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Incorporating ‘off-the-shelf’ reconstruction plates into the digital plan for mandible reconstruction

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ABSTRACT

This short communication describes the process to incorporate non-custom fixation plates into the digital workflow for in-house virtual surgical planning and proposes solutions to improve surgical precision when executing the digital plan. A custom-made two-stage digital pin positioning and alignment system was built to articulate the screw channels by matching the digital pins to the scan. The location and angle of each digital pin is then translated into the design of the mandible and fibula cutting guides. This protocol overcomes some of the inherent disadvantages of not being able to print or mill a patient-specific plate.

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Introduction

Digital planning for maxillary and mandibular reconstruction is becoming routine in institutions performing large volumes of microvascular reconstruction.[1] Many centres are developing in-house capabilities to contain costs and minimise delays for oncology cases.[2-5] Reliable implant-retained dental rehabilitation following mandibulectomy or maxillectomy depends on optimal bone placement, which is difficult to achieve without pre-operative planning, either analogue, based on physical models, or digital, using virtual planning. Dental rehabilitation requires a coordinated plan prior to surgery involving the ablative surgeon, reconstructive surgeon, prosthodontist and design engineers, who perform the digital planning. We have previously described our early experience with in-house virtual surgical planning.[2] However; several challenges remained when compared to patient-specific plates, principally because we are unable to 3D print or Computer Numerical Control (CNC) mill a titanium plate for bone fixation. The purpose of this paper is to describe a novel solution that allows the incorporation of non-custom or ‘off -the -shelf’ plates into the digital plan for mandibular reconstruction with a free fibula flap using 3D printing and optical scanning.

Abbreviations and Acronyms:

DICOM Digital Imaging and Communications in Medicine; ROI Regions of Interest; STL Stereolithography; FDM Fused Deposition Modelling; SLA Stereolithography Apparatus; CNC Computer Numerical Control; PLA Polylactide Acid

Material and methods

This study was carried out following institutional ethics approval (HREC LH20.055). Image acquisition and 3D printing of native anatomical models was performed according to a previously published protocol.[2]

Virtual Reconstructed Mandible with Implant Planning

An “occlusal-driven” planning strategy was deployed by first defining the optimal location of dental implants prior to contouring the fibula. The virtual cutting planes for osteotomies of the mandible are defined and translated to the fibula as starting- and end points.A virtual mandible with multiple fibula segments is created reproducing the desired mandibular contour and bone volume around the implants. The virtual mandible is FDM 3D printed at 250µm using Facilan™ C8 high-performance polylactide acid (PLA) thermal plastic extruded from a heated print head assembly.

An ideal wax-up of the denture is produced and positioned on the 3D-printed reconstructed mandible as a reference object. The mandible and denture are optically scanned using a Shining EINSCAN-PRO 2X PLUS 3D scanner and EXSCAN PRO software (Accuracy: 0.04mm, Turntable coded targets alignment). The scan data is imported into CAD software and superimposed over the digital planning file. The STL files of the scanned maxillary teeth, dental wax up, planned fibula reconstruction, dental implants and native mandible are superimposed to ensure ideal alignment of the implants. Cutting and dental implant drill guides are developed using Autodesk 3dsMax 2020 (Autodesk, San Rafael, CA 94903, USA) polygonal modeling tool and sub-object modifier. The virtual neo-mandible is 3D printed for contouring of a stock (non-custom) reconstruction plate. Using locking screws, the reconstruction plate is mounted onto the 3D printed mandible model and the plate and screws are removed.

To incorporate the reconstruction plate into the virtual plan, the location of the locking screws needs to be registered. For patient-specific plates, this is achieved by digitally planning the plate and screw position, and then 3D printing or CNC millinga titanium plate as per the digital plan. Most institutions do not have this capacity, so a walk-around approach is described: 3D printed physical alignment pins are inserted into the screw holes in the 3D-printed mandible and the entire model is scanned optically using a Shining EINSCAN-PRO 2X PLUS 3D scanner. Virtual (digital) pins are superimposed and aligned on the scanned pins using the custom-made digital pin positioning and alignment algorithm. Digital pins are then then translated to the cutting guides. Screw spacing and fibula segments are compared between digital models and physical models to ensure the dimensional error is <0.2mm.

Reconstruction Plate Locking Screw Channels Articulation (Figure 1)

3D Printing Surgical Guides

Mandible and fibula cutting guides models are triangulated, exported, and SLA printed (Raft Thickness: 2.00 mm, Density: 1.00, Touchpoint Size: 0.7 mm, Height Above Raft: 5.00 mm, Slope Multiplier: 1.00) using surgical resin. After printing, 3D prints undergo a two-stage 10-minute wash using Isopropyl alcohol and exposed to Ultraviolet (UV) light radiation for 60 minutes at 60°C. Post-processed SLA printed models undergo dimensional accuracy verification. Stainless steel sleeves are friction fitted into the implant drill guide slots. And all models and guides are packaged for disinfection and steam sterilization (3 minutes at 138 °C).

Mandibulectomy and Reconstruction

A two-team approach was used for concurrent mandibular resection and harvest of the fibula free flap. The mandibular cutting guides were secured to bone using 2mm screws, the reconstruction plate screw holes are drilled, and osteotomies performed. The fibula flap is left vascularised whilst the cutting guides are secured to the bone and the reconstruction plate screw holes drilled and osteotomies performed. The reconstruction plate is fixed to the fibula segment using unicortical locking screws and the flap pedicle is divided. The bone is then inset to the mandible using the locking plate and bicortical screws placed via the pre-drilled screw holes. After revascularisation, the implant drill guide is applied to the fibula and implants placed.

Mandibulectomy and Reconstruction (Figure 2)

Discussion

This short communication describes the novel clinical application of 3D printing (FDM and SLA), optical scanning, and custom matching and alignment algorithms to incorporate non-custom reconstruction plates into the digital plan. In our previous study, we described virtual surgical planning in an institutional context utilising low-cost 3D printed cutting guides and proprietary reconstruction plates pre-contoured to the 3D printed virtual mandible prior to surgery.[2] However, it is difficult to know intraoperatively whether the reconstruction plate has been positioned in accordance with the digital plan without specific reference points. Integrating, the reconstruction plate screw holes into the patient-specific osteotomy guides provides precise and intuitive reference points for fixing the bony fibula fragments on the reconstruction plate, and then to the mandible. Whilst some institutions may already be able to produce patient-specific plates, the regulatory constraints in most countries inhibitory.

The goals of microvascular reconstruction of the mandible and maxilla extend beyond restoring bone continuity and aesthetics. Long-term functions such as speech, swallowing and mastication rely on restoring normal occlusion via dental rehabilitation.[6] In many patients, this can only be achieved through implant retained dental rehabilitation, which in turn is dependent on optimum bone positioning, which is difficult to achieve without preoperative planning. Conventional freehand contouring of osseous flaps is technically difficult, time consuming and unlikely to optimally position the bone for osseointegrated implants.[5,7] Unwanted outcomes such as malocclusion, temporomandibular joint dysfunction, facial asymmetry or poor bone contact at osteosynthesis sites are common outcomes without careful planning.[8,9]

The algorithms described articulate and visualise screw channel position, orientation, and length to optimally configure their unique relationship to the reconstruction plate. The screw channels in the cutting guides match the reconstruction plate locking screw channels, and the plate itself will act as a positioning guide. In this way, we can overcome some of the deficiencies of institution-based digital planning, where custom (patient-specific) plates cannot be manufactured. In particular, the reconstruction plate and fibula segments are fixated in the same location and angulation as the virtual surgical plan. In addition, the fibula segments can be fixated to the reconstruction plate whilst still vascularised, improving operational efficiency and precision. To our knowledge, this development of incorporating patient-specific osteotomy guides and 'off-the-shelf' reconstruction plates for mandible reconstruction has not been reported before.

Alternative approaches for plate fixation have been described using surgical guides which act as an external fixator.[4] while positioning guides can significantly improve the accuracy of mandible reconstruction, angular and vertical errors may occur in complex cases involving multiple fibula segments. In addition, a positioning guide can be difficult to use due to interference with soft tissue and the reconstruction plate, depending on its location. Finally, planning the screw position prevents placement of screws close to osteotomy or implant sites. Digital planning is commonly applied in complex mandibular defects, and the seamless integration of additive manufacturing in reconstructive surgery is increasing rapidly.[10] Virtual surgical planning and 3D printed patient-specific guides increase the accuracy and precision of reconstructive surgery, reduce operating times in complex cases, reduce intraoperative complications, thus reducing hospitalisation and postoperative morbidity.[10]Culié et al. (2016) in a series of 29 cases, found that computer-assisted planning and 3D printed surgical guides led to decreased operating time and ischemia time, particularly in complex cases.[1] Despite these benefits, the use of proprietary digital planning is associated with long turnaround time and substantial costs prohibiting ubiquitous use globally.

Conclusion

We have described a customised in-house virtual surgical planning protocol that incorporates patient-specific osteotomy guides and proprietary reconstruction plates with the goal of streamlining mandibular free flap reconstruction.

Author Contributions:

Kai Cheng, David Leinkram, Dale Howes and Jonathan R. Clark planned and carried out the virtual surgical planning. Kai Cheng developed the digital pin positioning and alignment system and carried out 3D printing. Jonathan R. Clark, David Leinkram and Sydney Ch'ng carried out the surgery. Payal Mukherjee contributed to optical scanning. All authors provided critical feedback and helped shape the research and manuscript. Kai Cheng took the lead in writing the manuscript.

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Conflicts of Interest:

The authors declare no conflict of interest.

Captions to figures

Figure 1. 3D printed physical alignment pins are inserted into the screw holes in the 3D-printed mandible and the entire model is scanned optically. Digital pins are superimposed and aligned on the scanned pins using positioning and alignment algorithm. Digital pins are then then translated to the cutting guides.

Figure 2. The mandibular cutting guides were secured to bone, the reconstruction plate screw holes are drilled, and osteotomies performed. The fibula flap is left vascularised whilst the cutting guides are secured to the bone and the reconstruction plate screw holes drilled and osteotomies performed.The reconstruction plate is fixed to the fibula segment using unicortical locking screws and the flap pedicle is divided. The bone is then inset to the mandible using the locking plate and bicortical screws placed via the pre-drilled screw holes.

Figure 1.

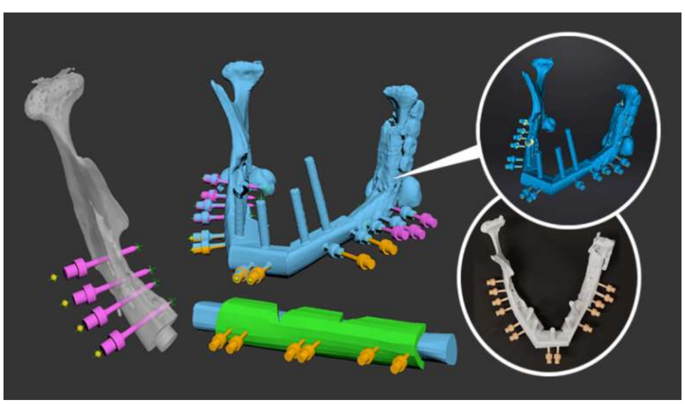

Figure 2.

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