A Comparison of 2D and 3D Navigation

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Introduction

Navigation methods that use traditional orthogonal views are limited since three-dimensional information is lost to two-dimensional displays. We performed a user study with thirteen surgeons and residents with an image-guided system for pedicle screw placement that used standard orthographic navigation and a 3D view method.

The placement of pedicle screws is a technically demanding procedure owing to the accuracy and precision required for safe placement of hardware in an anatomically complex structure that is in close proximity to sensitive neural, vascular and visceral elements. As such, we chose pedicle screw placement to demonstrate our navigation methods, even though the functional benefit of computer-assisted navigation for this procedure has been questioned [1].

Navigation Techniques

We developed a navigation system that used two navigation paradigms. In the first method, traditional orthographic views were used (see Figure 1). The top left quadrant showed the 3D patient model. The remaining quadrants showed the coronal, axial, and sagittal views of a CT volume. The second navigation method used multiple coronal slices for navigation (see Figure 2). The first column showed the 3D model followed by the axial and sagittal views. The next three columns showed coronal slice at 5 mm intervals from the entry point of the planned path to the vertebral body [2]. The expectation was that the surgeon would use the coronal views to align the surgical instrument, much like aligning a target in a video game. The axial and sagittal views would be used to judge the depth of the instrument.

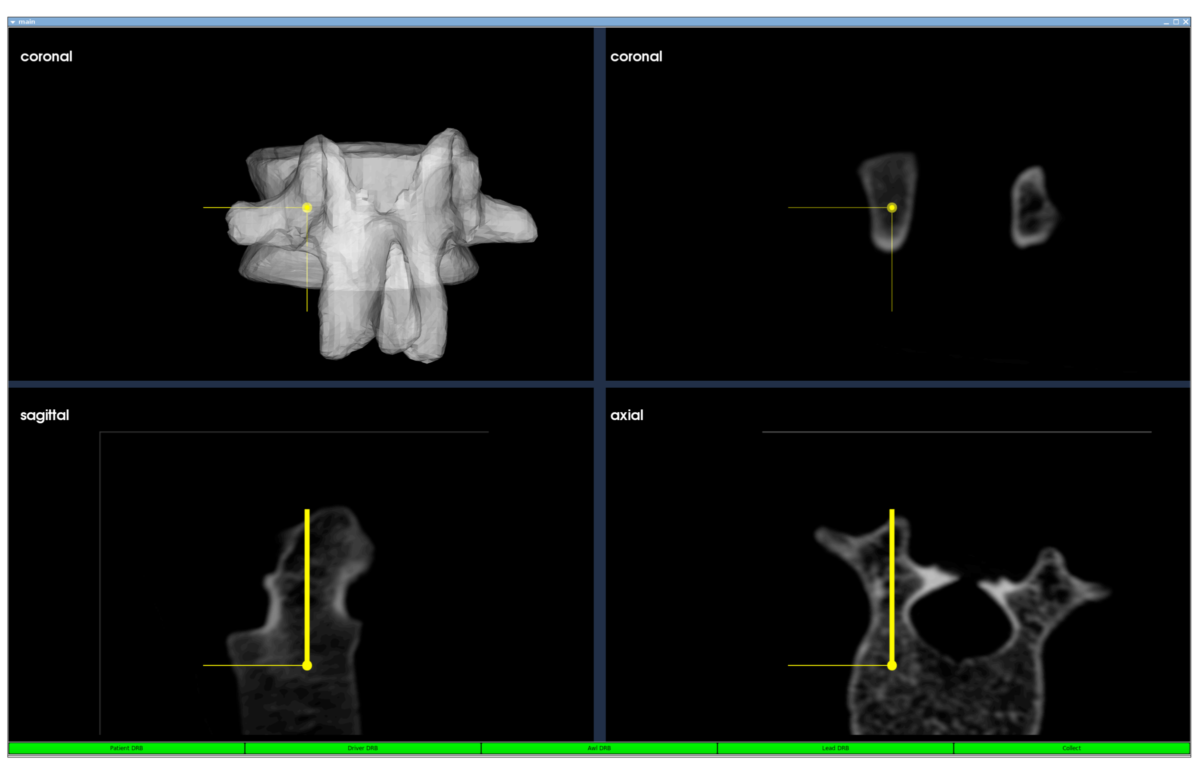

Figure 1: The 2D navigation method used in the study. The top left quadrant shows the 3D patient-specific model. The remaining quadrants show coronal, axial, and sagittal slices taken from a resampled CT volume and aligned with the planned path in yellow. The green buttons indicate that all of the surgical instruments are currently visible to the tracking system.

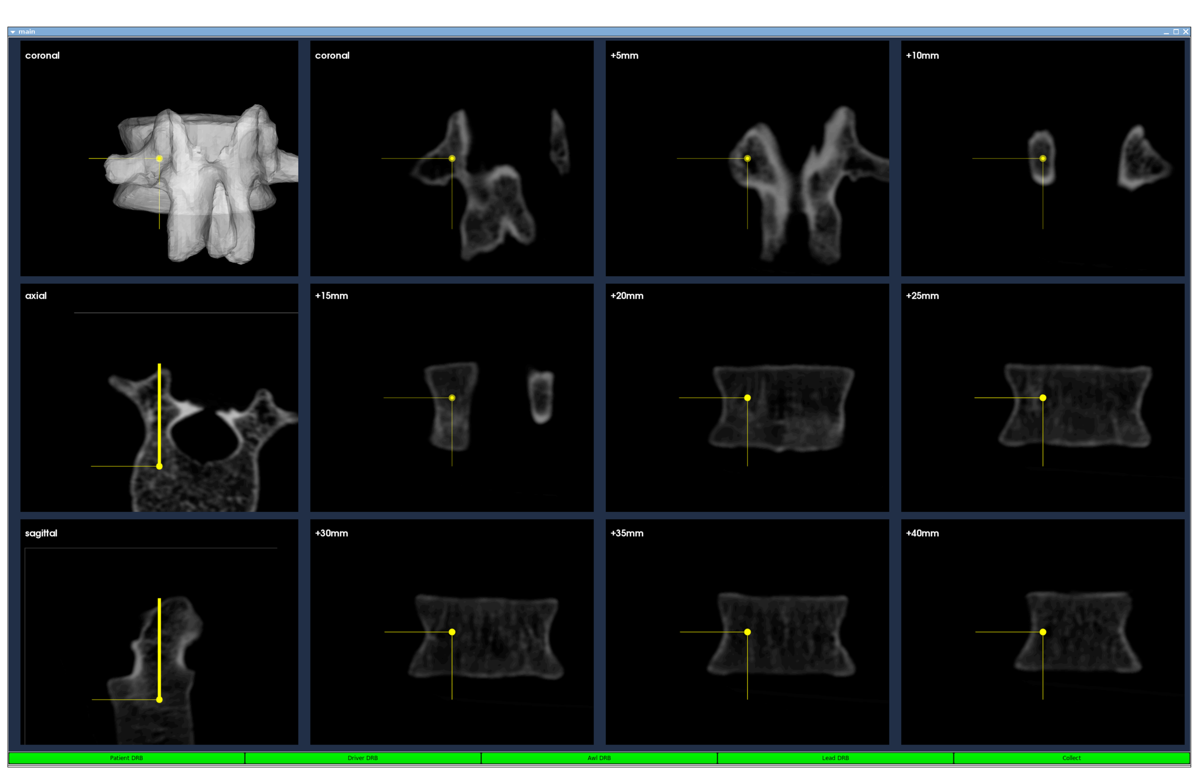

Figure 2: The 3D navigation method used in the study. The first column showed the 3D model followed by the axial and sagittal views. The remaining columns showed coronal slices at 5 mm intervals from the entry of the planned path to the vertebral body.

User Study Design

A Polaris optical tracking system (NDI, Waterloo, ON) tracked the position and orientation of the tools. Three tools were used: a regular Robertson (square tipped) screwdriver, an Expedium Spine System bone awl (DePuy Spine, Inc. Raynham, Massachusetts, USA), and an Expedium Spine System bone tap. Passive targets were a fixed to each tool. Plastic bone models were cast specifically for the study (Figure 3). Mounts were manufactured for fixating the bone to a board. The mount and plastic models were manufactured such that the models could be inserted and removed from the mount with ease and precision; no intermediate registration of the physical model to the CT model was required. A fourth passive target was attached to the board for tracking the bone model. A cloth was used to mimic soft tissue, to obscure the vertebral body of the bone model from view. The apparatus is shown in Figure 4.

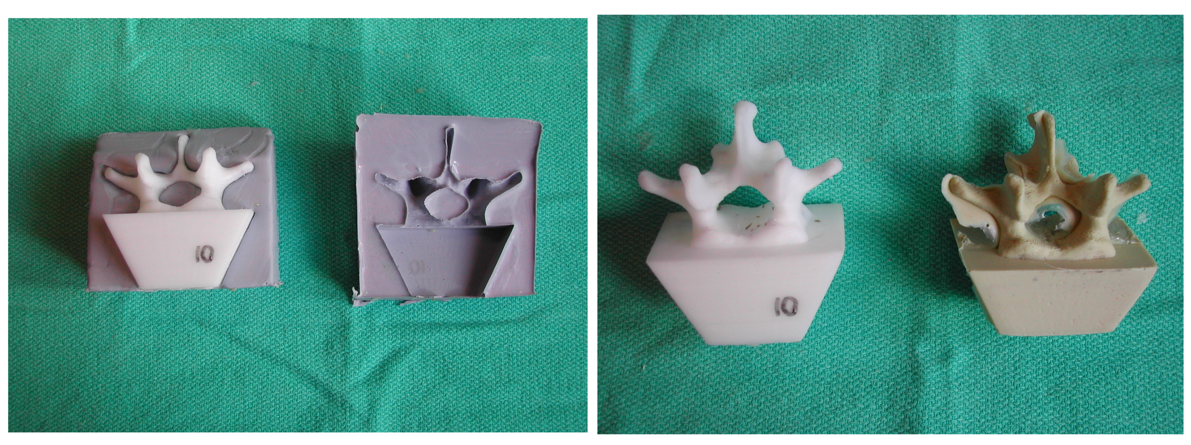

Figure 3: Steps in a custom model casting. (1) The two-part mould and the template. (2) The original prototyped model and the final cast model.

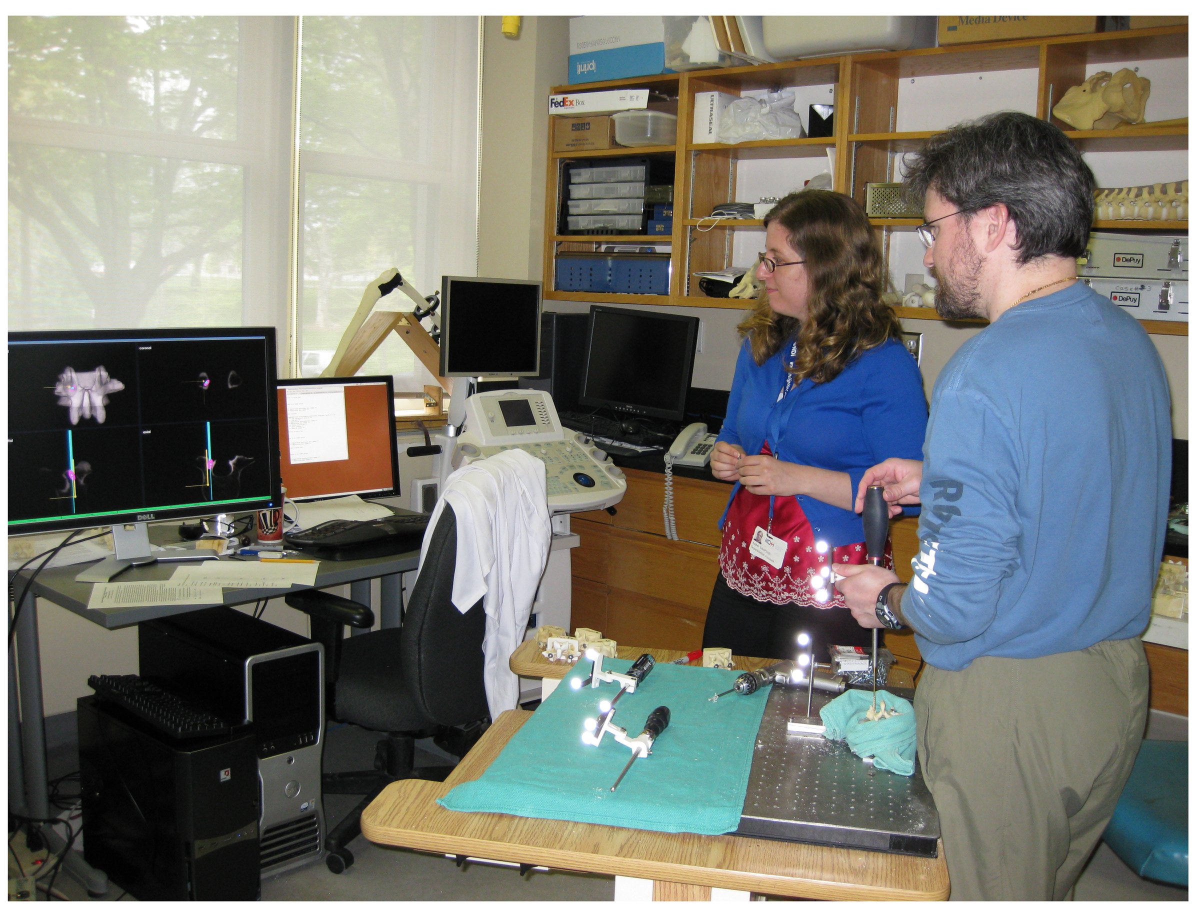

Figure 4: Experiment setup used in navigation study. The subject was using the navigation system to guide a tool. The optical tracking system was located just out of the camera frame, to the left.

Four orthopaedic surgeons, four senior residents and fellows, and five junior residents participated in the study. Each subject inserted eight pedicle screws for each condition for a total of 104 screws. The order of the conditions was randomized over all subjects.

Surgical performance was measured based on the superior rotation deviation of the final screw location from the preoperative planned path, the external rotation deviation of the final screw location from the planned path, the size of any medial breach of the pedicle (impingement), and the time it took for the subject to insert one screw.

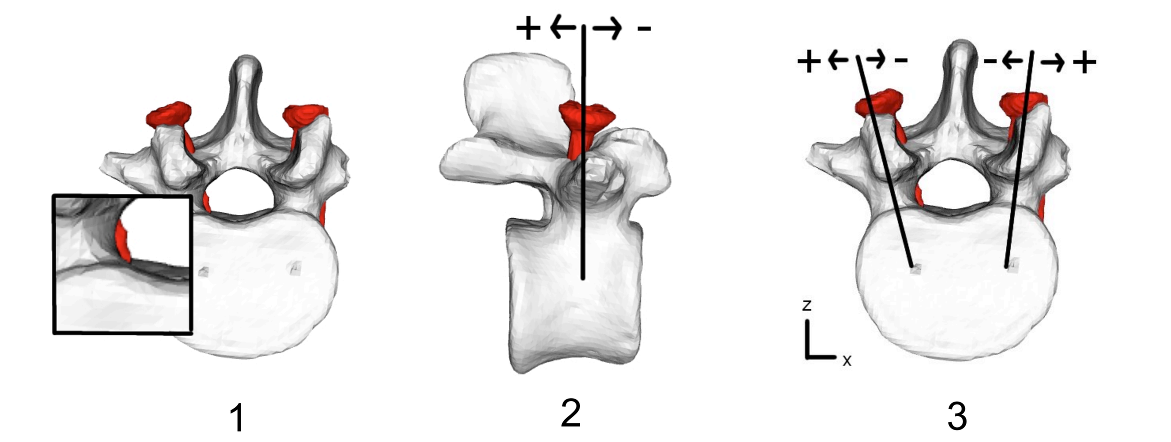

Figure 5: Measurements in study. (1) Medial breaching of the pedicle. This impingement was measured by an independent observer. The size was taken to be the distance from the bone to the widest point of impingement. The discrepancy between the planned path and the final screw location was measured using (2) external and (3) superior rotation error measurements. The black line represents the planned path. Negative external rotation indicates lateral breaching of the pedicle and positive external rotation indicates medial breaching.

Results

Tukey post hoc tests showed a significant effect of navigation method with respect to time ($p<0.01$). The analysis did not show significant effects with respect to superior rotation error ($p=0.976$), external rotation error ($p=0.997$), and impingement ($p=0.933$).

Equivalence tests showed that the theoretical difference was within a clinically unimportant interval for superior rotation error (delta = 2 degrees, $p<0.01$), external rotation error (delta = 2 degrees, $p<0.01$), and impingement (delta = 2 mm, $p<0.01$).

Table 1 lists the means for all measurements by navigation type.

Table 1: Reported means for all measurements for 2D and 3D navigation methods.

Results	2D	3D
Sup. Rot. Err. [deg]	1.5 ± 0.6	2.0 ± 0.5
Ext. Rot. Err [deg]	−2.1 ± 0.6	−1.8 ± 0.6
Impingement [mm]	0.1 ± 0.0	0.2 ± 0.1
Time [s]	192 ± 10	156 ± 6

Discussion and Conclusions

The current study supports the use of both traditional orthographic views and multiple coronal slices as safe navigation methods for the insertion for pedicle screws by surgical trainees and experienced surgeons.

Secondly, the study suggests that the novel multiple coronal slices navigation method allows for faster insertion of pedicle screws. This may have the benefit of a reduction in operative time, however it is an area that requires further investigation.

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