

# Fully Automated Determination of Pedicle Screw Accuracy and Pedicle Breach Utilizing Computer Vision and Cartesian Coordinate System

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**INTRODUCTION:** Historically, the accuracy of pedicle screw placement has relied on computed tomography (CT) scans to assess the accuracy of positioning of the screws as well as the position of the screw relative to the medial wall of the pedicle. More recently, a technique involving the overlay of preoperative pedicle screw trajectories onto postoperative imaging has enabled a more precise measurement of the deviation in pedicle screw placement compared to the initial surgical plan. Nonetheless, these approaches still necessitate manual alignment of preoperative and postoperative CT scans, along with manual measurement of pedicle screw breach along the medial wall. This research endeavors to introduce an automated system designed to determine the accuracy of pedicle screw placement relative to the preoperative plan. Moreover, the study aims to develop a fully automated method for the detection and measurement of pedicle screw breach after placement.

**METHODS:** This IRB-approved study utilized three cadaveric specimens. Preoperative screw planning used generic 3D CT visualization software, with the planned screw tip and tail positions then transferred to the robotic planning environment. The screws were planned transpedicular, with the objective of placing them along the mid-axis of the pedicles in the axial plane. The cadavers underwent bilateral instrumentation using robotic-assisted navigation, spanning T2 to L4 vertebrae using 4.5mm pedicle screws with lengths from 25 to 40 mm. Two surgeons proficient in robotic workflow performed the instrumentation. A postoperative CT scan of the entire vertebral column was conducted. Using an automated segmentation tool, each cadaver's preoperative CT scan was labeled, and computer vision techniques were employed to automatically align each vertebra with its corresponding post-operative counterpart. Our computer algorithms measured and compared screw positions compared with the preoperative plan, including translations and angulations along all three axes. Calculation of predicted medial pedicle breach was performed, defined as the point where the detected medial wall of the screw intersected with the preoperative medial wall of the pedicle. To evaluate the extent of actual medial screw breach, postoperative laminectomies were conducted at every level, allowing visual assessment to measure and analyze the observed medial screw breach.

**RESULTS SECTION:** Eighty-eight pedicle screws were placed, 30 in one cadaver and 29 in two cadavers, with one screw skipped due to limited arm reach of the robot and one screw skipped due to clamp position blocking bony access. Deviation from planned to placed screw trajectory was determined using a 3D Cartesian coordinate system relative to the inferior end-plate of each vertebra: X = medial(+)/lateral(-), Y = anterior(+)/posterior(-), Z = superior(+)/inferior(-), and is detailed in Table 1. Right-pedicle geometry was mirrored for bilateral comparisons. Mean absolute error (MAE) for the distances of screw tail and tip location in the axial plane was 0.98mm and 0.77mm, and the MAE for the screw tail and tip in the sagittal plane was 0.70mm and 0.56mm. The MAE for summary angular deviation was 1.87 degrees. A total of three screws out of 88 were detected as medial breaches based upon open dissection/laminectomy and visual/manual inspection and measurement. Two of the breaches were less than 2mm and 1 breach was less than 4mm. Using computerized algorithmic analysis of screw position compared with the plan to evaluate for breaches, we had one false negative (incorrectly identified as breach), one false positive (incorrectly labeled as non-breach) and two true positives (correctly identified as breach).

**DISCUSSION:** This study introduces a novel, automated algorithm and tool for defining accuracy of robotically-assisted pedicle screw placement as well as an automated analysis tool for predicting and quantifying pedicle screw breach during pedicle screw placement. The current sample is limited by the small number of screws placed. Future plans include utilization of accuracy and breach data to improve accuracy of pedicle screw placement and planning as well as to provide real-time feedback regarding accuracy and medial breach in the operating room.

**SIGNIFICANCE/CLINICAL RELEVANCE:** This algorithmic computerized workflow establishes a crucial foundation of accuracy and breach data for surgeons and engineers dedicated to enhancing the safety, precision, and dependability of robotically assisted pedicle screw navigation in the operating room. Notably, our accuracy and breach data demonstrates favorable comparison, characterized by lower MAE in the axial and sagittal planes as well as total angular error, when compared with the robotically assisted pedicle screw data available to date.

**Table 1: Accuracy Breakdown**

	Screw Entry X	Screw Entry Y	Screw Entry Z	Screw Tip X	Screw Tip Y	Screw Tip Z	Angular Deviation	Minimum Distance of Screw to Medial Wall (mm)	Screw Diameter (mm)
Mean	-0.42	-1.55	-0.51	-0.10	-1.64	-0.39	1.87	2.13	4.5
Min	-2.63	-4.99	-2.46	-2.47	-5.25	-1.9	0.05	-0.92	4.5
Max	2.96	0.89	0.92	2.05	0.66	0.86	5.20	5.35	4.5
RMSE <sup>1</sup>	1.23	1.93	0.85	0.93	1.96	0.68	2.09	2.47	4.5
MAE <sup>2</sup>	<b>0.98</b>	<b>1.61</b>	<b>0.7</b>	<b>0.77</b>	<b>1.66</b>	<b>0.56</b>	<b>1.87</b>	<b>2.16</b>	<b>4.5</b>
ABS MAX <sup>3</sup>	2.96	4.99	2.46	2.47	5.25	1.9	5.2	5.35	4.5

<sup>1</sup>Root Mean Square Error <sup>2</sup>Mean Absolute Error <sup>3</sup>Absolute Value Max