Three-dimensional computer-aided surgical workflow to aid in reconstruction: From diagnosis to surgical treatment

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ABSTRACT

The development of three-dimensional computer-aided surgical workflow has simplified the planning of complex reconstruction cases. It can also be helpful in planning distraction osteogenesis cases. This article examines the evolving role of three-dimensional computer-aided surgical workflow in maxillofacial surgery.

Keywords: Computer-aided design computer-aided manufacturing, planning, reconstruction

INTRODUCTION

One deficiency in planning complex reconstructive surgery using either autologous bone or tissue engineered constructs is the inability to predictably produce complex facial contours using commercially available reconstruction plates and meshes.1-5 Commercially available metallic reconstruction plates are supplied as generic sizes and shapes being designed on the basis of the “average” patient.6 These reconstruction plates are often made from titanium and are supplied as straight or slightly contoured metal plates with predrilled holes for retention by screws.6-12 The surgeon may spend considerable time during surgery bending and shaping the plate to fit the contour of the patient’s bone. Titanium reconstruction plates currently used for mandibular defects are subject to both over-bending and a lack of passive fitting, which may eventually lead to fatigue fractures.6,7 Such over-bending may also be hazardous to distraction hardware, where repeated bending of footplates to adapt them to difficult anatomical confines may make the footplates or distractor stems susceptible to fatigue fractures.6,7 The accuracy of custom made parts makes such repeated bending unnecessary.6,7,12 The aim of this report is to outline three-dimensional computer-aided workflow for use in major cranio-maxillofacial reconstruction and distraction cases.

MATERIALS AND METHODS

One solution to this problem is to use computer-guided surgical planning technologies like additive manufacturing to produce a passive fitting implant designed for patient specific anatomical needs. Progress in medical imaging and continued incremental increases in computer processing power available for both three-dimensional patient data acquisition and subsequent image processing make it possible for clinicians to diagnose, more accurately plan, simulate and treat their patients [Figures 1-4]. To date the most common use of additive manufacturing has been the fabrication of patient specific skull models for preoperative planning. These skull models are fabricated using patient specific imaging data in the form of Digital Imaging and Communications in Medicine (DICOM) files, which are then converted into stereolithography (STL) files, the standard manufacturing format used to print patient specific skull models. The use of such three-dimensional medical models helps surgeons to plan, simulate the planned operation and manually prebend commercially available reconstruction plates. Recent developments in the area of additive manufacturing allow the prefabrication of patient specific, customized, reconstruction plates using the patient’s DICOM data. The advantages of rapid prototyping in designing or manufacturing reconstruction plates...
are that they do not require intraoperative bending and offer improved passive fitting. In light of possible material failure, better structural designs may be developed according to individual anatomy at the design stage.

**RESULTS**

Step by step reconstruction of major segmental mandibular defects resulting from ameloblastoma resection using computer workflow in nonradiated patients is possible with a tissue engineered construct consisting of beta-tricalcium phosphate (β-TCP) granules, rhBMP-2 in conjunction with adipose stem cells.[10-12]

In case 1 [Figures 1-4], the patient had a large recurrent ameloblastoma of the left ramus and body of the mandible. A medical grade computed tomography scan was performed from which the DICOM files were converted to STL files.

A three-dimensional stereolithic model was manufactured to help the clinicians visualize the lesion and its defect. Surgery was planned to use the combination of a handheld three-dimensional skull model and the virtual images of the tumor defect on the monitor of the computer workstation. Figure 1 shows the resection lines and resection jig in blue blocks. Then as shown in Figure 2, a plate was planned on the computer workstation designed to span the resection at the posterior and inferior borders of the mandible. A virtual resection was then completed on the computer workstation [Figure 3]. In the operating room after exposure of the mandible, the virtually planned reconstruction plate was applied to the mandible and fit perfectly to the posterior and inferior borders. The design of the plate permitted the resection of the mandible using a piezo cutting system without removal of the plate once it had been applied [Figure 4].

In case 2, all the planning was virtual. The authors found it unnecessary to print the stereolithic model. Rather the resection lines and resection jigs were designed on the monitor of the computer workstation [Figure 5]. It was possible to rotate the skull image on the workstation so that the base of the skull and right and left inferior borders of the mandible were visible. Symmetry of the reconstruction plate was assured by comparing the mirror image contours of the inferior borders of the mandible [Figure 6]. The reconstruction plate was designed with space for adequate screw fixation [Figure 7]. Finite element analysis was used to test the loading of the custom designed hardware in order to be certain that the reconstruction hardware could manage the anticipated loading of the mandible [Figure 8]. With the mandible exposed in the operating room, the reconstruction plate was applied and secured to the inferior border and angle of the mandible. A piezo cutting system allowed resection of the tumor according to the resection guide shown in Figure 5. A titanium containment mesh was applied to encase the β-TCP granules, which were seeded with adipose derived stem cells.
cells [Figure 9]. The patient went on to heal in an uneventful manner with good radiograph integration of the stem cell seeded construct [Figure 10].

**DISCUSSION**

The authors illustrate the gradual incorporation of three-dimensional computer-aided surgical workflow, from diagnosis to surgical treatment, in order to provide patients with complimentary hardware to help restore mandibular ameloblastoma resection.[11] The hardware can be designed for any major cranio-maxillofacial reconstruction using nonvascularized bone grafts, vascularized bone flaps, stem cell-based reconstructions or cases using distraction osteogenesis[12] [Figures 11-14]. Such computer designed hardware must be tested.[9] Since bench testing is an expensive alternative to test repetitive loading and fatigue, the authors recommend virtual testing of custom designed hardware with validated finite element analysis models[9] [Figure 8].

In the case of distraction osteogenesis, there are important advantages over stock distraction devices, planning software used to design distraction devices. Distractor foot plates can be accommodated to anatomical constraints and distractor vectors are planned to be complementary avoiding convergence or divergence of the vectors of distraction.

**Figure 5:** Case 2 - This computer generated virtual planning image shows the resection jig in place with the shape of the reconstruction plate based on the mirrored healthy side of the mandible

**Figure 6:** Basal view of skull with planning software, showing defect modeled to be mirror image of unaffected side to ensure symmetry of reconstruction

**Figure 7:** Custom made reconstruction plate modeled by reconstruction software

**Figure 8:** Virtual testing of custom made reconstruction plate takes place by modeling and finite element analysis

**Figure 9:** Intraoperative photograph showing the titanium containment mesh in place and its underlying space filled with granular scaffold of beta-tricalcium phosphate and rhBMP-2

**Figure 10:** Immediate postoperative panoramic radiograph of case 2 showing reconstruction plates, titanium containment mesh and granular scaffold in place on the body and angle region of the left mandible
CONCLUSIONS

This preliminary case series shows that computer-aided surgical workflow has a promising role in the management of major reconstructive defects in the jaws using nonvascularized or vascularized bone grafts, stem cell based reconstruction or distraction osteogenesis.

ACKNOWLEDGEMENT

The authors wish to thank Mr. Jani Horreli for the help with using the Romexis software and planning of these complex cases.

REFERENCES

1. Goh BT, Lee S, Tideman H, Stoelinga PJ. Mandibular reconstruction in adults: A review. Int J Oral Maxillofac Surg 2008;37:597-605.
2. Arias-Gallo J, Maremonti P, González-Otero T, Gómez-García E, Burgueño-García M, Chamorro Pons M, et al. Long term results of reconstruction plates in lateral mandibular defects. Revision of nine cases. Auris Nasus Larynx 2004;31:57-63.
3. Langer R, Vacanti JP. Tissue engineering. Science 1993;260:920-6.
4. Sándor GK, Suuronen R. Combining adipose-derived stem cells, resorbable scaffolds and growth factors: An overview of tissue engineering. J Can Dent Assoc 2008;74:167-70.
5. Sándor GK. Tissue engineering: Propagating the wave of change. Ann Maxillofac Surg 2013;3:1-2.
6. Abou-ElFetouh A, Barakat A, Abdel-Ghany K. Computer-guided rapid-prototyped templates for segmental mandibular osteotomies: A preliminary report. Int J Med Robot Comput Assist Surg 2011;7:187-92.
7. Christensen AM, Humphries SM. Role of rapid digital manufacture in planning and implementation of complex medical treatments. In: Gibson I, editor. In Advanced Manufacturing Technology for Medical Applications. Sussex UK: John Wiley and Sons Ltd.; 2006. p. 16.
8. McDonald JA, Ryall CJ, Wimpeny DI. Rapid Prototyping Casebook. London UK: Professional Engineering Publishing Stratasys; 2001. p. 260.
9. Narra N, Valášek J, Hannula M, Marcían P, Sándor GK, Hyttinen J, et al. Finite element analysis of customized reconstruction plates for mandibular continuity defect therapy. J Biomech 2014;47:264-8.
10. Sándor GK, Tuovinen VJ, Wolff J, Patrikoski M, Jokinen J, Nieminen E, et al. Adipose stem cell tissue-engineered construct used to treat large anterior mandibular defect: A case report and review of the clinical application of good manufacturing practice-level adipose stem cells for bone regeneration. J Oral Maxillofac Surg 2013;71:938-50.
11. Wolff J, Sándor GK, Miettinen A, Tuovinen VJ, Mannerström B, Patrikoski M, et al. GMP-level adipose stem cells combined with computer-aided manufacturing to reconstruct mandibular ameloblastoma resection defects: Experience with three cases. Ann Maxillofac Surg 2013;3:114-25.
12. Sándor GK, Numminen J, Wolff J, ThelefTT, Miettinen A, Tuovinen VJ, et al. Adipose stem cells used to reconstruct 13 cases with cranio-maxillofacial hard-tissue defects. Stem Cells Transl Med 2014;3:530-40.

Cite this article as: Sándor GK, Bujtár P, Wolff J. Three-dimensional computer-aided surgical workflow to aid in reconstruction: From diagnosis to surgical treatment. Ann Maxillofac Surg 2014;4:128-31.

Source of Support: Nil
Conflict of Interest: No.