Interactive Planning of Miniplates

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ABSTRACT

In this contribution, a novel method for computer aided surgery planning of facial defects by using models of purchasable MedArtis Modus 2.0 miniplates is proposed. Implants of this kind, which belong to the osteosynthetic material, are commonly used for treating defects in the facial area. By placing them perpendicular on the defect, the miniplates are fixed on the healthy bone, bent with respect to the surface, to stabilize the defective area. Our software is able to fit a selection of the most common implant models to the surgeon's desired position in a 3D computer model. The fitting respects the local surface curvature and adjusts direction and position in any desired way. Conventional methods use Computed Tomography (CT) scans to generate STereoLithic (STL) models serving as bending template for the implants or use a bending tool during the surgery for readjusting the implant several times. Both approaches lead to undesirable expenses in time. With our visual planning tool, surgeons are able to pre-plan the final implant within just a few minutes. The resulting model can be stored in STL format, which is the commonly used format for 3D printing. With this technology, surgeons are able to print the implant just in time or use it for generating a bending tool, both leading to an exactly bent miniplate.

Keywords: Miniplates, Planning, Interactive, Facial Defects, Computer Aided Surgery, Computed Tomography.

1. DESCRIPTION OF PURPOSE

Reconstructing facial deformations due to bone fractures or born deformations is the daily routine of a surgeon. Causes of bone fractures are outer forces, such as from a car accident, removed tumors or deformation treatment [1]. All those operations (osteosynthesis) have in common that they use so-called miniplates [2]. These miniplates in their raw form are straight titanium plates consisting of at least two finishing ring sections at both ends, where screws for implant-bone fixation are drilled, connected by a bridge section. The raw implant is available in countless variations, consisting of further middle-ring sections, orthogonal bendings or circular ring section arrangements. In this work, we focused on the MedArtis (Basel, Switzerland) Modus 2.0 series, the miniplates most frequently used by the surgeons of the Medical University of Graz in Austria. With the purpose of stabilizing the defect, the implants are fixed perpendicular to the fracture on both fracture sides. The miniplates in their raw form are stiff and straight, which makes it necessary to bend them along the fractured surface. In open surgery, the bending process and the need for readjusting the bent sites to gain an accurate implant is very time consuming. An alternative method generates a STereoLithographic (STL) template out of the Computed Tomography (CT) data and pre-bends the implant on those. STL templates move the time and effort to the preoperative phase, but leads to an even higher expense overall. In this paper, we propose a novel method for computer aided planning of miniplates for facial surgeries. Using our software, the surgeon has the possibility to plan the implant independently of the facial location. Furthermore, the planning time drops to only a few minutes and allows readjustments without any material costs. The resulting virtual implant can be 3D-printed from STL format, used as bending tool or even as a final implant.

Computer-aided planning for facial defect surgery can be roughly categorized into two main groups. The first category encompasses rapid prototyping methods for pre-bent implants, useful for planning implants for complex facial reconstructions [3]. Based on a CT scan [4]-[6], a 3D physical model is generated, which serves as a bending guide for the implant or as a template for constructing a patient specific one [7]. This treatment also uses advanced software tools, like Materialise's MIMICS (Leuven, Belgium), for repositioning fractured bones to model the final outcome [8]. The software is commercial and requires substantial training. Furthermore, in some cases the generated models need to be adjusted during surgery, since the repositioning could not be performed as planned. The second category uses computer-aided planning software to generate patient-specific implants. Most of the solutions in this category focus on the repositioning of fractured bone tissue rather than implant generation [9]. Materialise provides the software tool PROPLAN CMF, which covers a broad range of applications in medical 3D printing. The software allows repositioning

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hard tissue parts and calculating the resulting outcome, including soft tissue stress due to the applied deformations for surgical pre-planning. Additionally, the OBL software from Materialise provides a tool for patient specific titanium mesh implant generation. These software solutions are comprehensive, but have a high cost. Moreover, many surgeons prefer miniplates, like the products of MedArtis, over personalized titanium mesh implants. Our software helps surgeons to minimize time and costs by providing a flexible planning software for miniplates. To the best of our knowledge, there is no work that has studied the interactive planning for facial reconstructions using miniplates. Our software is designed to be easy to use and can be provided as open source.

The rest of this contribution is organized as follows: Section 2 presents details of the methods, Section 3 discusses experimental results and Section 4 concludes the paper and gives an outlook on future work.

2. METHODS

For this study, high-resolution (512x512) Computed Tomography data sets from the clinical routine have been used, provided by surgeons from the Department of Maxillofacial Surgery at Medical University of Graz in Austria. The software application was developed using the medical imaging and visualization platform MeVisLab (Bremen, Germany, http://www.mevislab.de/download/) [10]-[12], which provides an interface for connecting existing and new, proprietary algorithms using a dataflow network. Figure 1 shows a flow chart overview of the software. The user loads the dataset (*Load Data Set*), defines the implant's center position (*Set Initial Point*) and orientation (*Mouse Wheel*) and chooses the implant type (*Model Selection*). With this information, we calculate the centerline (*Baseline Calculation*) [13]-[18], subsequently used as a proxy for fast display during interaction (*Viewer*). The baseline calculation relies on ray-triangle intersection [19], where intersection rays are set up dependent on the surface's triangle normal vector and has been used for fast self-collision detection and simulation of bifurcated stents [20]-[22] to treat abdominal aortic aneurysms [23], [24]. The baseline position and orientation can be changed by the user with direct manipulation. If the user is satisfied, the full-resolution implant is generated ring by ring (*End Ring Section* and *Middle Ring Section*), followed by generating the connecting bridge parts (*Implant Generation*). Finally, the miniplate can be saved for later use (*Implant Save*) or converted to STL format for 3D printing (*Export*).

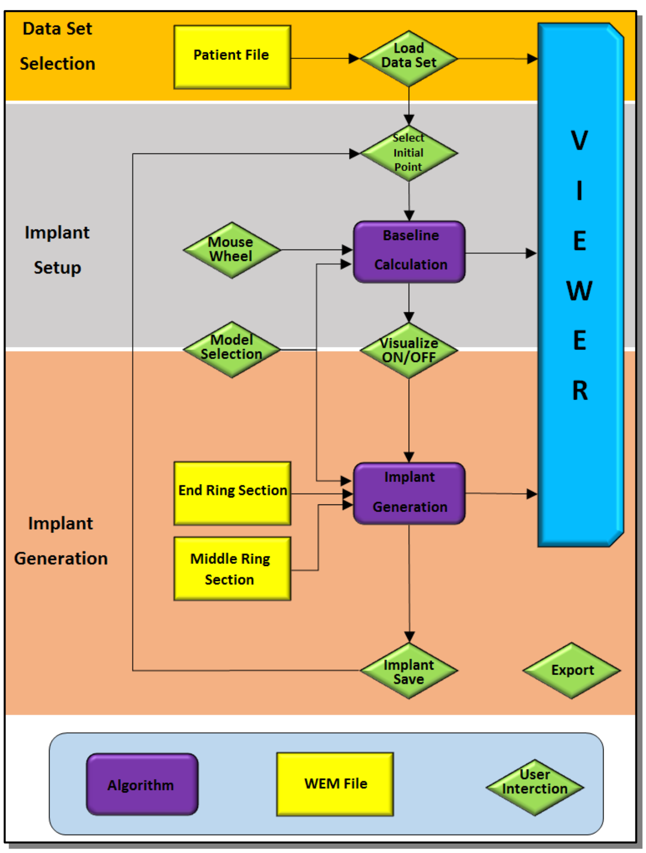


Fig. 1: Flow chart of the proposed application, starting with loading the patient data set and ending with saving/export the patient-specific designed implant for further usage, like 3D printing. Overall, the flow chart is divided in three main sections: *Data Set Selection*, *Implant Setup* and *Implant Generation*.

3. RESULTS

An early prototype of our miniplate planning tool was described by Gall [25] and Gall et al. [26]. In this paper, we present full results and a precise description of the methods. The current user interface is shown in Figure 2, with the control panel and the 3D visualization of the clinical data set on the right side, showing a clinical datasets with the baseline (green dotted line) and a virtual implant (gold) on the patient's forehead. Additionally, the miniplate and the baseline are shown in a magnified view (blue rectangle).

Figure 3 presents an example that contains all three available implants, each located in a typical position. For better illustration of the bending, enlarged insets are shown on the right. We informally evaluated the usability of our software with subjects from a variety of backgrounds. Subjects with an engineering background helped us assess the general handling and learning curve. Subjects with a surgical education helped us assess the accuracy of implant placement, computational time, and user friendliness for non-engineers. In summary, all subjects found the software as easy to learn and understand. Especially the surgeons found the option of first visualizing a baseline very comfortable. Furthermore, the time used for generating an implant was found to be very short. A test case where a mandibular media fracture had been simulated could be treated in under five minutes by all users, using two of the provided miniplate models.

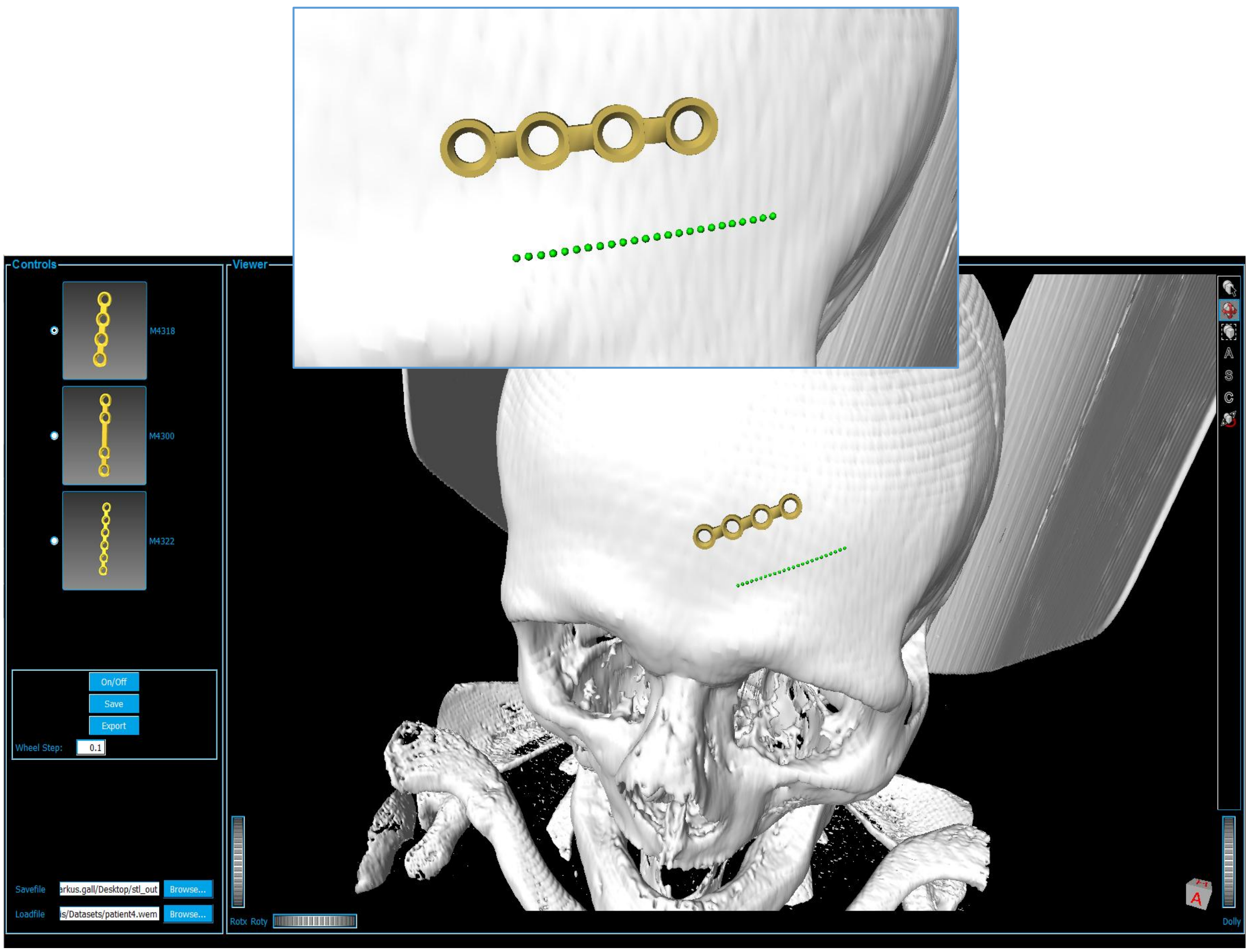


Fig. 2: User interface separated in two main parts: The control panel including all interaction fields for user friendly handling is on the left side. On the right, the visualization panel is shown where a data set with an applied miniplate (gold) and a baseline (green) are shown. Additionally, the miniplate and the baseline are shown in a magnified view (blue rectangle). Furthermore, several interaction fields have been added after the surgeon's feedback to enhance the user experience.

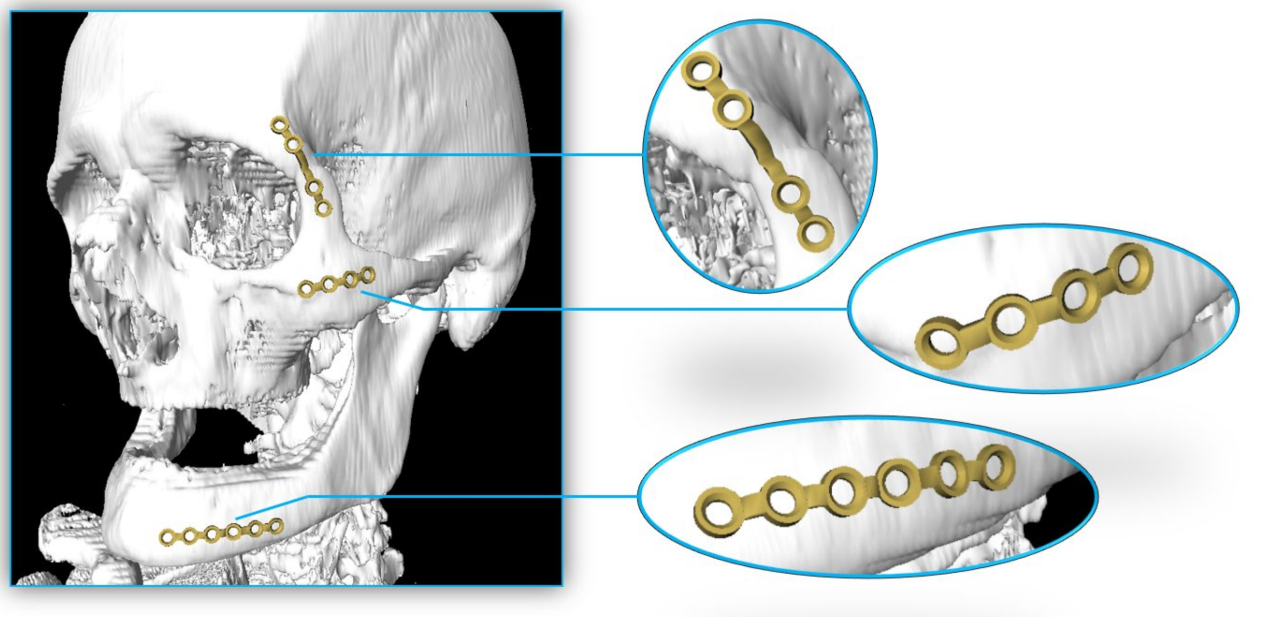
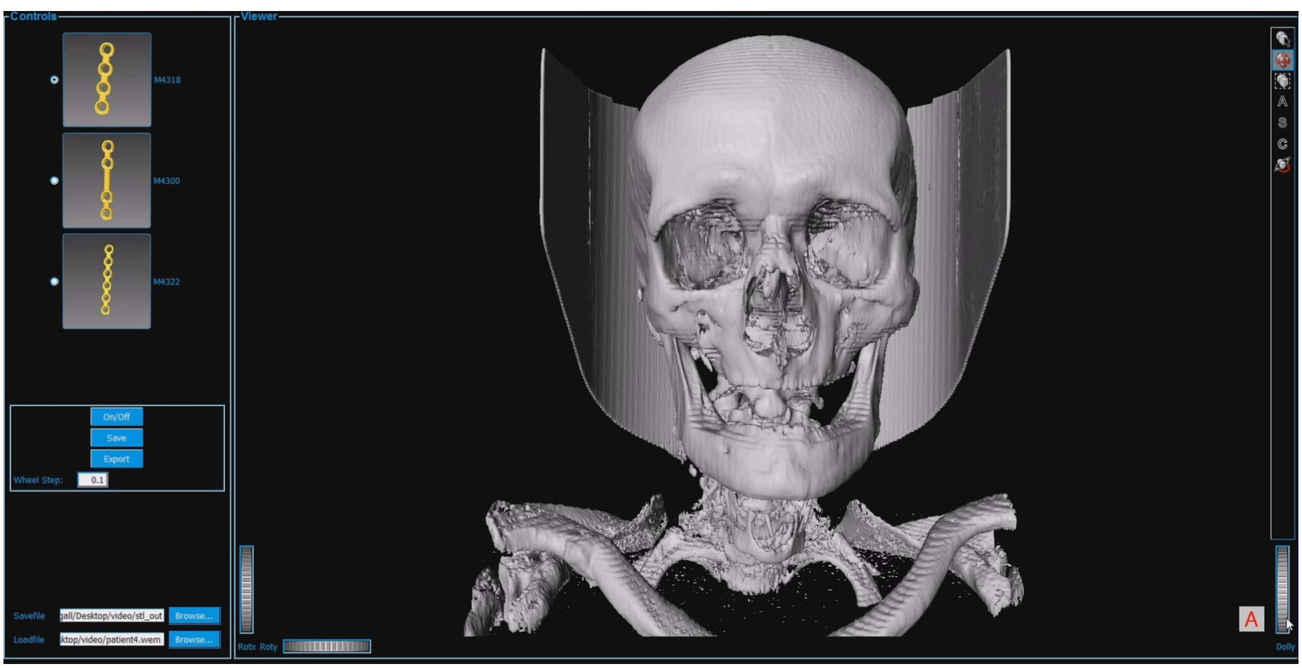


Fig. 3: Patient's data set with applied miniplates (gold) on several locations where fractures occur frequently, like a mandibular angle fracture (bottom). Each of the three available implants is used in this example case. On the right side, the different models are zoomed out for better observation in their bent state.



Video 1: Step-by-step tutorial video showing the interactive planning of MedArtis miniplates under MeVisLab for facial defect reconstructions http://dx.doi.org/10.1117/12.2249748.1

4. CONCLUSIONS

In this contribution, the interactive planning of facial fracture treatment using common miniplates has been presented. The end user loads a clinical data set and interactively chooses the location of the implant on the bone structure. Depending on the selected implant model, a proxy derived from the miniplate baseline shows the user all necessary properties for a correct placement. When the user is satisfied, the final implant model is generated and can be 3D printed. In an informal evaluation, all subjects liked the short training time, reduced planning time, accuracy and user friendliness.

There are several areas for future work. The most obvious extension is support for more implant types up to personalized ones [27]-[29]. Another useful extension will incorporate bone [30]-[40] and tumor segmentation [41]-[50], and bone repositioning, allowing to plan surgeries with displaced bones. Moreover, adding the option of photo-realistic visualizations [51] of soft tissue will aid the surgeon in the aesthetic planning. While we have concentrated on facial reconstruction, it is straight forward to adapt the approach for other body areas were implants play an important role, like oral implantology, pelvis and cervical vertebrae implants [52]. We would like to display implants using Augmented Reality during surgery [53]-[55] and Virtual Reality for surgical planning [56], [57]. A long-term plan is to perform a clinical trial on the precision of the implants compared to conventional methods.

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https://www.youtube.com/c/JanEgger/videos

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