A Complex System for Optimal Individual Planning and Supporting Implant-Prosthetic Treatment for Oncological Patients after Resective-Reconstructive Surgery

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Abstract. The main goal of this paper is to describe implantoprosthetic module implemented in Maxillo-Facial Surgery (MFS) System and show its application in oncological treatment. Advancements in navigation systems and image processing algorithms have evolved image-guided surgery domain which has resulted in higher surgery accuracy and smaller risk of recurrence. Nowadays, more and more people are diagnosed with malicious tumor cases with different symptoms. This paper addresses maxillo-facial instances which are very challenging in treatment. The basic approach in this kind of oncological surgeries assumes resection of tumor tissue and later proper bone reconstruction to preserve aesthetic face look. Another very important aspect which cannot be neglected is the dental structure restoration after resection surgery. In MFS System this procedure is divided into two steps: virtual planning and intra-operative phase. Each of them relies on CT dataset and STL 3D model.

Keywords: bioimplant, virtual planning, image guided surgery, implantoprosthetic treatment.

1. Introduction

Oncological surgeries in maxillo-facial area are complex and very complicated. Tumor changes affects both soft and bone tissues which results in face degeneration. Proper cancer resection is the most important issue for patient’s health, but one cannot forget about face aesthetic look reconstruction which is also very crucial part. In a basic approach surgeon analyses and detects cancer tissue on CT or MRI scans and later intra-operatively tries to resect assumed region basing on his visual impression and experience. Later, the area of resection is tested through histopathology examination to check if resection should be enlarged. For simple cases this scenario is sufficient, but in more challenging ones support as well as control system is required, because restricted visibility and presence of blood and other tissues in the vicinity of proper resection cut make it almost impossible to perform assumed plan. Advancement in image guided surgery techniques allows to increase overall surgery accuracy and minimize the risk of recurrence [1].

It should be emphasized that oncological treatment does not finish right after surgery where resection and reconstruction is performed. Of course these steps are the most determinant aspects because the former ensures that cancer tissue is removed with proper safety margin and latter tries to restore facial appearance by filling created bone loss with specially prepared and manufactured implants. Another important problem which has been neglected lately, but now is gaining greater attention is proper dental structure restoration [2]. In most cases this step is done long after resection and reconstruction surgery and is triggered independently by patient, while the whole oncological treatment should be connected and unified because each phase is a small part of a greater chain and knowledge from the previous phase should be applied to the next one.

One can find many application examples (commercially available on the market) which tries to deal with oncological surgeries, but there has not been any complex system guiding through virtual planning and
aiding surgical procedures. Due to these reasons, we have implemented the Maxillo-Facial Surgery System (MFS System) in cooperation with surgeons from M. Skłodowska-Curie Memorial Cancer Center, Warsaw, Poland who provide valuable information how to optimize oncological procedures and create software which aims at supporting surgeons not interrupting their work. MFS System is equipped with modules for planning virtual resection basing on CT or MRI scans, reconstruction applying tissue engineering- bioimplant (whole idea behind bioimplant concept was broadly described in [3]) and finally module for implantoprosthetic treatment with both planning and applying virtual scenario during real surgery. To assist surgeon and control tool location, MFS system is provided with optical (Polaris, NDI) and electromagnetic (Aurora, NDI) navigation system.

The main goal of this paper is to present implantoprosthetic module in MFS System and provide its application in the oncological treatment. Firstly, general algorithm will be described with additional remarks about constraints and crucial requirements. Later, two staged procedure will be shown divided into virtual planning and surgery assistance. Whole article finishes with conclusions and plans for future work and improvements.

2. Dental Structure Reconstruction Algorithm

2.1. Input data

For the implantoprosthetic treatment planning the basic input data is CT dataset. After loading it, system allows to generate two 3D STL models: upper and lower jaw. Very often additional segmentation is needed because during CT examination patient has clutched jaw so automatic thresholding cannot assure two disjoined parts. DICOM set is also used to prepare three projections: Axial, Sagittal and Frontal as well as two panoramic views. For implant planning, MFS system provides database with 60 STL models in different sizes and shapes: conical, internal and tapered (see Fig. 1). User can load various dental implant types and decide which one fulfils specific patient's case criteria.

![Fig. 1 Example of dental implants used in MFS system: A-conical, B-internal, C-tapered](image)

2.2. Dental implant localization

In this section the algorithm for dental implant localization will be described. The first and also the most important constraint is that new implant must be introduced in the jaw according to the same axis as two neighbouring teeth in the jaw [4]. Keeping this in mind, user has to determine axes in two places surrounding area where new implant must be placed. Initial implant location is determined as a half of the distance between two selected points. Example procedure settings are shown in Fig. 2.

![Fig. 2 Dental implant localization using information from two neighbouring teeth: A-long axis of the left neighbouring tooth, B-long axis of the right neighbouring tooth, C-implant location determined according to A and B and in the middle between A and B](image)
When planning implant position few constraints must be preserved:

- new implant cannot collide with other neighbouring tooth and should be put parallel to other teeth,
- new implant should be chosen to resemble size and shape of other teeth,
- implant cannot intersect with nerve canal in the lower jaw and intraoral dental sinus,
- proper distance with safety margin should be kept between implant and neighbouring teeth.

3. Implantoprosthetics Treatment in MFS System

3.1. Virtual planning

The basic source for planning dental implants is STL model of upper and lower jaw, but single 3D model is not sufficient and additional information must be presented on 2D planes using CT dataset. User can switch between 3 projections and panoramic views (Fig. 3 shows application in each state). This is common approach because user can control location on 3D model, but also it is possible to check whether implant would not ruin other tissues and if it is properly placed in the bone.

![Fig. 3 Two different views used in implantoprosthetic treatment: A-3 projections (Axial, Sagittal, Frontal) + 3D components, B-2 panoramic views + 3D model + 2D projection defined by user.](image)

After determining initial implant position according to algorithm described in section 0, user can modify its rotation and location. Rotation can be changed only by modifying two neighbouring axes. When user goes into modification phase then in each step current modification plane is shown to direct user with possible movements. Additionally, surgeon can change STL jaw model transparency to check if implant is correctly placed in the bone and whether this location ensures proper implant’s stability. Fig. 4 shows implant modification interfaced used in MFS System.

![Fig. 4 Implant modification phase implemented in MFS System. A-translation of the first axis in OYZ plane, B-translation of the second axis in OXZ plane. Blue plane is used to indicate possible modification direction.](image)
When user changes axis or implant coordinate each component is refreshed and parameters are recalculated to indicate if proper safety distance between axes and implant is preserved. At the end of virtual planning phase whole procedure is saved to binary file and can be used intra-operatively.

3.2. Intra-operative phase

In the intra-operative phase virtual planning procedure is read and navigation system is used to track surgical tool position and control precise dental implant placement in the jaw. Before final procedure starts, few preparation steps must be carried out. First of all, registration procedure is needed to match the virtual planning scenario with intra-operative phase. To calculate matching matrix Landmark Transform Algorithm is used which assumes that at least three corresponding points are collected from CT dataset and patient. In the next step drilling tool has to be calibrated. In MFS system we proposed universal algorithm for calibration which allows to use different types of surgical tools. For dental implants the most commonly used is high-speed dental handpiece drills, but they differ with the length of drill and corpus bend. Fig. 5 illustrates an exemplary drill and MFS System calibration window.

Each surgical tool in MFS system has its own coordinate system defined in ROM file, but we would like to navigate the tip of the drill. Due to this reason an additional transformation must be defined and it requires to calculate three perpendicular vectors. Two of these vectors are determined after collecting measurements using navigation system (three points for each vector). The first vector is obtained in step A, while the second in phase B from Fig. 5. The last C case determines offset between original coordinate system and new one located at the tip of the drill.

![Fig. 5 MFS calibration algorithm for implantoprosthetic treatment. 1-shows common dental drill (A high-speed dental handpiece), 2-three steps (A, B, C) in calibration algorithm.](image)

When everything is set up then surgeon can proceed to the final stage where implants are put in correct location under the control of navigation system. How the current surgery state is presented to the user is shown in Fig. 6. Beside the real-time visualization of surgery tools we try to provide user with information how drill should be oriented to ensure proper implant position according to virtual plan (correct rotation angles and drilling depth). Such information is graphically presented with the help of visual component marked in red rectangle in Fig. 6. Generally, surgeon aims at handing drilling device in such a position to ensure that two circles are located in the middle of component. This state indicates that drilling can be started because implant and drilling tool axes are parallel. The same visual component informs also about assumed drilling depth using orange circle. Its surface is changing as a logarithmic function to sensitize user when the required implant's depth is reached. Additionally, 2D projections are also refreshed to indicate current position of drilling tool tip using red guides. Note that jaw 3D model is transparent to provide better visibility.
4. **Future Work**

Implantoprosthetics module in MFS System provides basic capabilities to virtually plan location of dental implants and later realize this scenario under navigation control system. In the future work we would like to improve planning part and enrich this module with option for segmenting nerve canal in lower jaw. Basically, it can be done on axial projection, but it requires going through many slices with selection. Better approach involves generating DICOM projection according to the dental structure curve. Additionally, in the next version we would like to support cone-beam CT, because it has become increasingly important in treatment planning and diagnosis in implant dentistry.

5. **Conclusions**

This paper describes implantoprosthetic module implemented in MFS System and indicates its application in oncology treatment. It is divided into two phases: virtual planning and intra-operative step where for each stage the basic inputs are CT dataset and STL models. Initial implant location can be modified and the result is presented not only on 3D model, but also on three DICOM projections and panoramic view. After finding the final implant location, the whole procedure can be saved and later used intra-operatively where MFS system assists surgeon with the help of navigation system. Beside tool tracking, each implant location is also controlled giving precise implant orientation and drilling depth. Currently, MFS System is clinically tested in M. Skłodowska-Curie Memorial Cancer Center, Warsaw, Poland and results are very promising, but of course further and more profound test must be performed.

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7. **References**


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**Fig. 6** MFS system during implantoprosthetic surgery. Surgical tool presentation with additional information about current dental implant orientation (component shown in red rectangle). A- shows component state when drilling is about to start, B-shows component state when implant drilling has finished.