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Short Communication

Surgical planning using facial fracture 3D models: The role of cyanoacrylate glue and miniplating for anatomical reduction

Khong-Yik Chew[a,*], Yee Onn Kok[a], Wan Sze Pek[a], Chow Wei Too[b], Bien-Keem Tan[a]

[a] *Department of Plastic, Reconstructive and Aesthetic Surgery, Singapore General Hospital, Singapore*
[b] *Department of Vascular and Interventional Radiology, Singapore General Hospital, Singapore*

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ABSTRACT

Background: In comminuted facial fractures, peri-operative use of 3D-printed life size models is increasingly a useful adjunct. It allows for preoperative surgical rehearsal and plate bending, to achieve anatomical reduction with reduced operative time and cost. One problem encountered is difficulty contouring the fixation plate whilst maintaining the relative spatial orientation of comminuted fragments. This paper shares an effective method of overcoming this problem.

Methods: All comminuted facial fracture patients underwent counselling for 3D printing. Pre-printing thresholding and segmentation of each fragment (as directed by the surgeon) were done by the radiologist and the engineering team, using the multi-slice CT Face DICOM data. Life-size 3D-resin models of the fractures were printed. Fast-acting medium consistency cyanoacrylate glue (Zap-A-Gap®) and miniplates were used to assemble the printed model segments in 'anatomic reduction'. Aerosolized alcohol accelerator facilitated immediate glue curing, providing a stable model. The plates were adapted over this restored neonative 3D construct with bending inserts, sterilized and used intraoperatively. The 3D model

* Corresponding author.
E-mail address: khongyik@hotmail.com (K.-Y. Chew).

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was used to guide the operative sequence. Intraoperative CT was used in select cases to confirm anatomic reduction.

Results/Complications: All patients ($n = 5$) had comminuted fractures in at least one of the bony units (mandible, maxilla or orbits) and one was a pan-facial fracture case. 3D printed models aided fracture reduction and fixation, whilst avoiding the guesswork in ascertaining the contour of the mandibular arch. In addition, the pre-contoured mandible plates restored premorbid occlusion and projection, without the need for long-term archbars in all cases. Operative time was estimated to be reduced by 0.5–1 h. Resident teaching was enhanced by this approach.

Conclusion: The application of medium consistency fast-acting cyanoacrylate glue and miniplates facilitated the creation of the premorbid facial skeletal model and allowed pre-bending of the plates, thus saving operative time and cost.

Introduction

Three-dimensional (3D) printing, also known as 3D stereolithography or Rapid Prototyping (RP), via the Computer Assisted Design and Manufacturing (CAD/CAM) software, has progressively revolutionized surgical planning and simulation since the 1980s. From cancer reconstruction to complex fracture fixation and treatment of congenital deformities, stereolithography is now recognised as the gold standard in current practice. However, the technique has not gained traction owing to lack of access to this technology and concerns about cost.[1,2]

Our objective is to describe how we assemble and glue the 3D printed parts to create an exact replica of the fractured facial skeleton.

Methods

All patients with comminuted or panfacial fractures undergoing surgery by the senior surgeon in 2019 underwent counselling for 3D printing models. Comminution is defined as the individual bone unit fracturing into five parts or more. Five cases were recruited.

Preoperatively, a Siemens Somatom Force 384 CT scanner was used for 1 mm fine-cut scanning of the entire facial skeleton. Virtual 3D reconstruction of the CT images was done using Siemens and Hexaunion3D software. First, the critical fragments were marked out by the surgeon (Figure 1). Next, pre-3D printing thresholding and segmentation of each fragment were done by the radiology and 3D engineering team, using the multi-slice CT Face DICOM (Digital Imaging and Communications in Medicine) data.

Life-size 3D ABS (Acrylonitrile Butadiene Styrene) polymer models of the fractured facial skeleton were then printed using the Lite 600 printer (UnionTech3D, Shenzhen, China). It was imperative for the software engineer to double-check the printing scale and ensure the model was life-size as according to the CT data. The surgeon verified this by comparing the dimensions of the printed teeth on the model to that of the patient's teeth. This was a crucial step if the model were to be an accurate template for plate bending. The surgical team performed the surgical planning using the Synthes craniofacial sets. As some printed pieces did not fit well due to inaccuracies in segmentation, the burr was used to smoothen irregularities that interfered with the precision of the fit.

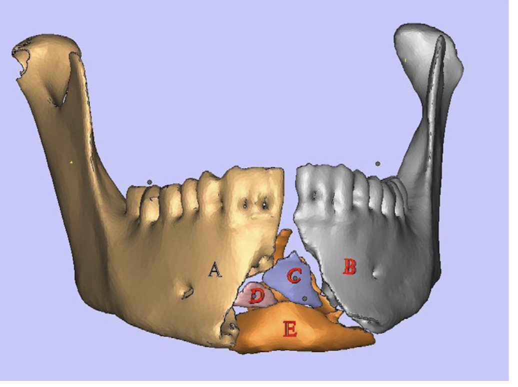

Figure 1. Surgeon-guided segmentation of CT image for 3D printing (Case 4).

Figure 2. Life-size 3D model of the reduced comminuted mandibular fracture assembled by cyanoacrylate glue and miniplates. This model was used as a template to pre-bend the mandibular trauma plate. (Case 4).

The model fragments were held in adequate 'anatomic reduction' by the main surgeon while the assistant applied the medium consistency fast-acting cyanoacrylate glue (Zap-A-Gap), followed by the kicker aerosol. The glue cured immediately due to the accelerant nature of the kicker spray. Assembly of the printed pieces was quick using this adhesion method.

Miniplates (Synthes, Pennsylvania) were used to enhance the strength of the assembled model. These plates were placed away from the standard plating surfaces e.g.: the inferior lingual border of the mandible. 3-hole plates (0.7 mm thickness) were used. For the mandible, the chosen trauma plate was adapted over the mandibular model with bending inserts (Figure 2). The bending inserts ensured that the screw holes did not warp during the bending process. In mandibular fractures, 'reduction' of the model was checked by articulating it with the printed upper jaw and checking the 'occlusion'. The bended pre-contoured plates were sterilised to be used intraoperatively. In select cases, intraoperative CT was done to confirm anatomic reduction.

Results

We share 2 illustrative clinical cases. No major complications such as implant infection, osteomyelitis, malunion or non-union occurred for all 5 cases. (Table 1)

Table 1
Patients' characteristics.

Patient	Age (years)/Gender	Injury Mechanism	Fracture Type	Cost of 3D Printing(SGD)	Estimated Operative Time Saved(Hour)
1	32/F	RTA	Panfacial	$2000	1
2	24/M	RTA	Mandible Lefort I	$2000	0.75
3	77/F	Assault	Bilateral Lefort I and II	$1500	1
4	31/M	RTA	Mandible	$2000	0.75
5	70/M	Fall	Mandible	$1500	0.75

RTA: Road Traffic Accident, M:Male, F:Female.

Illustrative cases

Panfacial Fracture (Case 1)

A 32-year-old female road traffic accident (RTA) casualty (motorcyclist versus car) sustained panfacial fractures with concomitant injuries of subdural hemorrhage, right central retinal artery traumatic occlusion and cervical spine fractures. Her facial fractures included bilateral orbital floor, right hemi-Lefort III and left hemi-Lefort I fractures, and a four-part mandible fracture.

The challenge was restoring facial symmetry and projection of the vertical and horizontal buttresses, especially with comminution and bone loss of the right orbital frame and wall. 3D panfacial modeling allowed for surgical planning and rehearsal to determine the best fit. Operative time was shorter as the surgeon had pre-contoured plates and the use of the model for intraoperative reference.

Comminuted Mandibular Fracture (Case 4)

A 31-year-old male RTA casualty (motorcyclist versus car) sustained a comminuted six-part anterior mandible fracture with concomitant injuries of subarachnoid hemorrhage and left clavicle fracture (Figure 1).

The 3D model allowed a surgical rehearsal to decide how to reduce and fix the individual bone fragments without devascularizing the teeth, lacerated buccal gingiva and the anterior mandible as a whole (Figure 2). The pre-contoured mandibular plates and model itself guided the intraoperative reduction, ensuring restoration of the mandibular arch and occlusion. A 2 mm trauma plate and bi-cortical fixation were essential for rigid fixation of the coronally split fragments (Figure 3).

Discussion

Our key idea was the superglue (Zap-A-Gap) technique for assembling the printed model. Using the alcohol accelerant, cyanoacrylate glue cured instantly and bridged gaps in the construct. This way, 'reduction' was rapid and multiple segments were pieced together instantly into a composite shape. Any error was rectified easily by breaking the inaccurate bond and repeating the process. Once the contour and reduction were satisfactory, plating was done over stress areas to reinforce the model. The advantages of the medium consistency Zap-A-Gap include its gap filling ability and compatibility with the model resin.

The latest model materials are plastics-derived, such as polylactic acid (PLA) and photopolymer resin, which have sufficient tensile strength to allow drilling and screw insertion. However, they do not tolerate autoclaving in high temperatures. To sterilize the models, we used gamma irradiation or disinfectant treatment with chlorohexidine or iodine.

Using 3D models in comminuted orbital fractures and mid-face fractures allowed us to compare the fractured sides, and we usually used the less comminuted side as a template (Cases 1, 3).[1,3,4] We were able to directly visualize the extent of bone loss, which facilitated the design of the bone grafts and implants needed. In mandibular fractures, it allowed ease of checking for the adequacy of 'reduction' after the model was reconstituted. By articulating the reconstituted model with its counterpart

Figure 3. Post-operative CT scan (Case 4).

i.e. the fractured mandible with the maxilla and vice versa, we ascertained temporomandibular joint congruity and dental occlusion (Cases 2–5).

The potential disadvantages of 3D printing included the additional cost, need for 3D software engineering and a lengthy turnaround time. Specifically, the 3D software engineer needed to be proficient in thresholding and segmentation.[5,6] This involved selecting, defining (or merging) the relevant fracture fragments and smoothening out pixel edges before printing.

Declaration of Competing Interest

N/a.

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Ethical approval

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