"Quantitative accuracy assessment of pedicle screw insertion in spine surgery: initial study using Artis Zeego II intraoperative imaging robotic system"

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ABSTRACT

Introduction In spine surgery, intraoperative computed tomography (CT) and fluoroscopy-based navigation systems have demonstrated significant improvements in accuracy and safety of pedicle screw placement when compared to freehand technique [1]. Evaluation of pedicle screw placement is assessed in terms of pedicle breaches typically detected through visual inspection of the CT and fluoroscopic images [2,3]. However, it is not yet possible to use intraoperative images to quantitatively assess the accuracy of pedicle screw insertion by comparing with a predefined insertion planning. This study aims to demonstrate the feasibility to quantitatively assess the accuracy of pedicle screw insertion using intraoperative fluoroscopic images and compare the achieved screw placement with a predefined insertion planning. Materials and methods The study was conducted using a synthetic model of a lumbar spine. The testbed consisted of a clamping device and a reference block (Figure 1a). The clampin...

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Quantitative accuracy assessment of pedicle screw insertion in spine surgery: initial study using Artis Zeego II intraoperative imaging robotic system

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Introduction

In spine surgery, intraoperative computed tomography (CT) and fluoroscopy-based navigation systems have demonstrated significant improvements in accuracy and safety of pedicle screw placement when compared to freehand technique [1]. Evaluation of pedicle screw placement is assessed in terms of pedicle breaches typically detected through visual inspection of the CT and fluoroscopic images [2,3]. However, it is not yet possible to use intraoperative images to quantitatively assess the accuracy of pedicle screw insertion by comparing with a predefined insertion planning.

This study aims to demonstrate the feasibility to quantitatively assess the accuracy of pedicle screw insertion using intraoperative fluoroscopic images and compare the achieved screw placement with a predefined insertion planning.

Materials and methods

The study was conducted using a synthetic model of a lumbar spine. The testbed consisted of a clamping device and a reference block (Figure 1a). The clamping device consisted of five template supports, produced by additive manufacturing, to rigidly fix the lumbar spine by means of fastening screws. A global reference frame (R0) was defined fixed to the reference block. The test bed was scanned using a CT-scanner and a virtual 3D CT model of the test bed was reconstructed for the planning of the pedicle screw insertion. The insertion planning consisted of ten sets of desired entry point, desired orientation axis and desired target point, defining the ten desired placement of screws in the pedicles of the five lumbar vertebrae. The insertion planning was recorded by storing pedicle screws coordinates (desired entry and target points and orientation axis) expressed in the reference frame R0. One operator freehandly performed the insertion of the pedicle screws (Figure 1b). The operator received a print with frontal, axial and lateral views for each pedicle screw and was instructed to respect the insertion planning as accurately as possible.

Three parameters were used to evaluate the insertion accuracy. The error in the entry point (mm) was computed as the linear difference between desired and achieved entry points. The error in the orientation axis (°) was computed as the angular difference between desired and achieved insertion axes. The error in the target point (mm) was computed as the linear difference between desired and achieved target points.

Fluoroscopic images of the test bed with the inserted screws have been acquired using the new Siemens Artis Zeego II intraoperative imaging robotic system (Figure 1c). The set of fluoroscopic images was reconstructed in 3D and the inserted screws were extracted using ITK-
Snap segmentation software. Then, each 3D model of the inserted screws was loaded in Paraview visualization and computation software. For each screw, one operator measured numerically the coordinates of the achieved entry point, orientation axis and target point in the reference frame R0, and computed the errors in the desired pedicle screw insertion.

The errors in the desired pedicle screw insertion computed numerically with the intraoperative fluoroscopic images were compared to reference mechanical measurements. The inserted screws were digitized with a precision of 1 µm using a Microscribe coordinate measuring machine (Figure 1d). The initial inserted-screw dataset consisted of measurement points expressed in the reference frame R0. Each measurement dataset was fitted to a least-square axis following guidelines for metrology and standards in mechanical engineering. The errors in the desired entry point, orientation axis and target point were then calculated using Matlab numerical computation software (Figure 1e).

Results

Of the ten inserted screws, visual inspection of the synthetic lumbar spine and visual inspection of the intraoperative fluoroscopic images did not reveal any pedicle breach.

The errors in the desired entry point, orientation axis and target point of the inserted screws, are presented in Table I.

The difference between the errors computed numerically with the intraoperative fluoroscopic images and mechanically with the coordinate measuring machine, averaged -0.8 mm for the entry points, -0.1° for the orientation axes and -0.3 mm for the target points of the inserted screws. The maximum differences were found in the right pedicle of L5 vertebra (-3.3 mm, 1.8° and 0.9 mm for entry point, orientation axis and target point respectively).

Discussion

This study showed the feasibility to compute the achieved errors on a predefined pedicle screw insertion planning using intraoperative fluoroscopic images with a very good accuracy when compared to reference mechanical measurements. The results observed here are currently undergoing clinical validation with complementary in vivo studies. Once completed, the quantitative accuracy measurement methodology using intraoperative fluoroscopic images that has been developed for the present study may be useful to investigate further pedicle screw insertion performed with the aid of several assistance technologies such as navigation and robotic systems.

References

Table I - Errors in the predefined insertion planning computed numerically with the intraoperative fluoroscopic images (image-based measurements) and mechanically with a coordinate measuring machine (reference measurements).

<table>
<thead>
<tr>
<th>Screw (vertebra, pedicle)</th>
<th>Computed errors on desired entry point (mm)</th>
<th>Computed errors on desired orientation (°)</th>
<th>Computed errors on desired target point (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>image-based</td>
<td>reference</td>
<td>difference</td>
</tr>
<tr>
<td>1 (L1, right)</td>
<td>1.6</td>
<td>1.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>2 (L1, left)</td>
<td>1.4</td>
<td>1.5</td>
<td>-0.1</td>
</tr>
<tr>
<td>3 (L2, right)</td>
<td>1.7</td>
<td>2.2</td>
<td>-0.5</td>
</tr>
<tr>
<td>4 (L2, left)</td>
<td>1.2</td>
<td>2.5</td>
<td>-1.3</td>
</tr>
<tr>
<td>5 (L3, right)</td>
<td>4.5</td>
<td>4.1</td>
<td>0.4</td>
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<tr>
<td>6 (L3, left)</td>
<td>3.3</td>
<td>2.8</td>
<td>0.5</td>
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<tr>
<td>7 (L4, right)</td>
<td>3.6</td>
<td>3.8</td>
<td>-0.2</td>
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<td>8 (L4, left)</td>
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<td>2.6</td>
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<td>9 (L5, right)</td>
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<tr>
<td>10 (L5, left)</td>
<td>2.8</td>
<td>5.8</td>
<td>-3.0</td>
</tr>
</tbody>
</table>

Figure 1 – (a) 3D virtual model of the test bed (lumbar spine and reference block) and planning of the pedicle screw insertion (blue and yellow) in ParaView visualization software. (b) Test bed and the inserted pedicle screws (freelyhand performed). (c) Accuracy measurements using intraoperative fluoroscopic images from Zeego interventional imaging robotic system. (d) Reference mechanical measurements with Microscribe coordinate measuring machine. (e) Errors in the desired insertion planning (entry and target points and orientation axis) computed in Matlab computation software for comparison between image-based and reference mechanical measurements.