Virtual Surgical Planning and Pre-operative Simulation for Maxillofacial Reconstruction with 3D Printing Technology in Tumor-affected Facial Deformity

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Abstract

Background

The high anatomical complexity of maxillofacial defects caused by tumor can pose a formidable challenge for clinicians when designing an appropriate plan for surgical reconstruction. The intention of this work was to restore the complex anatomy with maximum possible facial functionality and aesthetics of the patient. Based on the medical images generated by computed tomography (CT) scan an optimal therapeutic planning for complex maxillofacial reconstruction was designed.

Method

Firstly, the volumetric data sets were carefully evaluated and deeply inspected for accurate diagnosis. Regarding 3D visualization of the CT scan images 3D virtual models for regions of interest were created using a special software of 3D Slicer. Using the resulting 3D virtual models a well-defined virtual surgical planning was generated for multiple surgical procedures, including the osteotomies for bone defects, harvesting autogenous bone graft and creating a customized implant.

Results

The relevant patient-specific anatomical models for real surgery were translated into the 3D printed physical models, with which the surgeons can rehearse the surgery before coming into the operating room. Precisely defined multiple surgeries for complex maxillofacial reconstruction were proposed in this research that could be transferred to the real-time surgery.

Conclusions

The proposed surgical approach will be beneficial both for the surgeons and patient, including improvement in surgical precision and outcomes, reduction in operating time, as well as understanding surgical procedures and decision making etc.

Full Text

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Figures

Figure 1

Slicer interface on the left side and a maxillofacial CT data set on the right side: axial slice (upper left window), sagittal slice (lower left window), coronal slice (lower right window) and the volume rendering as-is a 3D visualization (upper right window).

Figure 2

Volume rendered 3D images, an image from the initial uploaded volumetric data set (at most left), changing Hounsfield units from low to high values (from left to right image)

Figure 3

Virtual 3D models: skin model taken from lower Hounsfield unit (upper row), facial skeleton model taken from higher Hounsfield unit (bottom row)

Figure 4

The close inspection of the virtual 3D model for the facial skeleton: a) right, b) left mandible and c) zygomaticomaxillary complex

Figure 5

Preparation for osteotomy: a) defining the cutting line, b) excision of ZMC and c) prepared basement for placing the implant

Figure 6

Creating a zygomatic implant: a) defining the cutting line on the healthy side from symmetric ZMC basement, b) mirroring an image on the defect side, c) creating implant and d) placing the implant on the prepared basement with three fixing holes.

Figure 7

Close inspection of the tumor area: a) showing mixed radiolucent radiopaque lesions (see in the text for arrow 1, 2 and 3), b) the right healthy side of mandible, indicating the circle for coronoid.

Figure 8

virtual 3D model as a defect resection template, exhibiting the defined cutting lines.

Figure 9

a) Virtual 3D model of cutting guide for the mandible and b) attaching the cutting guide on the mandible

Figure 10

a) Mandibulectomy on the both sides of arrows on the cutting guide, b) the resected mandible and c) virtual 3D model of the resected both mandible and ZMC

Figure 11

Virtual 3D model of pelvis; the circle indicating the harvest area for the bone graft

Figure 12

a) Iliac bone segmented from pelvis, b) attaching the cutting guide with jig together, c) removing the jig to fix the cutting guide only, d) cutting the iliac crest and e) the harvested bone for grafting.

Figure 13

a) Refining the mandible, b) the harvested bone graft and c) adjusting the symmetric according to the right part of healthy side

Figure 14

a) Stress states in the mandible and b) attaching the osteosynthesis plates

Figure 15

3D printed physical models for patient's head (upper row) and skull (bottom row)

Figure 16

a) 3D printed zygomatic implant with three fixation holes and b) implant fixation on the osteotomized basement of ZMC

Figure 17

Surgical simulation of mandibulectomy: a) lateral and b) anterior view of 3D printed physical model of mandible in the real size, c) attachment of cutting guide and d) osteomized mandible

Figure 18

Surgical simulation for harvesting bone graft from iliac bone: a) virtual 3D model, b) real-sized 3D printed physical model with cutting guide and jig, c) placing cutting guide with jig on the iliac crest and d) exact positioning cutting guide by removal of jig

Figure 19

Surgical simulation of mandible reconstruction (red dots are marked for screws)

Figure 20

Maxillofacial reconstruction; a) real-sized 3D printed physical model of osteomized skull, b) 3D virtual model and c) reconstructed 3D physical model

Figure 21

3D printed physical models: a) before and b) the expected outcome after surgery.