Computerized Treatment Planning and its Realization in Maxillofacial Surgery and in Dental Implantology

Ph.D. Thesis

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I. Introduction

Surgical procedures in the maxillofacial region relate to high expectations in treatment outcomes. The result of these surgical performances has immense aesthetic effect on the human face. Precise planning and accurate implementation of the plan during operation are having key roles of the result. This thesis focuses on the importance of medical imaging, image processing, accuracy and the usability of planning systems. The research shown in this work compromises with orthognathic surgery and dental implantology as the fields requiring the uppermost patient demands therefore the highest accuracy.

II. Aim of the Studies:

Several in vitro and in vivo studies were made to evaluate the accuracy of CBCT based surgical planning. The material and methods of these studies are mainly focusing on the surgical techniques and the result are differencing in a wide spectrum. Computerized treatment planning is an exceptionally interdisciplinary area of imaging, computer science, engineering and medicine. The aim of this research is to understand the basics and approaching the question in a scientific way. Therefore the following hypotheses were investigated:

1. How much effect does the resolution of imaging have on the accuracy of a three-dimensional model used for surgical planning?
2. How much effect do the further digital imaging steps have on the accuracy of a model?
3. How accurate is an orthognathic surgery planned virtually?
4. Is improving accuracy of the post-operative outcome possible?
5. Implementing the experiences in guided implantology.
6. A method and system for designing and manufacturing surgical guides.

III. Material and Methods

The following three chapters are logically built together as the essential approach of the thesis. Therefor they are having the „Aims and Introduction”, „Material and Methods”, „Results” and „Conclusions” parts separately. The three chapters are then discussed together in details.

1. *THE DIGITAL BACKGROUND*

The aim of this chapter is to understand the basis of imaging needed for computerized treatment planning. What are the image processing steps from capturing a scan to having a fine and seemingly accurate three-dimensional model on the computer screen?

a. The accuracy of three-dimensional model generation. What makes it accurate to be used for surgical planning?

Advanced imaging techniques, software and computerized manufacturing techniques have made three-dimensional (3D) computer models available not only for research and development, but also for routine clinical applications. The generation of a virtual model requires imaging and subsequent image processing steps.
When considering a virtual model, the clinician must be aware of the need for adequate source imaging and the image processing steps required to create the final model. Some of these steps are performed by user interaction while some are "hidden" procedures within the software. The impact of the image processing steps may subtly influence the accuracy of the final model.
We report on the use of high resolution CBCT imaging, and on image processing parameters relevant to creating an accurate virtual model of the occlusal surface.

b. Material and Methods

Image acquisition
A standard dental plaster model was scanned using an experimental high resolution CBCT scanner with an isotropic image resolution of 0.082 mm using standard CBCT image acquisition parameters. The DICOM information were transferred to a desktop computer and post-processed in a commercial software package for image visualization and data analysis and a reverse engineering software package.

Image processing and analysis
The workflow for creating a virtual model was evaluated using the CBCT data and divided into six major image processing steps. The first three steps, evaluating the impact of the (1) image resolution, (2) thresholding procedure, and (3) smoothing of the labeled threshold data, are performed on the 2D CT data before surface model generation. Then a 3D triangulated surface model was generated to evaluate the effect of (4) different model generation techniques, (5) smoothing the surface model and (6) reducing the number of triangles of the surfaces.

c. Results:

The impact of CT scan resolution and the 5 subsequent workflow steps were assessed.

1. Resolution
Beginning with the highest resolution, the data revealed a linear increase in the deviations between the models generated from reduced resolution CT scans and the gold standard model. In the non-isotropic image resolution part (i.e. from 0.5 to 0.8mm) there was a less steep slope, compared to the isotropic part. For each image resolution, the max+/max- values showed similar absolute deviation values. Between the highest and lowest resolution, there was a four-fold increase of the deviation, with maximum absolute values of about 0.45 mm (corresponding to +0.438/-0.492 mm).

2a. Threshold segmentation with low threshold value
The data showed the maximum deviation in the positive direction from the corresponding resolution GS (CGS) increased as CT resolution decreased in models with isotropic voxels, and did not change in models with non-isotropic voxels. The max+ and max- values showed different absolute values. The max- values showed an approximately linear increase up to 0.8mm, regardless of model isotropy. The max+ values showed as similar increase from 0.1 to 0.4mm, but afterwards the values remained virtually unchanged, between the 0.4, 0.5, 0.6, 0.7 and 0.8mm resolution CT scans.

2b. Threshold segmentation with high threshold value
The data illustrated the maximum deviations from the CGS in the positive directions increasing linearly as CT resolution was decreased. The maximum negative deviation increased with decreasing resolution in the models with isotropic voxels, but did not change significantly with the non-isotropic voxels. This is the inverse of the results described in section 2a. The max+ exhibits a linear increase up to 0.8 mmm and the max- values remained stable at resolutions above 0.4mm.
In both assessment 2a and 2b, the distance maps show a uniform deviation pattern within the overall occlusal surface, when compared with the CGS.

3. Smoothing 2D CT data
The data displayed a linear increase in model deviation as CT resolution was reduced. In contrast to assessment (1), (2a) and (2b) this smoothing procedure lead to a characteristic change in the surface topology of the occlusal surface with loss of areas with small-radius curvatures. The loss of details in area of tight curvature lead to a flattening of the occlusal cusps (thus reducing the height of the occlusal cusps) and of the occlusal fissures (thus filling the occlusal fissures), leading to an overall flattening of the occlusal surface topology as shown on the distance maps.

4. Model generation using the Marching Cubes algorithm
Among both for the max+ and max- values, there was a linear increase in deviation from the CGS until 0.4mm image resolution. The rate of deviation accelerated at lower

resolutions than 0.4mm. Large deviations were observed for values at a non-isotropic image resolution of 0.7 and 0.8mm, deviating > 1.6 mm from the CGS. The Marching Cubes Algorithm resulted in a similar non-uniform change in the surface topology, as observed in (3).

5a. Smoothing on generated surface models with moderate settings
The data demonstrated linear growth in deviation until the 0.4mm resolution group, and then ceased to change. This procedure did not change the max values. Maximum deviations approached 0.12mm.

5b. Smoothing on generated surface models with extensive settings

The data displayed growth in deviation. In contrast to 5a, when using these settings the max+ increased with lower image resolution. At the non-isotropic level of 0.7 and 0.8 the max+ deviation reached up to 1.6mm.

6. Reducing the number of the triangles
Reducing the triangle number by 50% did not change the max+ deviations. Below a CT resolution of 0.3mm, the reduction in model complexity lead to deviations by between 0.1 and 0.2 mm.

d. Conclusion

Intuitively resolution is the essence of an accurate model. No image processing step can compensate for lack of resolution in the original data. Inadequate resolution amplifies the negative effects of image processing. However, image processing can severely degrade the quality of a model generated from high-resolution data. The evaluations shows that each processing step effects the quality and accuracy of the 3D model. Each step is dependent on the image processing techniques chosen in previous steps. Errors introduced early in the workflow are multiplied by subsequent image processing steps. Particularly, early decisions made during manipulation of label field data in 2D scans have a dramatic effect on final model accuracy.

2. TRANSFORMING THE DIGITAL PLAN TO REALITY

The accuracy of clinical orthognathic cases will be shown as a preliminary study.

The aim of this chapter is to create accurate three-dimensional models for planning a clinical case with the knowledge gained previously. The usage of high-end technologies such as planning softwares, surgical wafer manufactured with three-dimensional printer and evaluation softwares are also part of this case report and technical note.

e. Evaluation of the Accuracy of Ten Clinical Orthognathic Cases

Traditional planning of orthognathic surgeries based on two dimensional imaging requires strong imagination of the structures in their three dimensional positions. The need of many precise data transfers between surgeon, orthodontist and technician makes planning unpredictable and time consuming. Recent advances of both image acquisition systems and 3D virtual planning softwares made a breakthrough in visualizing and planning these complex facial deformities.
The aim of this preliminary study is to compare the pre-operative plan with the post-operative result from ten orthognathic cases. The deviations are showing the accuracy of the surgeries visualized on deviation maps.

Material and Methods

The CBCT data of ten already treated orthognathic cases were randomly chosen into this preliminary study. All the cases were scanned, planned and operated in the same institute (Cranio Facial Center, Hirslanden Klinik, Aarau, Switzerland). The cases were planned in a commercially available treatment planning software and then the surgeries were performed with intermediate splints manufactured with a three-dimensional printer according to the plan. Each patient folder contained the following data: (1) pre-operative CBCT scan from the skull (2) the plan of the osteotomized segment (ROI) in the same coordinate system with the pre-operative data (3) post-operative CBCT scan from the skull.

The digital evaluation of the cases were made in the AO Research Institute, Davos, Switzerland. Three-dimensional models were made from each datasets. Data (3) was transferred to data (1) and (2). Data (3) was aligned to data (1) through non-moving anatomical landmarks. With this alignment the post-operative model of the plan (3) got in the identical coordinate system with the model of the osteotomized segment (2). Point to point distance calculation was made between the two models and visualized on the ROI with a distance map. Mean and standard deviations were calculated in all ten cases.

Results

The evaluation showed a mean deviation between the pre-operative plan and the post-operative outcome of 3,94 mm with a standard deviation of 1,26 mm. Distance map visualization is shown and numeric results from the ten cases are displayed.

Conclusion

Despite the high resolution CBCT scans, the 3D planning and the individual rapid-prototyped splints, the deviations between the pre-operative plans and the post-operative results are considerable in most of the cases. Utilizing the knowledge gained in imaging and image processing might increase accuracy in the 3D models, therefore the post-operative results.

f. Correction of a Severe Facial Asymmetry with Computerized Planning and with the Use of a Rapid Prototyped Surgical Template: a Case Report / Technique Article

Correction of severe facial asymmetry is a challenging task due to the geometric complexity of the dentition, the bony structures and the soft tissues. Mandibular asymmetry is usually associated with a unilateral vertical maxillary excess and an occlusal cant, therefore, in most cases the deformity cannot be treated with single-jaw surgery.
The aim of this study is twofold, first, to investigate whether virtual 3D model surgery is suitable for treatment planning of an asymmetric two-jaw surgery, and second, to examine if rapid prototyping may eliminate the need for manual model surgery and the conventional fabrication of the inter-occlusal splint in the dental laboratory. A case of a severe facial asymmetry is reported when computer aided surgical planning was performed and the intermediate wafer was designed virtually and was manufactured by a three-dimensional printer.

Case Presentation / Technique Description
A 26-year-old male complained of facial asymmetry and eating difficulties. Clinical evaluation revealed severe right-sided hemi mandibular elongation with small compensatory transverse canting of the maxillary occlusal plane.
Preoperative orthodontic treatment lasted for 18 months and consisted of alignment and elimination of the transverse and sagittal dental compensation and arch coordination.
After pre-surgical orthodontic treatment was completed, computed tomography scan was obtained with an isotropic image resolution of 0.3 mm and standard image acquisition parameters. The patient was scanned in a supine position. The digital imaging and communication in medicine (DICOM) data were directly transferred to a personal computer. An in-house developed 3D planning software (JMed software, TraumArt Ltd, University of Szeged, Hungary) was used to reformat DICOM stack images into a 3D structure and to perform virtual preoperative surgical planning.

A model of a virtual intermediate surgical wafer was created with the maxilla in the planned position and the mandible in its original place. The model of the wafer was printed with a 3D printer from a bio-compatible synthetic material that is suitable for short-term mucosal membrane contact. The splint was checked for occlusion on the patient’s lower and upper dental arches and fitted well in both cases.

Following that the mandible was rotated into the correct position with virtual bilateral sagittal split osteotomy to visualise the movements of the osteotomized segments.
In the surgical phase Le Fort I osteotomy was carried out as planned. The mobilized maxillary segment was rotated clockwise and was repositioned by application of the virtually planned intermediate wafer and mandibulo-maxillary fixation. The virtually designated intermediate wafer fitted well during surgery. Miniplate fixation to the vertical facial buttresses was performed. Mandibulo-maxillary fixation was then

released and the bilateral sagittal split mandibular osteotomies were carried out. The distal segment of the mandible was rotated to the right and placed into the desired occlusion. Final splint was not used as the teeth were in good occlusion. Osteosynthesis was performed with titanium miniplates and screws.

The facial symmetry was improved significantly after the operations. The occlusion is stable and the patient is satisfied with his facial appearance. There is no sign of relapse after 18 months following the first surgical procedure.

Results

A postoperative CT scan was made to evaluate the difference between the virtual Le Fort I osteotomy and the surgical result. The preoperatively planned model of the segmented maxilla was superimposed on the postoperative CT scan. The distance map generated between the superimposed models showed a deviation of 2.15 mm on the bony structures.

Conclusion

Latest computerized and rapid prototyping technologies let us fully imagine, design and control orthognathic procedures without information loss among the surgeons, orthodontists and dental technicians. Any number of alternative treatment strategies can be investigated simultaneously during the planning phase. Computerised simulation surgery can be extremely useful in severe asymmetric cases when precise treatment planning with traditional methods is hardly possible. With this method manual model surgery and other laboratory steps can be avoided. The surgical wafer splint can be planned virtually and fabricated by a 3D printer.

3. *UNDERSTANDING GUIDED IMPLANTOLOGY*

g. Aims and Introduction

The aim of this chapter was to understand the potential that guided implantology gives us today. Case reports are demonstrating the possibilities of current technology. Further steps were made to develop an easy to use guided system with a workflow that can be part of the everyday routine.

Prosthetically driven implant surgery in reference to surrounding anatomical structures has been a subject of interest to dental clinicians for a number of years. Correct implant positioning has a number of advantages such as a favourable aesthetic and prosthetic outcome and the potential to ensure optimal occlusion and implant loading. Moreover, the consideration of correct implant positioning may enable design optimization of the final prostheses, allowing for adequate dental hygiene. Consequently, all of these factors may contribute to the long-term success of dental implants.

h. The Use of CAD/CAM Technology in Implant Surgery and Prosthetics.

The growing use of CAD/CAM technology in implant dentistry makes treatment planning and performing easier, faster, predictable and more comfortable for the patient. The possibilities in current technology from patient arrival to the final restoration will be shown in this case report. Through a rehabilitation of a totally edentulous maxilla.

Case Presentation

The patient is a 36 years old female with a completely edentulous upper jaw. The reason of teeth loss were negligent dental care, lack of oral hygiene and unfortunate choosing of dental professionals. She was wearing acrylic complete denture. Implant placement could not be carried out due to the extensive horizontal and vertical atrophy of the maxilla.

Material and Methods

Implant planning was performed after four months of bone healing. A CT template was fabricated according to the existing complete denture in order to visualize the prosthetic concept. Imaging was performed according to the manufacturer's double-scan technique. The technique requires a scan from the patient wearing the CT template in place and a second CT scan from the template itself. The CBCT was carried out with standard parameters.

The types, sizes and positions of the implants along with the location of the fixation pins were determined in the planning software. The plan was sent to the manufacturer.

The surgery was performed two weeks after the planning. The primer stability of the implants were satisfying respectively therefore transgingival healing abutments were used. The inside of the patient's complete denture was modified not to load the healing abutments during the three months of healing.

Screw-retained ceramic bridge on zirconia frame was planned with a commercially available software. The teeth positions of the complete denture was taken into consideration when planning the frame work on the computer. The digital plan was sent to the manufacturer and the final frame work was received three days later. The ceramic work have been done locally and finalized within a few intraoral try-in.

Results

Since the alveolar bone have not reach the optimal dimensions after bone grafting, pink ceramic have been used for the perfect aesthetic outcome. The patient was satisfied with the result.

Conclusion

Modern CAD/CAM technologies are not only part of the surgical steps but playing an important role in the prosthetic planning as well. The presented case showed all steps of the state of the art in virtual planning which might be used in the everyday practice. With the use of these technologies not only the unexpected complications can be avoided but surgeries can be far more accurate with the highest aesthetic standards and prosthetic guidelines taken in consideration.

i. Method and System for Designing and Manufacturing Surgical Guides

The subject of the invention is a method and system for a fast and precise way of designing and manufacturing surgical guides.

The method comprises an impression from the oral structures made with an impression tray containing radiographic markers. The patient is digitized with the impression tray in its place and the impression tray is digitized separately. The two digital data stacks are than registered with a treatment planning software and the digital treatment plan is made. The digital model of the surgical guide is then made with a guide designing software. The physical model of the surgical guide is than manufactured according to the digital model.

The system contains a planning software for registration and treatment planning, a guide design software for creating the digital model and the physical model of the guide, a surgical kit and the planned and manufactured patient's specific surgical guides.

Presenting the Invention

The technology presented in this invention also operates with the dual-scan protocol. It uses an impression tray with radiographic markers fitted on (hereinafter „tray"). The first scan is made having the tray with the impression in the patient's mouth and the second scan is made from the tray with the impression separately.

The radiographic markers are spherical radio dens points integrated in the material of the impression tray in a specified number and position.

The significance of registration is when the planning software superimposes the identical marker points automatically. Therefore the two data stacks gets in the same coordinate system in the three-dimensional space. With this transformation a file format for planning is achieved.

The treatment plan is made on a planning software. It contains the type of the surgical kit as well as the type, sizes and positions of the implants.

The plan together with the digital model of the impression is then transferred to a surgical guide designing software. As a first step the border lines and the dimensions of the surgical guide are determined. These steps are made by a dental technician in a computer program. The following step is to remove the undercuts from the model. For that the direction of the guide insertion has to be shown. This procedure is crucial since the material of the surgical guide is more rigid than the impression material. This led to the perfect fit of the surgical guide during operation. The location of the tubes holding the metal sleeves in the future are determined by the plan. The shapes and dimensions of the tubes are given in the computer program to achieve maximum stability of the device. The insertion of the surgical tools are simulated virtually therefore free tool insertion and comfortable surgery is ensured. The patent ID is then placed on the surface of the surgical guide. The software generates the final three-dimensional model of the surgical guide which is then manufactured by a three-dimensional printer. The software also produces a patient specific surgical protocol. The protocol contains all the details of the planned implants, and a sequence of the drills needed to be used for the perfect result (Figure 35).

The printed model of the guide is going through some additional finalizing steps such as polishing, insertion of the metallic sleeves and cleaning.

The Advantages of the Method

The method shown in this invention allows the user to perform the CBCT imaging right at the first patient visit without the need of the intervention of dental technician, making plaster casts or using surface scanning devices. The invention saves significant amount of time and cost for both the doctor and the patient. Furthermore the chances for inaccurate procedures such as creating plaster casts or fabricating scan appliances are eliminated.

Conclusions

The invention offers a solution for easy, fast, accurate and cost effective manufacturing of surgical guides. The method eliminates the need for the time consuming and costly production of scan appliances. The invention makes planning and performing guided surgery easier and fitting into the everyday practice.

IV. Discussion

This thesis was focusing on the importance of medical imaging, image processing, accuracy and the implementation of new technologies. The research shown in this work targeted orthognathic surgery and dental implantology as the fields requiring the uppermost patient demands therefore the highest precision.

No image processing step can compensate for lack of resolution in the original data. Inadequate resolution amplifies the negative effects of image processing. However, image processing can severely degrade the quality of a model generated from high-resolution data. The introduction and widespread use of cross-sectional imaging in maxillofacial surgery and implant dentistry using cone beam computed tomography (CBCT) makes appropriate imaging accessible. Although latest CBCT machines have their benefits, radiation dose have to be considered. CBCT imaging exhibits a significantly lower radiation dose risk than conventional CT, but higher than that of two-dimensional radiographic imaging. Different CBCT devices deliver a wide range of radiation doses. Substantial dose reduction can be achieved by using appropriate exposure parameters and reducing the field of view to the actual region of interest (De Vos et al 2009, Bornstein et al 2014).

The evaluations shows that not only the image resolution but also each processing step effects the quality and accuracy of the 3D model. Each step is dependent on the image processing techniques chosen in previous steps. Errors introduced early in the workflow are multiplied by subsequent image processing steps. Particularly, early decisions made during manipulation of label field data in 2D scans have a dramatic effect on final model accuracy (Varga Jr et al 2013).

A potentially satisfactory alternative to 3D model generation from CT data is optical scanning of dental structures. Use of this technique does not escape the need for CT in many cases, nor does it eliminate accuracies from 3D model image processing. If detail of the underlying structures is needed for surgical planning, CT scanning is still required, as is often the case in orthognatic and surgical procedures affecting dental structures. An additional source of error within optical scanning is the merging and alignment of CT-derived and optical scan-derived model data (Schutyser et al 2005, Swennen et al 2008). Finally, models generated from optical surface scanning must still undergo image processing of the 3D model, potentially introducing the inaccuracies detailed in this study.

Accurate 3D models require a combination of appropriate resolution imaging and image processing. The importance of resolution in the source imaging is well understood by surgeons. The critical nature of image processing is poorly recognized and this study demonstrates it as a source of significant error. Adequate quality models can be produced using average resolution CT scanners as long as the importance of image processing is understood.

Computerized planning and the use of digital data gives the possibility to fully imagine, design and control surgical procedures without information loss among the surgeons, orthodontists and dental technicians. Any number of alternative treatment strategies can be investigated simultaneously during the planning phase. However these new techniques have to be learned by each professional of the team and they do not substitute the anatomical knowledge and surgical skills.

The results gained in the case report of the correction of a severe facial asymmetry are showing promising results, however evaluation of more cases will be needed to show significance.

The systematic reviews are indicating that computer technology applications in implant dentistry are sufficiently accurate to justify use. There are sometimes however concerns over some of the reported accuracies, which indicates maximum deviations from the planned position that exceeded clinically acceptable parameters. It is suggested by the author of the paper that this might be due to intraoperative movement of the surgical template. (Hämmerle et al 2009). Guided implantology requires a different surgical technique than conventional free-hand implant placement. The operator has to rely on the surgical guidance which is often a unusual sensibility. The learning curve for this procedure could be quite steep, so caution should be exercised in the early stages of acquiring these skills. (Jung et al 2009).

Computer-assisted implant placement reveals high implant survival rates after 12 months of observation. However, future long-term clinical data are necessary to identify clinical indications and to justify effort, and costs associated with computer-assisted implant surgery (Tahmaseb et al 2014).

Guided implant site preparation is often used as a synonym for flapless or trans-gingival approach. Surgical access of the soft tissue should be chosen by the clinician by evaluating the clinical situation. Flaps can be also raised when using surgical guide, however the correct fit of the template must be controlled. Guided surgery gives the possibility for trans-gingival implant site preparation and implant placement.

Flapless surgery appears to be a plausible treatment modality for implant placement, demonstrating both efficacy and clinical effectiveness. However, these data are derived from short-term studies with a mean interval of 19 months, and a successful outcome with this technique is dependent on advanced imaging, clinical training, and surgical judgment. (Bordala 2009).

Computerized treatment planning is an exceptionally interdisciplinary area of imaging, computer science, engineering and medicine. Each professional need to be able to discuss with the other to understand the nature and the potential in this field. The extremely fast development of this topic makes it an interesting area for research, education and development which has to be reviewed day by day.

V. **Summary**

The aim of this research was to understand the basics and approaching the questions in a scientific way. The following statements are made based on this research:

1. How much effect does the resolution of imaging have on the accuracy of a three-dimensional model used for surgical planning?

Inadequate resolution amplifies the negative effects of image processing. Beginning with the highest resolution, the data revealed a linear increase in the deviations between the models generated from reduced resolution CT scans and the gold standard model. For each image resolution, the max+/max- values showed similar absolute deviation values. Between the highest and lowest resolution, there was a four-fold increase of the deviation. The distance maps demonstrated a uniform deviation pattern on the occlusal surfaces.

2. How much effect do the further digital imaging steps have on the accuracy of a model?

Image processing can severely degrade the quality of a model generated from high-resolution data. Each step is dependent on the image processing techniques chosen in previous steps. Errors introduced early in the workflow are multiplied by subsequent image processing steps. Particularly, early decisions made during manipulation of label field data in 2D scans have a dramatic effect on final model accuracy. The effects of the following image processing steps were shown: thresholding procedure, smoothing of the labeled threshold data, different model generation techniques, smoothing the surface model and reducing the number of triangles of the surfaces.

3. How accurate is an orthognathic surgery planned virtually?

The distance map evaluation showed a mean deviation between the pre-operative plan and the post-operative outcome of 3,94 mm with a standard deviation of 1,26 mm.

4. Is improving accuracy of the post-operative outcome possible?

The results of the case report shows improving of the accuracy is possible. Deviation of 2,15 mm was shown however further evaluations need to be made.

5. Implementing the experiences in guided implantology.

The knowledge gained in 3D modelling, computerized planning and rapid prototyping helps to understand the details of guided implantology. Further accuracy studies are running at the present.

6. A method and system for designing and manufacturing surgical guides

The subject of the invention is a method and system for a fast and precise way of designing and manufacturing surgical guides. The patent is currently pending.

Publications Related to the Thesis

I.

Varga E Jr, Hammer B, Hardy BM, Kamer L

The accuracy of three-dimensional model generation. What makes it accurate to be used for surgical planning? Int J Oral Maxillofac Surg 2013 Sep;42(9):1159-66.

IF: 1,521

II.

Seres L, Varga E Jr, Kocsis A, Rasko Z, Bago B, Varga E, Piffko J

Correction of a Severe Facial Asymmetry with Computerized Planning and with the use of a Rapid Prototyped Surgical Template: a case report/technique article. Head Face Med

IF: 0,981

III.

Varga E Jr, Czinkóczky B, Korpásy V

CAD/CAM technológia alkalmazása az implantációs sebészetben és protetikában. Magyar Fogorvos 2012/6 283

IV.

Varga E Jr, Erdőhelyi B, Bagó B

Eljárás és rendszer implantációs sablon tervezésére és előállítására

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