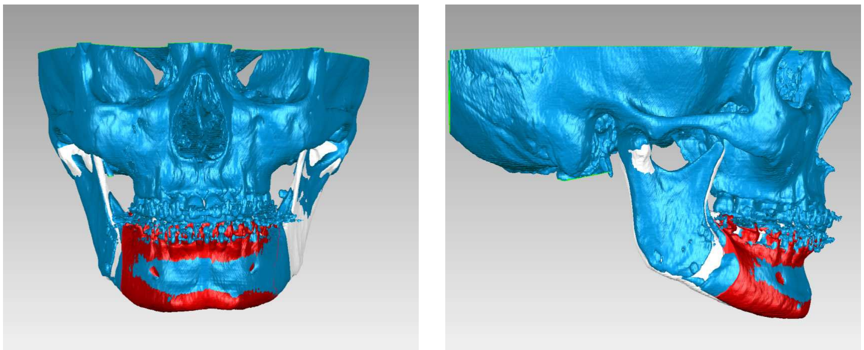
Splints and CPDs manufactured using CAD/CAM technology allow to keep the condyles the closest to their preoperative position with postoperative planned occlusal position.

Recently, different approaches to the problem of accurate positioning of base fragments have been described. Metzger presented a technique for manufacturing splints using a three-dimensional printer which combined the advantages of conventional plaster model, precise virtual 3D planning and the possibility of transforming the acquired information into a dental splint [MHMS+08]. To product our splints, first we designed a virtual splint and placed it between the teeth. The software performed a Boolean operation by subtracting the impressions of the teeth from this splint resulting in S1. Then virtual splints were exported to a 3D printer. The first splint corresponded to preoperative position. The second splint was virtually determined with the mandible and required 5,5 mm advancement and 2 mm mouth opening. The precision of the first splint



(a) Left 3D view (b) Anterior 3D view

Fig. 7. In cadaver, planed (red) and post operative (white) occlusion were aligned. Comparison of planed (blue) and post operative condyle (white) positions showed infra millimeter movement



(a) Anterior 3D view (b) Right 3D view

Fig. 8. In patient, planed (red) and post operative (blue) occlusion were aligned. Comparison of planed (white) and post operative condyle (blue) positions showed infra millimeter movement

was controlled on cadaver before surgery. We have noted that these splints fit perfectly and precisely the occlusal surface, allowing a stable and accurate bone positioning, as suggested by Metzger. Their production do not require plaster model, avoiding disadvantages described by Olszeweski [OR04].

In 2009, Beziat reported very interesting results after sagittal split osteotomies peroperative splints and CPD [BBFG09]. Changes in antero-posterior direction were present in 74% of cases with an average amplitude of 0,32 mm. In transversal direction, they were present in 54% of the cases with a smaller amplitude of 0,19mm. This may be the consequence of the changes in the postoperative position of the condyle or of errors due to the splints production. In 1994, Ellis compiled questionnaires answers of nine of eleven surgeons who published articles concerning the use of condylar positioning devices. Six of nine surgeons continued to use the CPD : 3/6 on a routine basis and 3/6 in difficult or extreme cases or in cases with preoperative temporo-mandibular disorders (TMDs) [Ell94]. One of the reasons for giving up the use of CPD on a routine basis by the six surgeons were : too time consuming and too difficult to use. We have reproduced Beziats process, but by producing lateral plates with CAD/CAM technology. The right and left latero-maxillo-mandibular plates were designed inspired by Leiggener fibulas guide [LMT$^+$09]. The plates were designed to fit to their anatomic maxilla and mandibular sites using a Boolean operation by subtracting the impressions of bone surface from the ends of the plates. CPDs are anatomically perfectly congruent with the bone surface of the patient, reducing the modeling time of the plates. Modification of mandibular condyles position is minimized (rotation caused by the gap between proximal fragments due to the mandibular protrusion). With this technique, CPDs turn into an easy way to process, positioning itself alone on the bone surface. Their use allows to check the condylar movement, without being based on the surgeons experience. The technique we have described employs advances in virtual planning and manufacturing 3D printed splints. The planning must be improved for preoperative and post operative occlusion. The positioning guides described are enough to obtain a precise and reproducible position of occlusion and condyles prior to osteosynthesis of a SSRO. We believe this is the first time a virtual planned and printed CPD has been described in a SSRO.

The disadvantage of the latero-maxillo-mandibular plates is the necessity of maxillary incision. We propose a latero mandibular plate fixed on the occlusal splint. It will reduce the time of surgery and will permit all advantages for the precision of the movement that we described in this anatomic study. This new splint is precise and easy for surgeons who use a CPD.

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