MANUFACTURING COMPLEX ANATOMICAL MODELS IN AN INTEGRATED APPROACH CT/CAD/CAM FROM RIGID POLYURETHANE FOAM. A CASE STUDY

Diana POPESCU[1], Dorel ANANIA[2], Cătălin AMZA[3], Gheorghe AMZA[4], Dumitru Titi CICIC[5]

Scopul principal al studiului de caz prezentat în această lucrare este acela de a evalua posibilitatea fabricării prin frezare CNC în 3 axe a modelelor medicale, în condiții de precizie ridicată şi preț scăzut, pornind de la date de scanare computer tomograf (CT), într-o abordare integrată CT/CAD/CAM (Mimics 10 – CATIA V5). Aceste modele medicale pot fi folosite pentru vizualizare şi comunicare (situații în care nu precizia, ci costul este factorul major), pentru activități de instruire în inserarea şuruburilor pediculare în vertebrele lombare şi evaluarea preciziei de inserare a acestora, ca şi pentru testarea design-ului ghidajelor sau al instrumentelor chirurgicale.

The main goal of the case study presented in the current paper is to assess the possibility of manufacturing accurate and cheap medical models from rigid polyurethane foam starting from CT (computer tomography) scan data, by following an integrated approach CT/CAD/CAM (Mimics 10 – CATIA V5). These medical models can be used for visualization, communication and teaching purposes (where not the accuracy, but the cost is a major issue), for surgical training activities such as practicing and evaluating the insertion precision of a pedicle screw in a lumbar vertebra, as well as for testing different designs for surgical drill guide or surgical tools.

Keywords: medical modelling, CT scan data, reverse engineering, CNC milling, polyurethane rigid foam

1. Introduction

The use of advanced computer-aided design (CAD), computer-aided manufacturing (CAM) or Rapid Prototyping techniques (RP) in the medical field

[1] Lecturer, Faculty I.M.S.T., University POLITEHNICA of Bucharest, email: diana@mix.mmi.pub.ro
[2] Lecturer, Faculty I.M.S.T., University POLITEHNICA of Bucharest, email: dorel.anania@yahoo.com
[3] Senior Lecturer, Faculty I.M.S.T., University POLITEHNICA of Bucharest, email: acata1@camis.pub.ro
[4] Professor, I.M.S.T., University POLITEHNICA of Bucharest, email: amza@camis.pub.ro
[5] Lecturer, Faculty I.M.S.T., University POLITEHNICA of Bucharest, email: dumitru_cicic2001@yahoo.com

for designing and manufacturing complex anatomical parts (scaffolds for tissue engineering, 3D solid replicas of different bone structures – skull, knee, vertebra, etc.), implants, prostheses, surgical drills or instruments, is a very actual research subject with recognized importance and impact over a large number of people [1], [2], [3].

Since the appearance and development of Rapid Manufacturing (RM) processes, accurate medical models, implants or prostheses are produced using these technologies. The advantages of such an approach are detailed in the literature [4], [5] a special importance being given to its commercial potential in producing customized biocompatible or bioabsorbable implants [6], [7]. However, in our view, RM processes are an expensive solution if the medical models are produced for visualisation, communication or educational purposes or for design evaluation of surgical templates and instruments. In all these applications, the material used for manufacturing the prototypes is of secondary importance (i.e. properties such as biocompatibility or sterilization capability are not considered) the main objective being to obtain an accurate shape for evaluating a design idea, for explaining or planning a surgery procedure, for testing the suitability of different virtual modelling approaches, or for assessing the errors introduced by thresholding value or reverse engineering process.

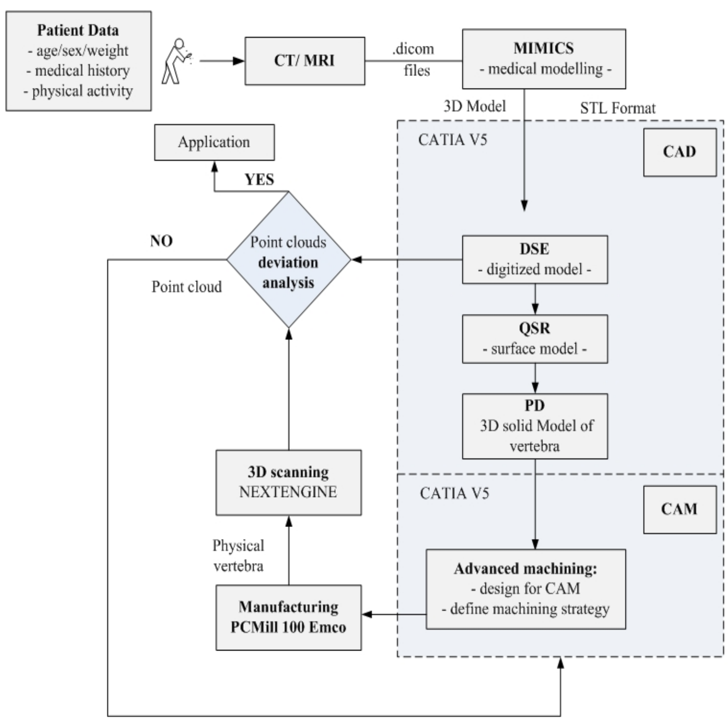

Fig. 1. Methodology for design and manufacturing of a complex anatomical structure

In this context, in the current paper we propose the use of rigid polyurethane foam for manufacturing L3 lumbar vertebra starting from CT data. In order to estimate the accuracy of the milled model, a 3D scanning is performed on the polyurethane vertebra and the point cloud thus obtained is compared with the point cloud imported in CATIA V5 Digitized Shape Editor (DSE) workbench from Mimics 10. This approach allows estimating the errors introduced by the 3D reconstruction and manufacturing the processes presented in figure 1. The physical models will be used in further research as test parts in the development of an intelligent training system based on X-ray for evaluating the insertion precision of pedicle screw in lumbar vertebrae. Furthermore, the analysis made in this case study demonstrate the feasibility of milling polyurethane foam (SikaBlock 300 [8]) for producing complex medical models with good accuracy. The price of the L3 polyurethane vertebra is half the price of the same part manufactured via Fused Deposition Modelling (FDM).

2. Reconstruction of the L3 lumbar vertebra from CT scanning data – 3D modelling

A typical process for obtaining a physical model from CT scan data using Mimics 10 [9] and CATIA V5 (CAD-CAM workbenches) involves the steps presented in figure 1 (PD – Part Design workbench).

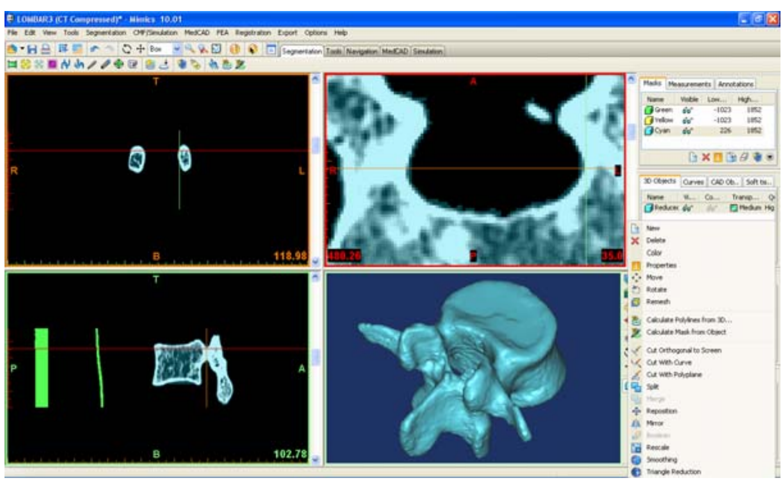

Fig. 2. 3D object creation in Mimics 10

Dicom files from [10] were imported in Mimics 10 software. After applying the usual processing steps (fig.2): creating segmentation masks (thresholding), mask editing, 3D object calculation and remeshing (for creating a more uniform triangles network), the 3D model is exported to CATIA V5 in a

STL file format. The STL file is imported in Digitized Shape Editor and subjected to specific operations for eliminating the model errors (isolated triangles, non-manifold vertices or edges, etc., as it can be seen in fig. 3). The polygonal mesh thus obtained is transformed in a surface model using Quick Surface Reconstruction (QSR) – option Automatic Surfaces (fig.4). Figure 5 depicts a visual representation of the deviation between the point cloud and the surface model.

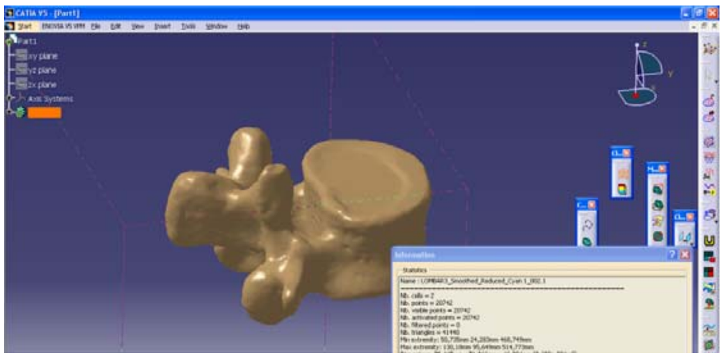

Fig. 3. Import of the point cloud and creation of the mesh

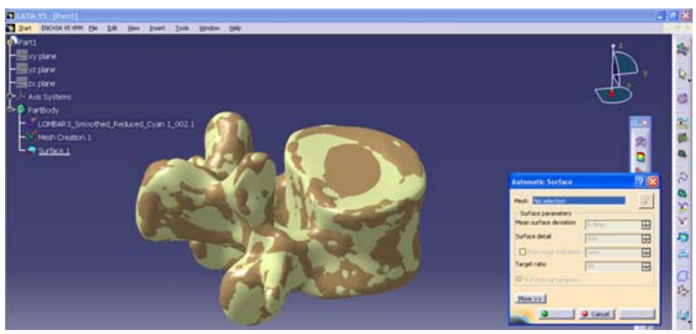

Fig. 4. Surface creation from mesh – Automatic surface option

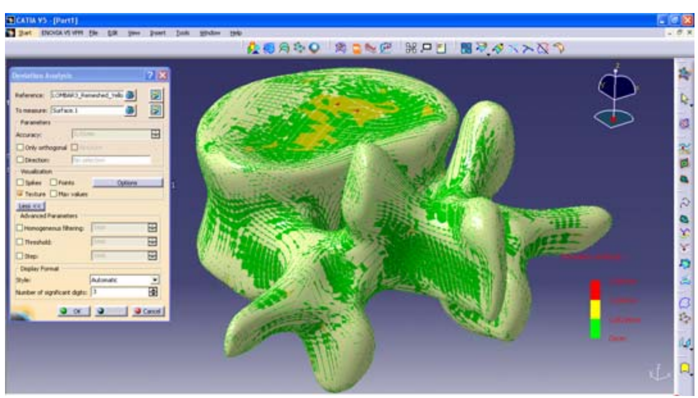

Fig. 5. Deviation analysis between point cloud and generated surface of the vertebra

3. CNC milling process for manufacturing lumbar vertebra

The model of the lumbar vertebra is manufactured by CNC milling on PC Mill 100 EMCO machine. It is a 3 axis CNC milling machine tool with the following characteristics: dimension of the machine tool: Lxlxh (mm x mm x mm) – 1730x875x1892; the workspace: XxYxZ (mm x mm x mm) -185x100x100; the main spindle speed – 60-5000rot/min; feedrate 0-3000mm/min. The machining precision is 0.02mm. The material for the model is SikaBlock M300 with the following characteristics: density: 240kg/m³; compressive strength: 4MPa, flexural strength: 5MPa, modulus of elasticity: 150MPa.

The first step was to create a 3D CAM model in order to generate a complex NC program for vertebra surfaces. A 3 axis milling CAM process was generated in order to obtain the NC program for the part shown in figure 4. To create a CAM model, the 3D design of the pieces has to be modified according to the manufacturing process demands. Some additional contours, plane and point must be created in order to define all the CAM parameters (fig.6). On this model, some tool trajectories were generated and optimised for roughing and finishing operation (fig.7). After CAM to optimisation, several different NC programs were generated. According with the complexity of the surfaces which have to be machined, the NC files have around 54000 lines for linear and circular trajectories. These NC files were uploaded on the PC MILL100 EMCO machine tool. The total machining time estimated in CATIA was 3.2 hours and the real machining time measured on the machine tool was 3.5 hours. A step of the machining on EMCO is presented in figure 8. The lumbar model made in SikaBlock M300 obtained on EMCO PC MILL100 based on CAM model in CATIA V5 R18 is presented in figure 9.

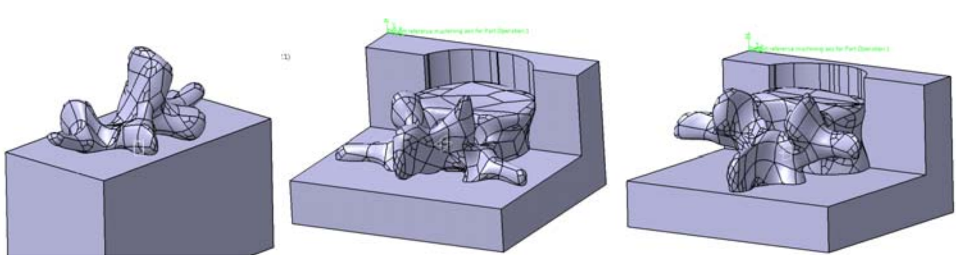

Fig. 6. 3D design of the model for CAM

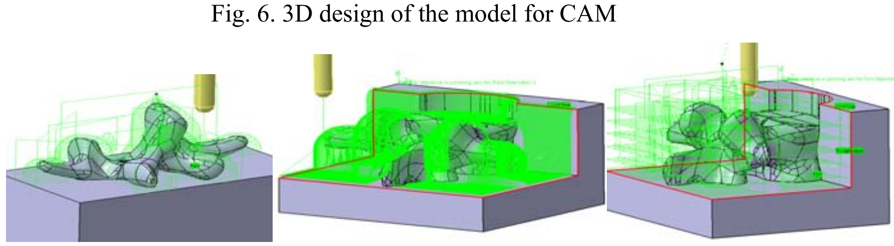

Fig. 7. Tool trajectories optimised in CATIA

Fig. 8. Machining the vertebra on EMCO PC MILL 100


Fig. 9. The obtained model of lumbar vertebra

4. 3D scanning of the lumbar physical model to evaluate the accuracy of the milling process

The evaluation of the accuracy of the vertebra model is made by 3D scanning of the model and by comparing to the point cloud from CV5 Digitized Shape Editor benchmark. The 3D scanner used is NextEngine [13].

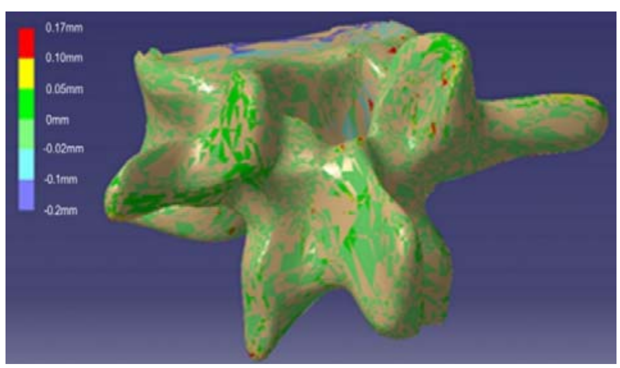

Fig. 10. Deviation analysis

The surface deviation between the physical model and the virtual model of the vertebra was in the range of [-0.2, +0.17] mm (fig.10). The scanning process was made for two different orientations of the vertebra and the point clouds thus obtained were merged and the resulted mesh was compared with the point cloud from Mimics 10.

5. Conclusions

The methodology of manufacturing accurate and cheap anatomical models from individual CT data is validated for a lumbar vertebra (L3) from polyurethane rigid foam. These models are manufactured on a milling machine and the accuracy of the physical prototype was assessed by comparing the point cloud data from 3D scanning and the point cloud data imported in CATIA V5 from Mimics 10.

The vertebra physical models are used as test parts in the intelligent X-ray training system which will be developed in further research. In order to position and orient the test part in the X-ray system, the model is manufactured by partially keeping the vertebral body in the material block with planar faces.

6. Further research

Further research implies the development of an intelligent training system based on X-ray for evaluating the insertion precision of pedicle screw in lumbar vertebra. Once the physical lumbar model is manufactured, one can use such a model for instructional activities: the insertion of pedicle screw and the automated evaluation of the insertion precision, as well as for the testing different designs for surgical drill guides.

In the case of pedicle screw insertion, it implies taking an X-ray image of the manufactured lumbar vertebra. This image is then subsequently automatically analysed by a computer algorithm and the insertion precision is measured.

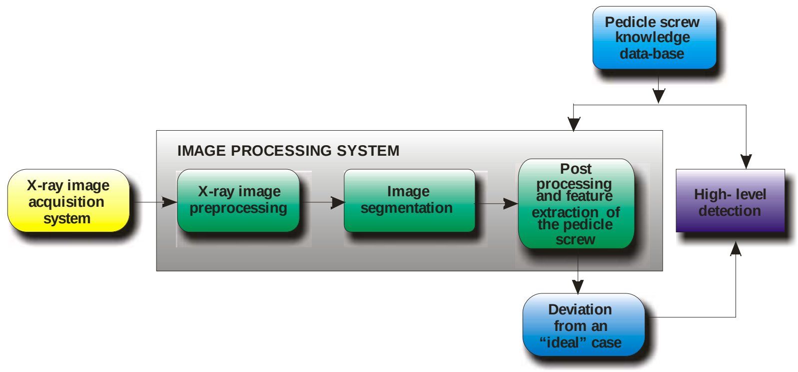

Fig. 11. Image processing system

The proposed system, an implementation of a general pattern recognition (PR) system, comprises the following units or systems (fig.11): image acquisition system, image pre-processing system, image segmentation system based on a Hopfield Neural Network and high level detection system [14].

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