Virtuális tervezés és 3D-s gyártás a fogászati szakterületen

Virtual design and 3D manufacturing in dental applications

János Kónya*, Klaudia Kulcsár**
*, ** Dent-Art-Technik Kft., Győr, Hungary
labor@dentarttechnik.hu
kulcsar.klaudia@dentarttechnik.hu

Abstract

The study's subject is a complex manufacturing process creating precise fit of fixed bridge prostheses. The materials and technologies used in our field are the sum of the most modern processing methods in the trade. The idea for the complex utilization possibility of both additive and subtractive technologies has emerged first at the University of Győr. Six years later, the ideal was realized as an optimized process in our laboratory. The role of virtual design has increased in dentistry; along with the penetration of implant prosthetics grew the qualitative requirements. The complex precision manufacturing process makes the required surface fitting possible for dual-phase implants.

Methods used in the process

Optical scanning, surface digitalization

The spatial coordinates of the model's surface points are defined with a non-contact projected line 3D scanner. From the processed information, the spatial locations of the surface's specific digitizable points can be determined.

Computer modeling and production planning

Product design is made in virtual environment using softwares developed for this express purpose. Manufacturing includes applied IT methods, procedures and services related to the operative phase of production execution.

Additive manufacturing with laser metal fusion (LMF) printer

LMF technology is the melting of the automatically layered metallic powder with the energy of a scanning laser beam. At each layer melting occurs at certain regions where needed, according to the cross-sectional area of the model at the given height.

Subtractive technology

At the 5-axis machining centers using special positioning clamping-desk, an automatic tool magazine is expected. The most important part of the follow-up work is fixing the 3D printed pre-product and locating the exact zero point.

Keywords: complex manufacturing, additive, subtractive, virtual design, implant prosthetics, dentistry, dual-phase implants, 3D scanner, CBCT, human bone, optical scanning, implant-supported denture, surgical template, tooth replacement, 3D printed, fixed implants, fixed prosthetics, sint and mill

1 Introduction

The use of dental implants becomes possible for patients who suffer from bone deficiency as we present in this study. With the insertion of such implants, a permanent tooth replacement can be created. This study presents the preparation technique for implant insertion and the complex manufacturing process of dentures placed onto implants. The technologies used in our specialized manufacturing process belong to the most recent machining procedures. With the spread of implantation prosthetics, the role of virtual design also increases in dental applications. Thus, the simultaneous use of both additive and subtractive technologies becomes essential. The applied precisional manufacturing technology enables the required accurate surface fitting between the implant and denture.

Operations in the whole process:

- computer-aided design and process planning
- optical scanning, surface digitalization
- additive manuafcturing with LMF (Laser Metal Fusion) technology
- subtractive technology

DESIGN OF IMPLANTATION PROSTHETICS

2 DESIGN AND IMPLEMENTATION PROSPECT OF IMPLANT POSITIONING

2.1 Virtual image analysis

The patient's CBCT image is delivered via e-mail or another electronic data traveller. Image processing begins with the conversion of the DICOM file to STL file format.

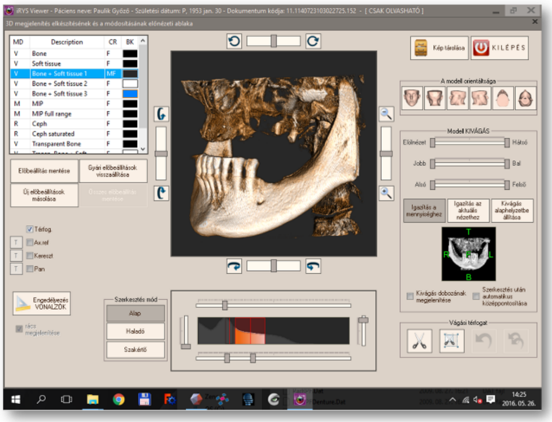

Fig. 1. CBCT imaging

Filtering of noise, shades, image disturbances, artifacts, and continuity defects originating from CBCT imaging are done by different image correction techniques. Afterwards, a preliminary examination takes place in a CT analysis software. Hereby, the layers and bone surfaces required for denture design are obtained.[3][5]

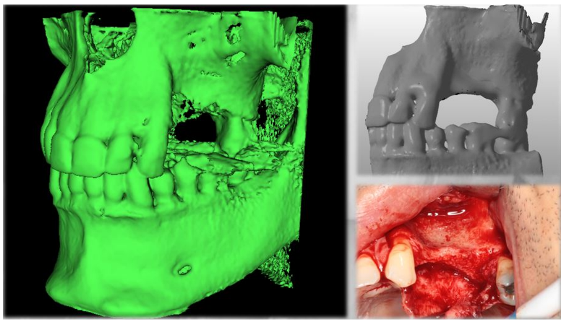

Fig. 2. Surface of bone

In the next step, we examine the bone surface generated this way, and calculate bone volume. Subsequently, the available bone structure is evaluated by means of quality and quantity. Hereby, we consider if existing bone volume is suitable for implantation. Occurrent existing dentition and bone volume are considered to decide the necessity of physical impression or supplementary CBCT images for denture fabrication.[2] [3][5]

2.2 Ideal, denture-based implant position design

During the modelling process, we use a dental design software, in which the ideal denture is created on the existing STL bone surface obtained from CBCT imaging. [5]

Antagonistic, aesthetical, mechanical, and functional aspects are considered here. [5][6]

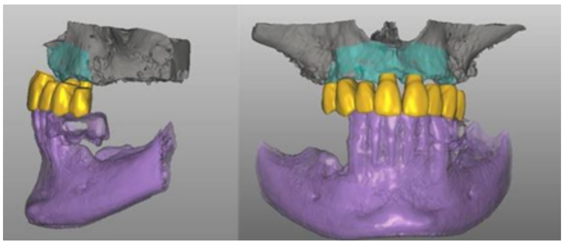

Fig. 3. The ideal denture on the bone surface

The number and size of dental implants was previously recommended by a dentist, oral surgeon.[5][6]

These implants are positioned in the bone tissue with the use of the designed, ideal denture. The choice and positioning of implants are influenced by anatomical site, screw-type trans-occlusal fixability of the denture, and functional occlusal loads. [2] [3][5] [6]

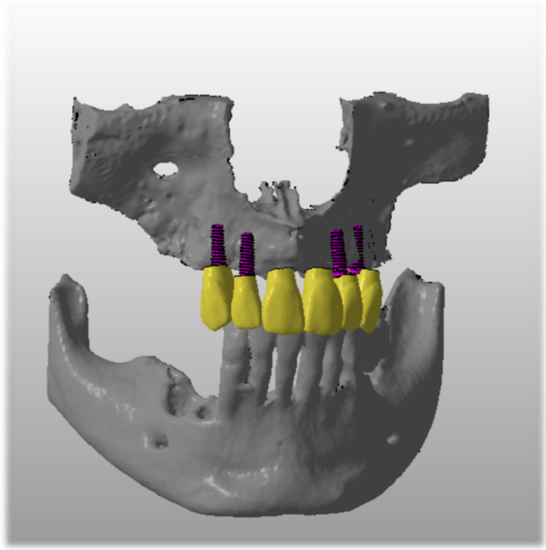

Fig. 4. The ideal position for implants

2.3 Determination and design of bone deficiency

Using the obtained data, possibly missing bone volume is reconstructed in a virtual environment by a surface-design software. Several factors have to be considered during this design process. One of the most important and decisive aspect is the restorable bone volume and the size of bone block graft.[3] [7]

Design is fully influenced by the aim of perfect bone integration, as possible bone loss has to be calculated during selection of geometrical sizes. Apart from these, another significant aspect is to define the borderlines of bone block grafts. The choice of optimal borderlines is based on the so called "nil nocere" principle. Here we consider neighbouring teeth, existing bone dimensions, nerve and mucous membrane relations.[3] [7]

With bone block grafts we are able to restore missing anatomical parts of mandibula and maxilla in a well-planned way. Bone deficiency can be the result of bone loss, bone disintegration, or accidental trauma. [3] [7]

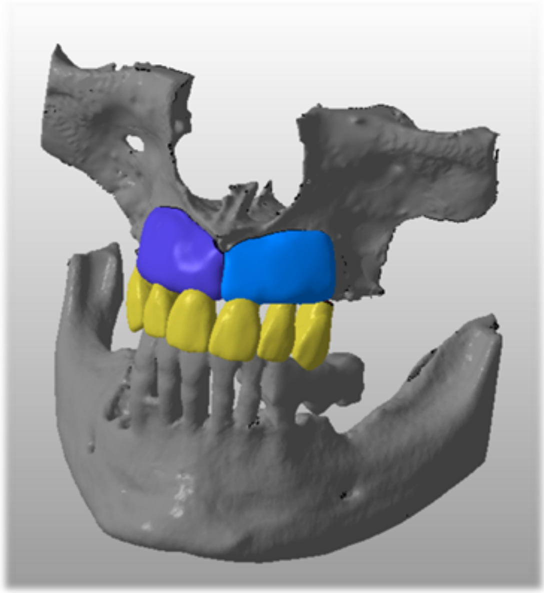

Fig.5. Replacing the missing virtual bone volume

We use human bone grafts for the restoration of missing bone tissue. Its surface nanostructure is of vital importance in the aspect of cell integration. Based on Hungarian patent, we utilize an albumin treatment, which is a protein enhancing integration and remodelling of the created bone tissue.

Besides the above-mentioned factors, in this phase the plans are checked by a medical specialist and an additional consultation takes place if necessary.

2.4 Machining

The bone component with a verified geometry and volume is prepared for machining. We choose a trabecular bone block graft material of adequate size. The bone block graft is then constructed by a 3D machining centre after defining its proper virtual orientation. [2]

Fig.6. Bone selection and machining

After machining, the lockpin and its place are removed from the shaped bone block. Fitting and insertability are tested on a 3D-printed model of the bone surface under real circumstances. The bone block graft with the proper documentation is then transported back to the tissue bank for cleansing, sterilization, and albumin-treatment. [2]

Fig.7. The machined bone block

3 SURGICAL TEMPLATE

The surgical template is designed by a free-surface modelling program based on the surgical plan of implant positions. The result of this design is a non-series surgical template. With the help of this aidance, drilling depth, direction, and micro-screw fixation can be determined.[3]

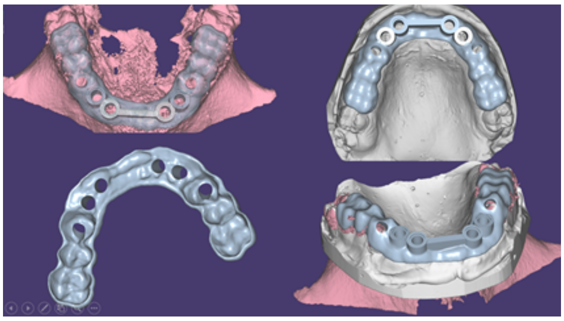

Fig.8. Designed surgical guide

The fitting of surgical template can take place on gum tissue, tooth, bone surface or the combinations of these. For the determination of bone surface, gum tissue, and articulation position, a supplementary CBCT image is needed with an additional physical impression.[3]

For this, we need to define the same coordinate system for the data obtained from CBCT imaging, and the optically-scanned version of the phyisically imprinted tooth surface model. During the design process, the necessary details of surgery and the requirements from the oral surgeon are all considered. It makes it possible to choose from full, semi, and pilot guide surgical techniques. [3] [8]

The next step is the 3D printing of the drilling template from a special purpose, sterilizable, photopolymeric material. Titanium sleeves ensuring position-drilling are inserted into the 3D printed template before sterilization process. These titanium sleeves belong to the implant, and are placed to the drilling equipment.[2] [4] [8]

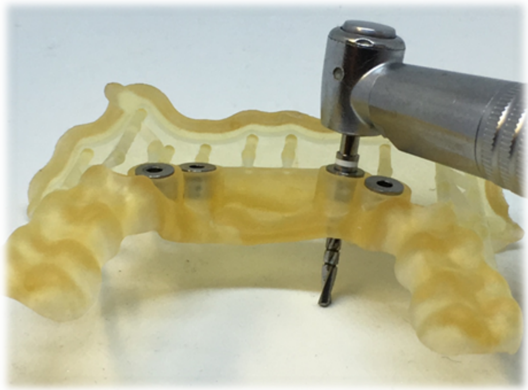

Fig.9. Printed surgical guide

4 TOOTH REPLACEMENT

4.1 *Optical scanning of implant-supported denture*

The production of permanent denture takes place after the implantation of bone graft, the insertion and osseointegration of the adequate number of implants, and the advancing healing. This procedure starts with the impression of implants in the oral cavity. It requires a special impression technique which stably fixes the position of implants. Afterwards, occlusal impression and antagonistic model ampression are carried out. The geometry obtained this way is complemented with technical analogues. Based on this, a gypsum model is created, which is the exact replica of the implants placed in the oral cavity. The required information base is obtained by joining together the antagonistic model and the occlusal impression. [10]

The following process is the optical scanning of models, during which the spatial coordinates of surfacial points of specimens are created by a non-touch projected-line 3D scanner. Information obtained and processed this way is enough for the software to calculate the spatial position of each point of the digitalized surface. The results of scanning are STL format model files. [10]

Fig.10. Optical scannig of inpalnt based dental restaurations

The average precision of dental scanners are 5 micrometres. This precision is indispensable for carrying out implantation projects. An articulational scan exposure is made using the antagonistic, the specimen, and the occlusal impressions. A detailed image of the antagonistic model itself is also created. In the following, the so-called master specimen is scanned together with the gingival area. In the next step, the exact position of implants in the specimen is determined by utilizing scan bodies that are identical to the type of the existing implant.

The scanned denture is then inserted to the identical-type virtual library that contains the factory standard precision nesting surface of the implant. The result of this is the defined position of implants with type-identical nesting surfaces in one sole model. This model enables further design steps.

4.2 *Virtual design*

Design takes place in a virtual environment by using a special purpose professional software. [11]

First is the choice implant fitting. Then, the exact determination of fitting types, and the run-off marking of surrounding gingival tissue takes place. The anatomical dental replacement with unique size and shape is created with the consideration of the patient's age and gender. The aim of this design phase is the aesthetical, functional, and phonetical restoration of the patient's dentition. Screwing directions are determined by the axes of implants used as pillars for the designed denture.[1] [2] [7]

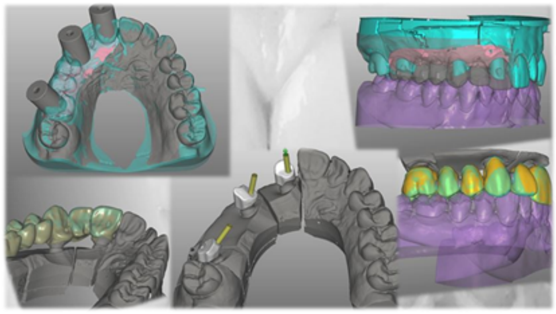

Fig.11. Virtual design of dental implants

4.3 *Visualization of anatomical model*

The virtually-designed implant supported anatomical denture is manufactured by a 3D printer from photopolymeric material. The created model is suitable for partial, functional tests in the surgery room. Hereby, fitting, articular position, reference planes, centerline, and anatomical dimensions are checked. This visualization helps the medical specialist, the patient, and the designer to connect virtual design with real-life implementation. Possible corrections after this test act as the base of the final virtually designed denture. [11]

4.4 *Corrections and modifications*

The anatomocal shape of our 3D printed model contains the necessary corrections such as smoothened articulation, re-defined centerline, modified vestibular or lingual dimensions. The anatomical plastic model is scanned together with the specimen, and fitted to the originally designed model. Necessary modifications are implemented, which can be performed in the virtual environment without any complete re-design. The final design stage is the reduction of the framework, where both base material and veneered material to be used are taken into consideration. Simultaneously, the part is prepared for additive manufacturing.

5 3D ADDITIVE AND SUBTRACTIVE MANUFACTURING

5.1 *Utilization of Sint&mill program*

In case of dental frame structures, different precision and surface quality is required. It defines if the finished or the semi-finished product needs further machining at FPD frames. [9]

Such informatic computational methods, procedures, systems, and services belong to computer-aided manufacturing that are in connection with the operative phase of product manufacturing, or material and technological processes. Here we can mention sint&mill software, which is used during manufacturing. With sint&mill, we define and offset the surfaces to be milled after reshaping. This software creates a connection between additive and subtractive manufacturing. The requirement of the refacing milling process is to add positioning and fixing lockpins to the 3D printed model that enable zero-point resetting in the milling machine.

5.2 *Creating a CAM model*

The necessary database is ready for the 3D manufacturing software. The model is placed and oriented on the printing platform. Support structures are designed. The finished 3D printing plan is uploaded to the printer and the physical realisation of the model starts. [9]

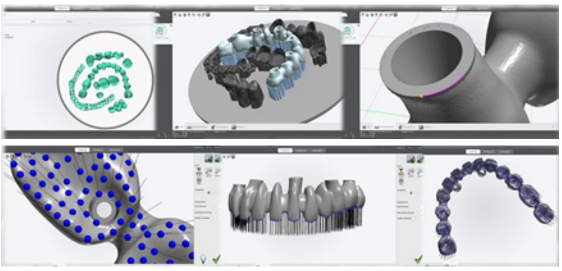

Fig.12. CAM model

5.3 *3D printing*

3D printing is an additive manufacturing technology, which builds up the denture frame with a laser by melting together given areas of the 20-micrometre-thick metal powder layers. Ideal scanning path of solid-state lasers is generated automatically by the software.[9]

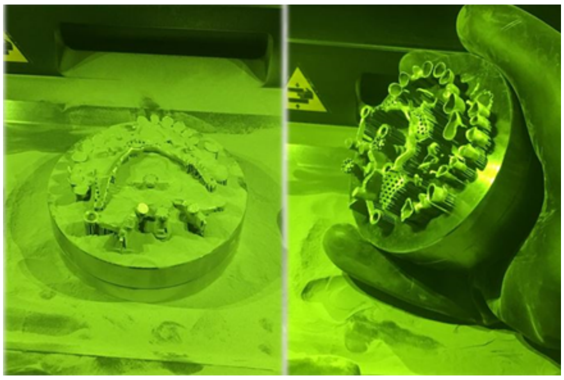

Fig.13 LMF - Laser Metal Fusion technology

5.4 *Post-processing, precision refacing, and finishing*

Following the printing process, the finished denture is removed from the printing area together with the platform. Afterwards, the remaining metal powder residues are removed. The surface is then blasted with aluminum-oxide particles to get a smoother exterior. Next step is the adequate heat treatment, during which controlled heating and cooling takes place. The purpose of this heat treatment is the controlled change of state of stress and the framework's material structure in order to achieve the desired physical properties. [4] [9]

Fig.14. Heat treatment

The denture is separeted from the platform after oxide-remover particle blasting. The remaining support layers are removed manually.

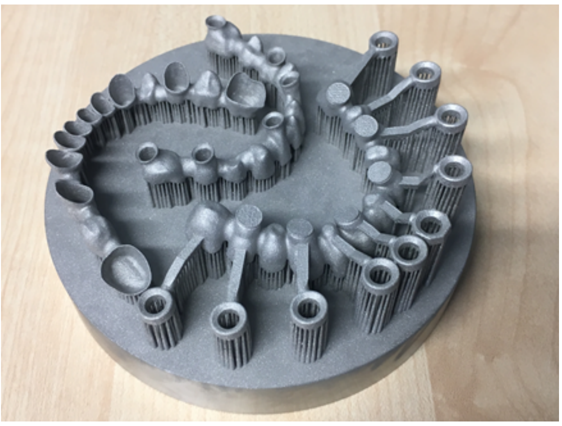

Fig.15. Printed, heat-treated, sandblasted platform

The framework prepared this way is then fixed into the zero-point-positioned vice of the 5 axis milling machine. Refacing milling is then carried out on previously defined areas of the workpiece.

Fig.16. Sint&mill process

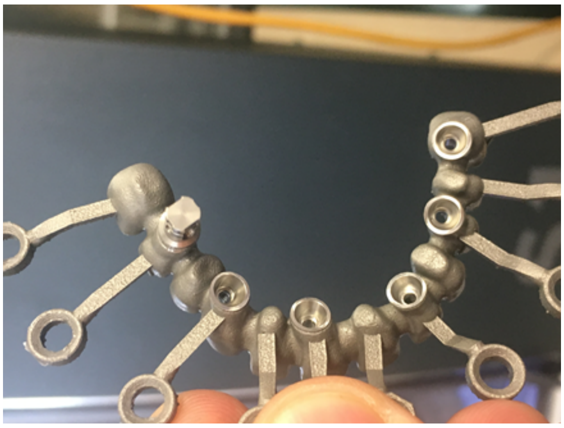

Fig.17. The milled and finished dental framework

The produced denture is transported back to the dental surgery room, where final fitting and geometric accuracy are both tested in the oral cavity. The last phase of implementation take splace in the dental technician laboratory, where ceramic and composite coatings are applied to get the lifelike anatomical and aesthetical denture shape. A carving aid is used to construct the veneer, which the replica of the anatomical plastic model on the work model. By fitting the final, reduced FPD frame into the copied negative, the veneer technician can see and check the dimensions of the material volume to be constructed.

6 SUMMARY

The spread and development of implantatable dental restorations necessitated the realisation of novel applications for patients without the sufficient amount of bone tissue. Thus, implantation becomes possible, and chewing ability can be fully restored by the proper number and position of implants. Precision fitting, material, and manufacturing process of the realised prosthetic implementation provides a possibility to protect implants and their encasing bone structure, and to enable permanent use of the denture. The experimental development of implementation, IT software processing, and the whole preparation for manufacturing is a technology solely developed and summarized by us.

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