Patient Specific Implants
Design Tool for Surgeons

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Abstract
One of the major issues in designing Patient Specific Implants (PSI) is the distance between the "language" of surgeons and the one of computer graphics technicians. This gap can induce mistakes in the process of a PSI design. The work described in this article removes the need for a computer graphics technician by implementing a PSI Design Tool that highly automates the PSI design process, and provides a user friendly step-by-step approach. As a result, a surgeon can be responsible for the full process achieving the optimal solution.

Keywords
Patient Specific Implants, Tomography, DICOM, Computer Graphics, 3D Modelling

1. INTRODUCTION

Patient Specific Implants (PSI) are described as the optimal solution for bone and joints replacement [1]. This technique creates implants that are tailored for the specificities of each patient, hence achieving better results. There are several studies focused in the creation of PSI, ranging from tooth reconstructions [2] to the fabrication of complex tissue substitutes [3]. The design of a PSI requires a 3D model of the patient's area to be treated, the modelling of the PSI and finally the manufacturing of the PSI itself, in a process that is iterative. This process requires medical anatomo-physiology knowledge and 3D modelling skills. The latter is usually assigned to a computer graphics technician (designer), inducing a higher complexity in the process and the possibility of achieving sub-optimal solutions due to differences in professional vocabulary and technical knowledge that can affect communication between the surgeon and the designer.

Currently, several biomedical areas such as dental and limb prostheses are already designed with the help of user friendly softwares that guide the user through the 3D modelling process of a "medical device". In the case of PSI, the existing market software solutions, like Materialise [4], are expensive and mostly directed to 3D technicians and not for surgeons.

The solution presented in this article aims to create a PSI design tool tailored for surgeons, without the need for 3D modelling expert skills, giving them full control over the PSI design process. It is expect that this work has a big impact in the PSI quality, allowing surgeons to provide better solutions to their patients, with less invasive techniques and faster healing, meaning quick recovery of patients normal life.

2. PSI DESIGN TOOL FOR SURGEONS

Under this chapter the developed tool for the creation of PSI by surgeons will be described. The purpose of this solution is to enable surgeons to have full control during the whole PSI design process. In order to let surgeons control the full process, the designed solution automates it as much as possible, carefully guiding the surgeon in a step-by-step approach. A user friendly interface was created with only the required functionalities available in each step and minimizing as possible the user inputs, thus, avoiding the need to involve third parties specialized in 3D modelling.

The workflow of the developed PSI tool (Figure 1) is composed by four main steps. First, a set of medical images, generated from a tomography are used to generate a 3D model of the patient's area to be intervened. Secondly this model is prepared to better suit the PSI creation. Thirdly, the PSI design takes place. Finally, the PSI plus auxiliary data needed to the PSI manufacturing, such as the screws used, are encrypted and exported.
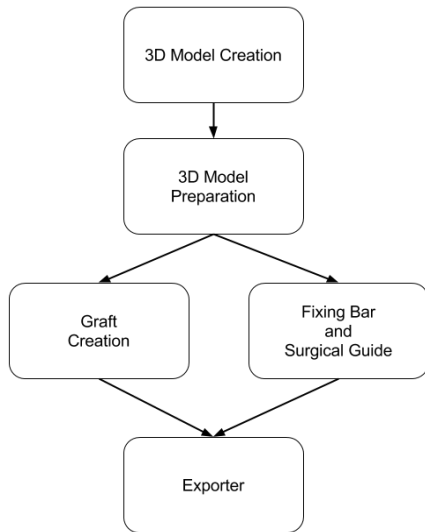
Figure 1 - Workflow of the developed PSI tool

Following sections will define in detail the developed system that, underneath, makes use of these tools: MITK - Medical Image Interaction Toolkit [5], Qt [6] and Blender 3D modelling software [7].

2.1 3D Module Creation

The first stage to design a PSI is the creation of a 3D model of the patient's area to be intervened. This task receives as input a set of medical images in the DICOM format [8] and returns a 3D model.

The user starts by importing the DICOM files to work on, selecting the series to segment. The second step is the segmentation of the regions of interest, in this case bones. It is possible to choose from a list of default types of bones thresholds or to make a custom segmentation (Figure 2) moving a slider that controls the threshold value, while the preview of the expected result is displayed. The 3D model is generated by applying the marching cube algorithm [9] to the segmentation result. In order to achieve a less complex and smoother output a decimation and a median filter are applied to the resulting surface.
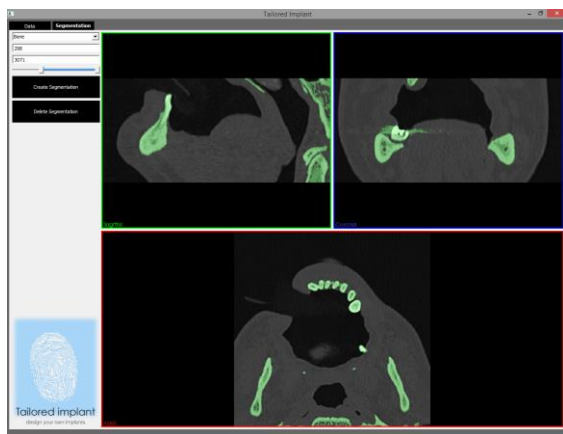

Figure 2 – Dicom Converter

2.2 3D Model Preparation

The generated 3D model from the previous step must be further edited in order to achieve a good working base to the PSI design. The tool allows an adequate visualization of the 3D model, so the user can clearly understand the patient's bone region, thereby avoiding risky areas like the nerves in the jaw. A simplification of the model can also be obtained by reducing it to just the area that needs to be worked. The deletion of parts of the 3D model creates holes in the mesh that need to be closed. An automatic process was implemented to close the mesh. This, involves a pre-preprocessing step, the remotion of all the faces that can be built from all the non-manifold edges, which are the faces that cannot be represented in the real 3D world, and may cause conflicts when trying to fill the holes.

With an adequate patient's bone model generated, the user can proceed to the next phase. Two different modules are available at the moment: graft creation or fixing bar and surgical guide creation.

2.3 Design of Grafts

A graft starts with a parallelepiped shape that can be molded to the desired shape. At first, the user adds a new graft and places it in the correct location, orientation and scale against the 3D model of the patient's area to be treated. The graft can then be molded to the desired shape, avoiding hard edges, with a smooth brush tool. Next, automatically, the software removes the graft portion inside the bone, by subtracting them, resulting in a graft that has a perfect cast against the bone surface of the patient's mouth.

The graft implantation in the bone requires the use of screws (see Figure 3). For that purpose, a set of 3D screws models are available. The user adds a new one and position-it correctly against the graft. Once again, the system automatically analyses the intersection of the 3D models and subtracts them, creating a final graft with holes ready for the screws placement.
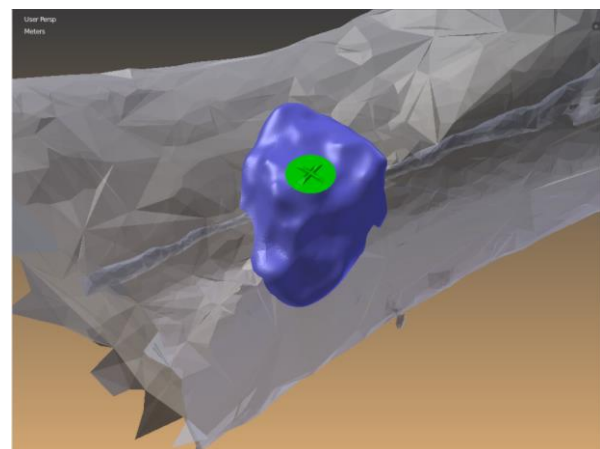

Figure 3 - Graft (blue) and screw (green)

2.4 Fixing Bar and Surgical Guide

If the user decides to produce a fixing bar (presently specific for maxillo-facial treatments) the first step is define the number of implants to import and load them into the scene (see Figure 4). Automatically, the system analyses the jaw of the patient and determines a good initial fit for their position, that can be further adjusted by the user.
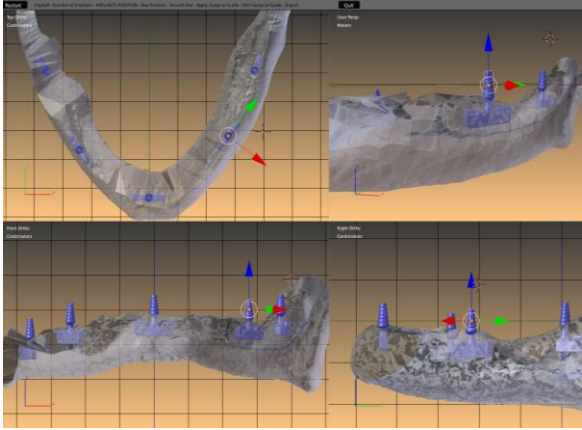

Figure 4 - Positioning Implants

The fixing bar is then automatically created. It will link all the implants that will be placed into the patient mouth. To create the bar, first a Bézier curve with a point in every implant position is generated, then, using a curve modifier tool, a rectangular shape travels along it, resulting in the fixing bar, see Figure 5. Since this is an automatic process, sometimes there is the need to make adjustments to it, so the user can place it correctly, trough subdivisions into the main curve that controls the bar.
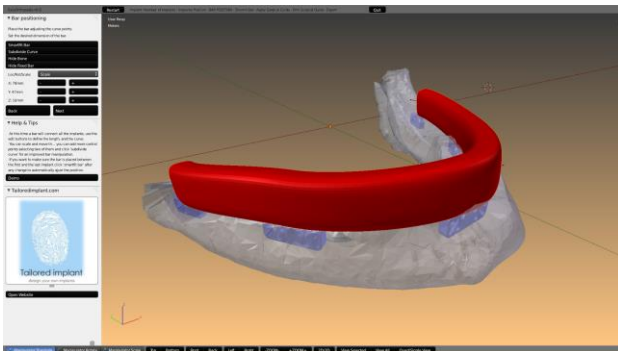

Figure 5 - Fixing bar

Multi-units (structures to fix the fixing bar to the patient's bone) are added to scene and holes in the fixing bar are created to accommodate them.

Finally, a surgical guide is automatically created to assist the surgeon, when making the holes into the bone for pin the fixing bar.

2.5 Exporter

The final stage of the PSI design process is the export of the PSI and auxiliary data necessary for the manufacturing and posterior deploy of it. When exporting, in addi-

tion to the 3D models of the elements that need to be manufactured and a list of used materials, a PDF file (Figure 6) is generated. This stands as an easy and effective way to review the final result, a posteriori, in three dimensions visualization, without the need of using special software. This feature uses both LaTeX [10] scripts and Meshlab [11] engine.
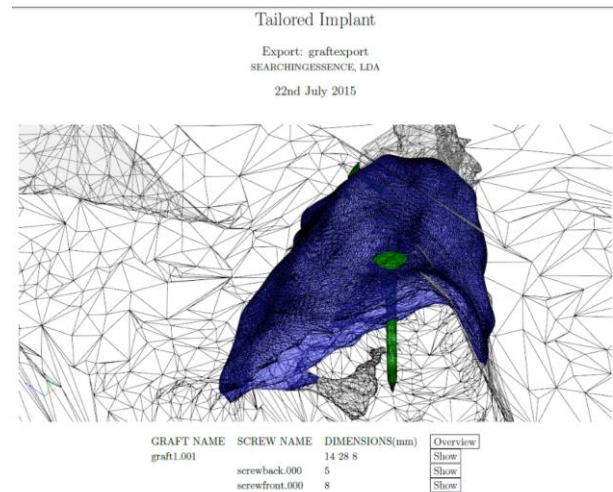

Figure 6 - PDF 3D Guide

The PSI design results are encrypted to guarantee that the outputs can only be used in the original software or accessed by accredited entities. For that purpose, a combination of Advanced Encryption Standard (AES) [12] and Rivest-Shamir-Adleman cryptosystem (RSA) [13] keys is used.

3. CONCLUSIONS

The implementation of a patient specific implants design tool, directed for surgeons, was described in this article. The process of PSI design was highly automated and a comprehensive step-by-step approach was implemented. The core technology has been developed based on many years of experience of a surgeon, and is very close to become available on the market. The feedback from the first tests with real users was very good. There is a real need of a comprehensive platform that allows the surgeons to be closer to the production phase, without having to worry in learning how to work with complex modelling softwares. Currently the solution is more focused in the dental surgery field, and future work will be centered in expanding for others fields like orthopedy.

4. ACKNOWLEDGEMENTS

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