Reverse engineering in computer-aided engineering of medical products

KRZYSZTOF KARBOWSKI
RYSZARD CZEPKO
WITOLD SUJKA *
MARIUSZ BANACH
PRZEMYSŁAW MASŁOWSKI

The article describes application of reverse engineering techniques in medicine. The analysis of computed tomography images and 3-dimensional structured light scanning for preparing of the large skull bone's prosthesis are presented.
KEYWORDS: CAD, reverse engineering, structured light, medicine

The removal of the bone flap is a widely accepted procedure in many clinical situations - this procedure is called "osteo-dural decompression". Typically, the use of such a radical solution is forced by increased brain volume as a result of mechanical trauma - usually a traffic accident. The consequence of this treatment is the need to restore the natural head shape and provide protection against mechanical damage, which in the opinion of many patients with bone defects, is an important psychological factor. Such a procedure enables for the patient to close a certain stage of treatment, followed by rehabilitation and return to normal social activity. The procedure of filling the skull cavity (cranioplasty) [1, 5] – with an autogenous graft (patient's own bone) or an implanted prosthesis (titanium mesh, polypropylene-polyester mesh, derivatives of synthetic hydroxyapatite) - is performed in various centres within a period from two weeks to six months from the first treatment. In Poland, due to its biocompatibility and low cost, for this purpose a rigid polypropylene-polyester fabric called Codubix® is used [3].

This work describes the designing procedure for preparing a massive skull bone prosthesis based on reconstructive engineering solutions: digitisation of images obtained with the use of computed tomography, virtual modelling and object scanning.

Case description

Reconstructive engineering, also known as reverse engineering, provides tools and designing methods based on the material product model.

In the described case, the starting point in the modelling process are images obtained in computed tomography, showing the patient's skull shape. These images require further analysis. Its goal is to find the edge of the skull bone, which will be later used to prepare a virtual model of the object. The detection of the skull bone edge was performed in a specially developed computer program using image analysis (Fig. 1). This program is described in detail in [2] and in [4]. It generates a cloud of points, basing on which the computer modelling system builds a virtual skull model (Fig. 2).

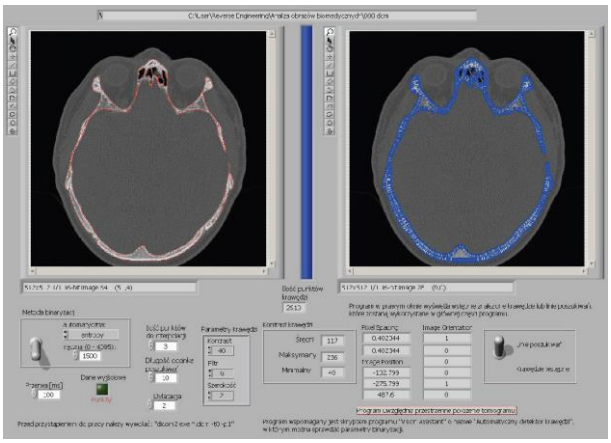

Fig. 1. Detection of the skull bone edge

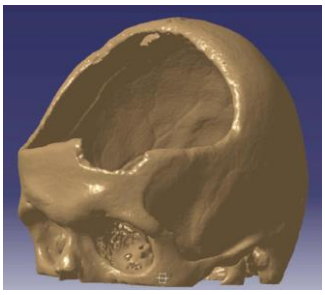

Fig. 2. Virtual skull model

The next step is to design a filling for the skull bone defect. If the defect is on the side of the skull, a mirror image of the non-deformed bones can be made, and then used in the modelling process. Difficulties arise in the case of the frontal bone defect. This type of filling can be prepared on the basis of computed tomography performed before a surgical removal of the skull bones - if it is available. Another method is the extrapolation of the non-deformed bone structures - such an approach is effective for small bone defects. Yet another idea is to use haptic modelling methods [4, 6].

When none of the above methods can be applied, the filling design is created depending on the creativity of the designer.

In the case of the patient whose skull model is shown in Fig. 2 pre-injury tomography was not available. Another problem in the designing process was the extent of the defect. The difficulty to design the filling using the computer modelling was due to the problem of the spatial assessment of the shape to be filled, which should fit the skull whole in an aesthetic way. This can be achieved by applying sculpture methods; forming the skull o modelling clay allows to evaluate the shape of the material not of the virtual model.

The prosthesis

The model of the skull bone filling was made of modelling clay. For this purpose, spatial printing technology FDM (Fused Deposition Modelling) was used, a model of the skull fragment was prepared, and then hand-formed (Fig. 3).

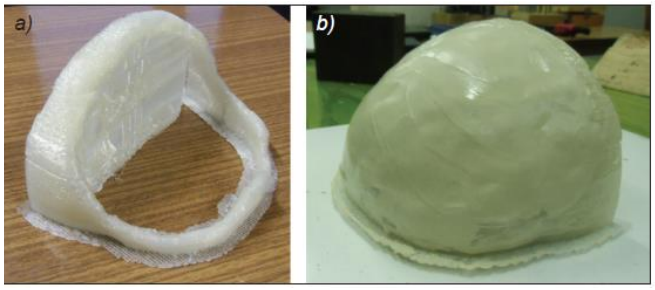

Fig. 3. Model of a) skull bone fragment, b) defect filling

The next step in the prosthesis designing process, was the digitisation the filling model. It was made with structured light scanning (Fig. 4).

Fig. 4. Digitisation the filling model

The digitised model of the filling was sent to the computer modelling system, which fitted it to the virtual model of the patient's skull (Fig. 5).

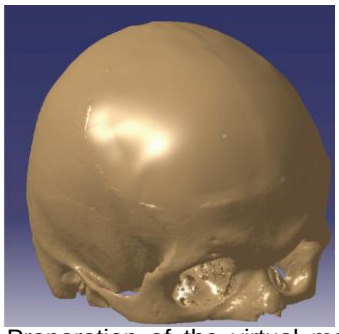

Fig. 5. Defect filling model

Preparation of the virtual model of the skull bone filling initiated the designing process of the prosthesis and of the matrix for its shaping. The form was made of aluminium alloy using three-axis milling technology (Fig. 6).

Fig. 6. Form for shaping the prosthesis

The form was used by the manufacturer of medical devices, the company Tricomed SA in Lodz (Poland), in order to form a cranial prosthesis shown in Fig. 7. The prosthesis was implanted in the patient on the neurosurgical ward of St. Raphael Hospital in Cracow (Poland).

Fig. 7. Prosthesis for cranioplasty

Summary

In the analysed example the reconstructive engineering methods and rapid prototyping were applied:

- for digitisation of the patient's skull: CT along with image analysis methods, which allowed for the detection of the skull bone edge, and then to prepare a virtual model of the patient's skull;
- for spatial print: FDM technology working on an "additive" principle by laying down molten plastic material in layers (in this case PLA polymer - polylactide), which allowed to prepare a model of the skull defect; then it was manually filled with plastic. The choice of modelling method was conditioned by the fact that in such a large skull defect the design of computer modelling did not provide the desired aesthetic effect.
- for digitisation of the defect filling model: structured light scanning. Scan results – a virtual model of the filling – it was fitted to the virtual model of the skull, and then the prosthesis shape and the matrix for its forming was prepared.

These methods allowed to prepare and implant a cranial prosthesis. It filled the bone loss and gave a very good aesthetic effect.

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