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On Progress in Developing a System for Individual Planning and Aiding Tumor Resection and Bone Reconstruction in the Maxillo-Facial Area

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Abstract. The paper concerns progresses on developing a system for individual planning and aiding oncological surgeries in the maxillo-facial area. The surgery consists of two phases: resective and reconstructive. State of the art is that these two phases are performed as disconnected operations separated with procedure of planning and producing an individual implant basing on CT. Another option is to apply bone autograft adjusted to the bone loss after manual resection. There exists no complete system supporting oncological treatment both in planning and real surgery. Our system enables performing the whole treatment during one surgery, because after the individual image-based planning of tumor resection and bone reconstruction, the manufactured implant fits exactly to the bone loss resulting from resection performed under control of computer navigation. The system has been developed to produce bioimplant with a scaffold of designed geometry and to implement it after precise and radical tumor resection.

Keywords: biomedical engineering, computer aided surgery, maxillo-facial oncological surgery

1. Introduction

Oncological surgeries require planning and aiding to provide an optimal tumor resection and post-resective reconstruction of bone [1]. These two phases are typically performed as separate surgeries. Between these two operations the implant is manufactured basing on post-operative image dataset. Another applied option is to take bone flap from pelvis bone, rib or fibula [2]. In any case a factor of great importance is a proper margin safety. It is crucial to provide it to prevent from tumor renewal and malicious complication. On the other hand the margin should not be oversized, there is no need to resect the healthy bone and replace it with an implant. Patient should not also suffer from bad aesthetic effect of the surgery or impaired chewing function. The surgeon needs to be careful about crucial structures (blood vessels, nerves, etc.), and tries to restore the shape of facial bones and proper chewing ability while reconstruction phase of surgery. Taking into account the complexity and all the requirements of the surgical procedure, the technical support in a form of appropriate system for planning and aiding surgery is necessary. Our aim was to develop a tool to support planning and aiding oncological surgery. The paper describes progress on developing such a complex system in cooperation with oncologists from Maria Skłodowska-Curie Memorial Cancer Center and Institute of Oncology in Warsaw, Poland. The described solutions are based on our common experiences, many aspects are results of improvements introduced after performed tests in laboratory conditions. The system has been optimized to be applied intraoperatively.

2. Material and Methods

The system consists of various modules, but in this paper we will focus on two of them used for: 1) Virtual planning of bone tumor resection and reconstructive surgery using medical images dataset, 2) Intraoperative support – computer aided tumor resection using optical and electromagnetic navigation and

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computer aided bio-implant stabilization using fixation plating system. The next sections describe the development of these modules.

2.1. Virtual planning of bone tumor resection and reconstructive surgery using medical images dataset

The software enables reading DICOM image dataset from CT and identifying the tumor margins. An automatic textural visualization of tissues is provided, but the tumor recognition is a manual procedure performed by the experienced physician. The manual neoplasm identification by an expert is inevitable, since the image of tumor in Computed Tomography is difficult for automatic recognition. Usually the identification of tumor is performed easily with a few cutting planes limiting its geometry with changing depth of safety margin. As soon as the expert finishes the segmentation on all CT scans the software provides 3D visualization of tumor in relation to other automatically recognized tissues. It is possible to visualize the tumor inside the bone tissue or the whole tumor segmentation.

The software calculates the surface area on each particular CT scan. Additionally, after finished segmentation the volume of segmented 3d object is calculated. It has been also developed a module to measure geometrical parameters such as distances or angles directly on the 3d models as well as 2d masks on particular slide. This option is very useful to measure the thickness of safety margin around the tumor (fig. 1).

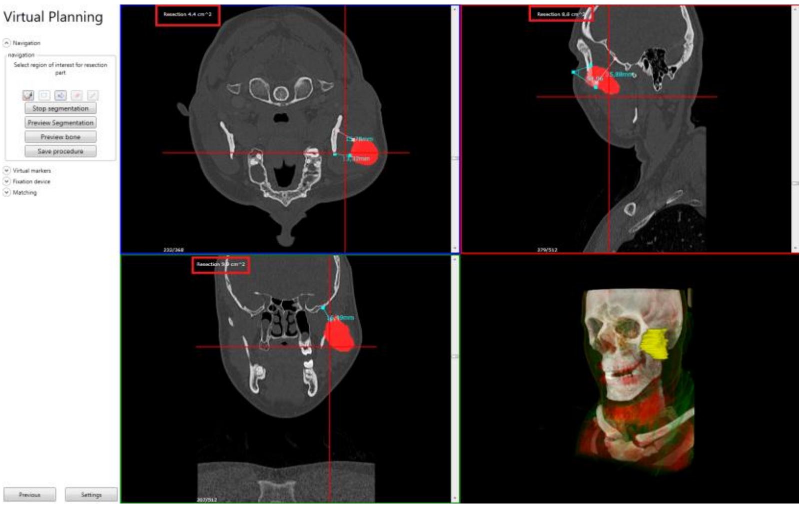

Fig. 1: Measurement of margin safety thickness

Planning of resection is finished with segmentation procedure. Here starts the reconstruction part. The software provides automatic algorithm of bone loss reconstruction. The algorithm demands input data: mirroring plane and segmentation of bone part to be reflected on the side with bone loss. The detailed description of partial mirroring was presented in our previous publication [3]. The last stage after mirroring is the alignment of mirrored part of bone on the side with bone loss resulting from resection.

Recently we modified the procedure of registration which enables transfer of surgery plan to the patient using navigation system. The surgeon needs to register landmarks on image dataset and corresponding points on the patient using navigated pointer in the coordinate system of the dynamic reference frame. To make this procedure less time consuming, the software enables planning of the markers in the pre-operative phase, so that intraoperatively the surgeon needs to localize only the markers on the patient.

Pre-operatively the user needs to design also the fixation points necessary for proper stabilization of bioimplant applied for reconstruction. During the planning stage, the surgeon selects the plating system to be applied intraoperatively and determines its location via fixation points. This method of fixation is one of the most efficient way to align bones with implant so far.

Intraoperatively our system helps the surgeon to navigate the fixation points (fig.2) and increases the accuracy of reconstruction using a bioimplant with a plating system. That option in the future might be easily expanded to design fixation points of implant equipped with mounting handles.

Fixation with plating system has already been used in case the bone grafts are applied, however still without control of navigation system. Commercial systems provide only support of resective part of surgery. Our future aim is to extend options of our system to support also reconstruction using free bone flaps - both planning and aiding the real surgery using a navigation system.

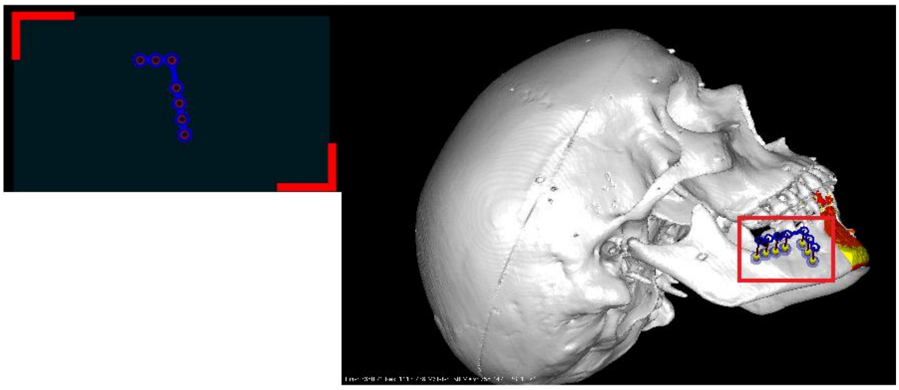

Fig. 2: Planning of bio-implant stabilization using selected plating system

2.2. Computer assisted intraoperative tumor resection

The second module of system supports the surgery stage. At the beginning of surgery it is crucial to perform precise registration of landmarks using a navigated pointer. Procedure of registration enables calculation of matching matrix to transform the location and orientation of surgical instruments from the dynamic reference frame to the coordinate system of medical images. What we improved is the procedure of data registration. First of all, the position of pointer is measured as long as 100 proper data are registered, all the outliers (basing on standard deviation of the registered dataset) are rejected and from remaining dataset of 100 registered points the mean coordinates are calculated. The outliers are caused for example by improper location of pointer. Another important problem we have observed is an RMS error characterizing the accuracy of navigated pointer localization. The RMS value changes with orientation of optical markers towards the navigation system, since the angle of markers view is limited. Therefore, we modified the registration procedure, so that whenever the RMS value is higher than user-defined threshold, the algorithm rejects the measured landmark position from the dataset used for matching procedure (fig. 3).

Fig. 3: Registration procedure with control of outliers and RMS error

Our efforts provided high accuracy of matching procedure. We apply algorithm of landmark transform from Visualization ToolKit [4], which calculates the matching matrix using pairs of corresponding points.

Second important stage of the intraoperative phase is a calibration of navigated instruments. All the navigated instruments have optical passive markers attached. The most important aim of this calibration process is to provide proper location and orientation of local coordinate system connected with instrument. It is crucial to provide long axis of tool to present it on screen on medical image background as a thin cylinder. The surgeon needs to observe changes of its tip location and long axis orientation. We provided possibility to calibrate surgical saw and driller, as the instruments applied in the resection procedure. The ideas of their calibrations and their locations visualizations with surgical scenarios are presented in figure 4 and 5. The calibration procedure should be repeated every time the geometry changes, it means also installing of a drill or a cutting edge. These elements can bend or shorten with the time of usability, so the surgeon needs to actualize the calibration data. We also provided a possibility to pivot an instrument with a defined calibration file. In pivoting procedure a tool offset is measured and the local coordinate system of instrument is translated to the tip of it. The software presents the error of pivoting procedure, provided by algorithm from the Image- Guided Surgery ToolKit [4].

We defined protocol to calibrate the oscillating saw. After mounting the cutting edge the surgeon needs to localize with pivoted pointer the three points on the surface of cutting edge in a proper order to define one plane of coordinate system. Two characteristic points on the cutting edge are localized to define one axis, and the last point in the middle of cutting edge defines the origin of local coordinate system. Additionally two points can be measured to define the width of the cutting edge.

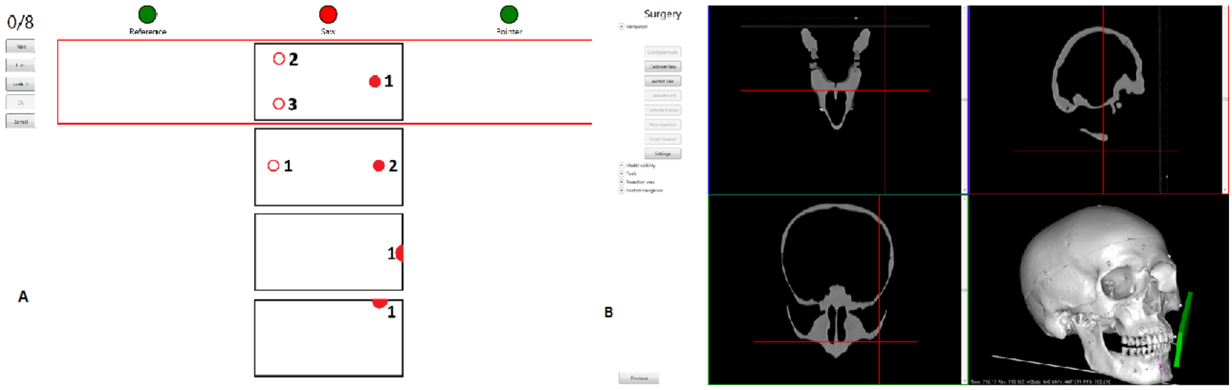

Fig. 4: A Calibration of saw (calibrating points), B Intraoperative visualization of the cutting edge

Similarly, we defined a protocol to calibrate a driller typically used to introduce stabilizing screws in the bone. Three points in the handle of rigid body mounted on the pointer defines OYZ plane, the three pins to mount markers defines OXZ plane and the tool tip defines the origin of coordinate system.

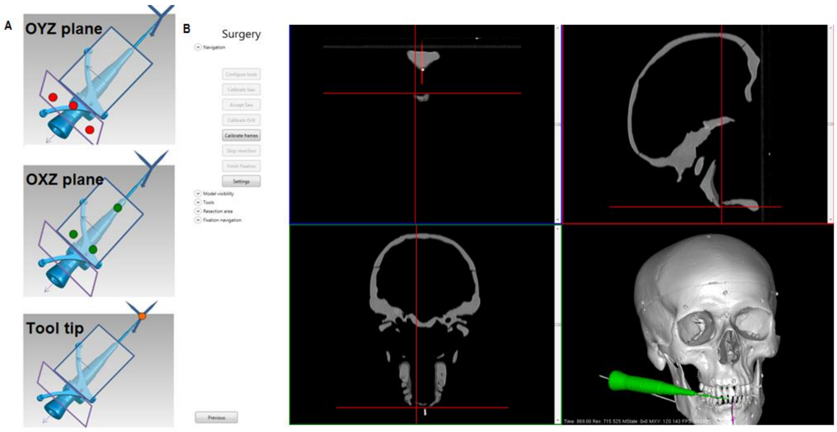

Fig. 5: A Calibration of driller (calibrating points) B Intraoperative visualization of driller

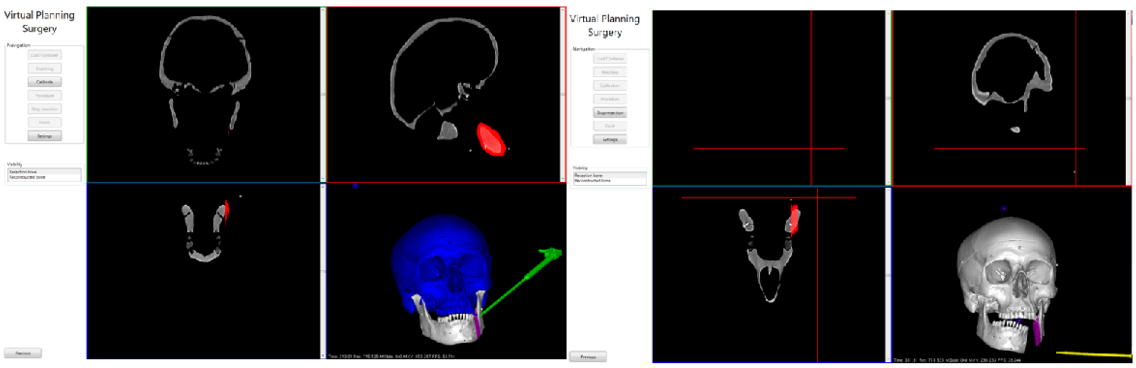

Fig. 6: View of surgical instrument with the background of surgical scenario

Before the resection procedure, the surgeon needs to apply reference frames on all bone segments requiring localization in the reconstruction phase. The assistance in the cutting procedure is a form of surgery plan presentation on the screen (fig. 6). The accuracy of procedure is controlled in a few stages of surgery – the surgeon needs to measure the control points to check the actual Target Registration Error.

2.3. Assisted intraoperative bone reconstruction

Our achievements on guided bone reconstruction module were described in previous publication [5]. Recently we developed the intraoperative module. In the reconstruction phase the surgeon needs to localize the fixation points and performs the holes for mounting screws. Figure 7 presents the visualization of surgical instrument and designed location of fixation markers. The graphical presentation shows with an orange ring proximity of target, additionally the values present the current position and orientation related to dynamic reference frame coordinate system. An additional option of software is the possibility to analyse the results of surgery using Virtual planning comparison module. The surgeon can compare the CT scans registered pre and postoperatively.

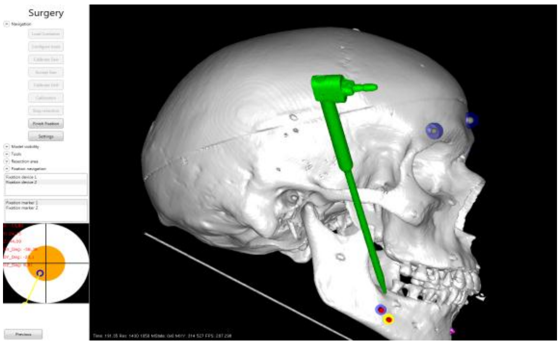

Fig. 7: Visualization of fixation markers

3. Discussion

The result of our work is currently under testing in clinical conditions. We keep optimizing the developed system in consultations with oncologists. Current accuracy value expressed with Target Registration Error when titanium markers are applied equals less than 1mm (average 0.75 mm). The modified protocol of data registration increased the repeatability of obtained accuracy. Also the preoperative manual identification of landmarks on images significantly shortened the time of intraoperative registration.

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