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COMPUTER-AIDED TECHNIQUE FOR DETERMINING SPINAL PEDICLE SCREW SIZE AND OPTIMAL INSERTION TRAJECTORY

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Abstract: *The paper presents a computer-aided methodology for generating the best trajectory for pedicular screw insertion in L3 vertebra and for determinining the pedicle diameter, hence the screw size. This information is important as first step in designing a drill template which can be used during the surgical procedures for an accurate positioning of the pedicular screw. The original aspect of the paper is related to the use of a commercial 3D CAD system for determining the pedicular insertion trajectory and for calculating the pedicle isthmus.*
Key words: *pedicle screw, drill guide, Rapid Prototyping, spinous process*

1. INTRODUCTION

The insertion of pedicular screw, used for fixation and stabilization of the spine and for enhancing the long-term biological fusion by holding bony structures together, poses specific problems to spine surgeons mainly due to the difficulty of accurately inserting the screw without damaging the pedicle.

The medical procedure of pedicular screws insertion, the choice of screws dimensions (diameter and length) and optimal trajectory are based on different aspects such as bone quality, pedicle anatomy and orientation (fig.1.a). A safe insertion of the pedicle screw means to enter from the lateral margin of the pedicle and exits to its medial wall [Foley, K.T. &Gupta, S.K., 2002] (fig.1.b), along the pedicle axis. Currently, C-arm fluoroscopy is used in the operative phase for inspecting and verifying the preliminary pedicle entry sites. Using CT scans the axial length and diameter of the pedicle are determined for choosing the pedicle screw. Also, information about the sagittal and axial angulations of individual pedicles are needed for determining the trajectory of the tap, the surgeon modifying the angle such as its virtual extension is within the pedicle. The screw length is determined by lateral fluoroscopy, considering that the screw should be inserted about 80% in the vertebral body [Rodrigues, L.M.R, et al. 2008]. However, this approach requires a lot of experience and skills from the surgeon, a possible misplacement could cause damage of the spinal nerve.

In order to increase the safety insertion, the literature and practice in the field consider several possible approaches such as fluoroscopy based Computer Assisted Surgery or CT. All these techniques are using intraoperative CT scans took during the operation for observing the position of the drill relative to the spine and thus correcting the drill trajectory.

Another possible approach is to design and manufacture a drill guide based on the individual patient anatomy, considering the following procedure: in a pre-operative phase the patient is scanned, the 3D model of the spine is obtained using a medical modeling software, the drill guide is design to fit to the anatomical specifications of the patient and then the template is manufactured via a Rapid Prototyping (RP) process.

Moreover, the diameter of the pedicle screw and its length can be chosen based on the smallest cross section of the pedicle (isthmus) available from the 3D model of the vertebra, as will be detailed further.

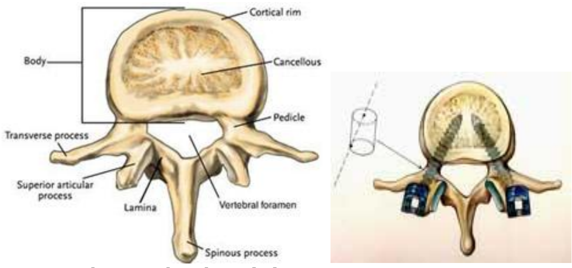

Fig.1. a. Lumbar vertebra, b. pedicle insertion

The current paper presents an ongoing interdisciplinary research project, which involves specialists from medicine (spinal surgeons), design (for medical modelling of CT data and guide design), manufacturing (for evaluating different RP techniques, setting specific parameters, etc.) and biomaterials fields. Our approach is based on the use of a RP drill template, which is designed having the spinous process as reference, for ensuring the right position and orientation of the drill guide. Although the spinous process is well defined as 3D coordinates and vertebral pedicles neighbourhood, the problem of determining the reference points of the guiding system and the minimal number of supporting points is very important for ensuring a high precision of the screw implant. The drill guide contains all the geometrical features necessary for imposing a correct insertion position, and the design of each composing element is based on the data obtained by CT data. Such of device is not currently available in Romanian hospitals, for pedicular screws insertion only few guiding systems being used, most of the time this procedure requiring X-ray control during the insertion.

2. SPINAL PEDICLE SCREW SIZE AND OPTIMAL TRAJECTORY DETERMINATION

The first stage of the project, presented in this paper, consists in obtaining the 3D model of a vertebra and then determining the optimal trajectory and the right screw size. The optimal trajectory is a line, along the pedicle axis, that contains the center of isthmus and it is perpendicular to the isthmus plane. This way, the drill angles materialized on the guide can be accurately transferred to the patient for exact placement of the pedicle screws. The design of the drill guide, as well as issues regarding the material, manufacturing process and clinical testing will be discussed in further articles.

2.1. Survey of the literature in the field

Previous researches referring to pedicle screw drill templates use as references the middle of the posterior surface of the spinous process at its thickest and the most posterior boundary of the spinal canal for determining the coordinates for assessing the accuracy of implantation [Porada, et al., 2001]. For increasing stability, supports are designed to fit also transverse process in a surface-to-surface approach or using different support structures which are in contact with the posterior surface of lamina.

[Porada, et al., 2001] and [Yoo, T.S., 2003] presents two methodologies which use SurgiCase, respectively a dedicated software based on OpenGL, for determining the screw insertion trajectory and screw size, considering the patient CT scan data.

[Lu, S., 2009] uses patient CT data to build a 3D model and then projects the pedicle model on lamina and vertebra planes. First, the smaller diameter of the pedicle projection is determined for establishing the maximum dimension of the screw, and then the circle is projected between the lamina and vertebral body for obtaining the screw trajectory.

[Pacheco, H.O., 2007] presents a patented approach for improving pedicle screw placement in which the optimal insertion trajectory is computed by linear least squares method.

Our approach will use CATIA V5 for determining the pedicle axis and then the pedicle isthmus, the same software being used in further research for designing the drill template.

2.2. 3D modeling – reconstruction of the of a spine vertebra

DICOM files from the spiral three-dimensional CT scanning of the lumbar vertebra L3 [Van Sint Jan, S., 1998] were used for reconstructing L3 vertebra in Mimics software. The 3D model was generated and then exported to CATIA V5 (CV5). Workbenches such as Digitized Shape Editor and Quick Surface Reconstruction were used to obtain the CATPart model from the STL file exported by Mimics. CV5 surface model of the L3 vertebra and the extracted surfaces which delimit the pedicle are presented in figure 3. The input from the user consists first in extracting the surfaces which form the pedicle shape. These surfaces are then sectioned with successive planes, parallel with the coronal plane. Each section has an almost oval shape, the centers of ovals are determined and then the axis line, which is approximately equally distanced of all the center points (mean line), is generated. The size of the screw is chosen considering the smaller diameter of the pedicle (fig.4) based on the sectioned previous determined, as the pedicle thickness and cross section varies along its length.

3. CONCLUSIONS AND FURTHER RESEARCH

The guiding system proposed is based on specific information about the patient's anatomy, imposing an individual solution for each clinical case, which recommends RP processes for manufacturing the guide. The guide will be held by the assistant surgeon or by the surgeon in the same orientation as the patient in the line of sight, this allowing minimally invasive approach with instrumentation in situ, reducing intra-operative X-ray and facilitating accurate screw placement.

The current paper presents the first two steps from the following methodology to design and manufacture a guiding system for inserting pedicle screws:

1. Planning the screws trajectories and determining the pedicle screw size based on the patient individual data
2. Establishing reference points/elements for guide positioning
3. Determining positioning constraints imposed by surgeon
4. Designing the drill guide
5. Rapid manufacturing of the guide
6. CT post-op validation for assessing the implant accuracy.

Further research will also consider the programming capabilities of CV5 software to automatically generate the screw insertion trajectory which approximately passes to the middle of the pedicle.

ACKNOWLEDGEMENTS

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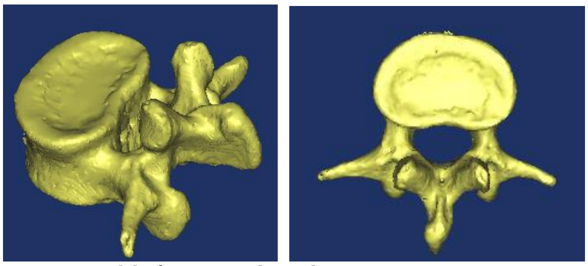

Fig.2. 3D model of L3 cervical vertebra – MIMICS 10.01

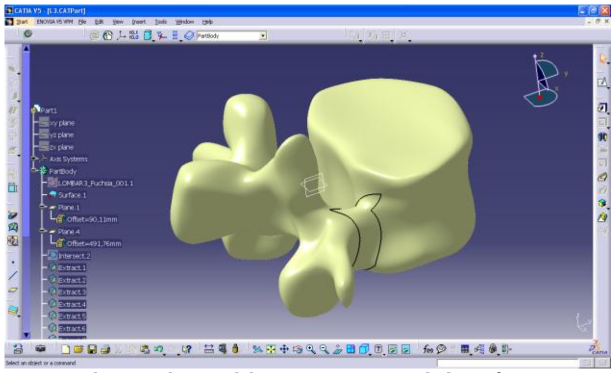

Fig.3. Lumbar vertebra model in CATIA V5 – pedicle surfaces

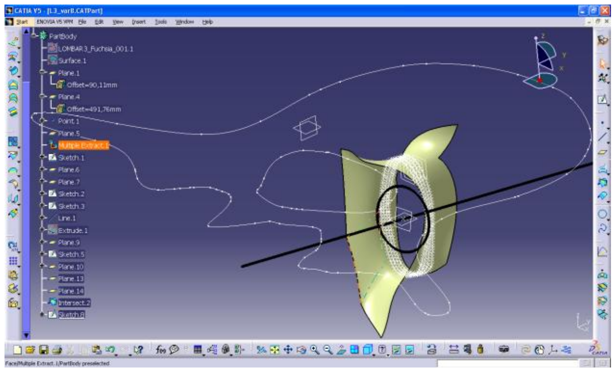

Fig.4. Pedicle axis and isthmus

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