Measurement of Spinal Pedicle Cannulation and Breach Forces: A Cadaveric Study

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Introduction: The insertion of pedicle screws to stabilize or correct the spine relies on the creation of a probe path with the correct trajectory to prevent breaching the cortical wall. When the cortical wall is breached, there is a much higher rate of complications due to the delicate tissues surrounding the pedicle. Possible complications include neurological damage, pain, or poor mechanical fixation. The more experienced the surgeon, the lower the risk of perforating the cortical wall due to higher accuracy of screw placement (Samdani et.al. 2010). An important reason for this is the learned haptic feel for correct placement. While pedicle screw insertion methods vary, generally a bone probe is used to cannulate a trajectory hole, which is then palpated to ensure the strength of the pedicle. The pedicle is tapped and the screw is then inserted. The difficulty of the procedure lies in discerning the proper insertion point, as well as in creating the trajectory hole.. A training simulator that consists of a physical bone model mimicking the geometry and material properties of human vertebrae, combined with a force feedback probe, can give residents the tactile feedback that an experienced surgeon encounters in a live surgery, while allowing mistakes and learning to occur in a safe environment. The purpose of this study was to investigate the forces and torques encountered while cannulating the pedicle tract in both correct and incorrect cannulations, i.e. breaching medially, laterally or anteriorly. The data collected will be used to further the development of a training simulator that exhibits realistic tactile feedback. Furthermore, the force/torque profile may indicate a pending breach of the cortical wall. An understanding of the range of forces used during cannulation and breaches is also useful for residents. To our knowledge, these forces have only been measured previously for a single specimen and not all DOF were reported (Pommer, 2009).

Methods: Two expert surgeons used a standard lumbar probe (Medtronic), which had been modified to incorporate a 6 DOF load cell (AIT-25 Nano; ATI Industrial Automation, Apex, NC, USA), as well as a plastic handle such that the surgeon would have an adequate grip on the probe (Figure 1). The modified probe measures both the forces and torques in the X, Y, and Z directions. The load cell was calibrated to 125 N and 3 Nm, with overload values of 250 N and 6 Nm. The handle and loadcell were protected with plastic to prevent fluids, from the cadavers as well as cleaning solutions, from reaching the load cell. Six fresh frozen cadavers were used for the study: 3 male, 3 female, average age 78 (range 65 to 92). The surgeons classified the bone as weak to normal. The cadavers were truncated from approximately T11 to the femur, allowing cannulations from T11/T12 to S1 vertebrae. All of the vertebrae available were used, resulting in 80 pedicles tested. The load cell was connected to a data acquisition system (NI USB-6210, National Instruments, Austin, TX, USA), which was then connected via USB to a laptop to acquire the force and torque readouts at 60 Hz. A separate data file was created for each pedicle. The probe was zeroed vertically (probe pointed down), after which the data acquisition was started. The surgeon was instructed to pause between each action within the same pedicle such that the force data would come to zero, thus indicating when an action was finished. Cannulation and breach actions were done in a randomized order, and four actions were attempted on all pedicles; cannulation, lateral, and medial breaches were consistently possible. Breaches of the anterior wall were attempted and subsequently halted due to a shouldering effect of the probe (i.e. the probe dimensions widened such that the resistance to forward movement was farther up on the probe), making breach impossible. The data were evaluated using an ANOVA, with significance defined as p<0.05.

Results: Cannulation axial forces (Fz) averaged 48 N; medial breach averaged 129 N; and lateral breach 86 N (Figure 2a). Due to the large amount of variability amongst specimens, lateral breach forces in some specimens were less than the cannulation forces in other specimens. Anterior breach values were excluded from the analysis due to the small number of successful breaches in this direction. Cannulation values were significantly lower than the breach values in all 6 DOF (p<0.001). The Z direction values were an order of magnitude higher than for the X and Y directions. Medial breach values were only significantly different from lateral breach values in the radial (X and Y) directions. Right/left comparisons did not reveal significant differences. Cannulation percent difference from the mean value averaged approximately 220% across the 6 DOF, whereas medial and lateral breach differences were higher, 420% for medial and 340% for lateral. The average of all 6 DOF measured approximately 150% lower for cannulation than for breaches. The T12 axial and combined radial forces were slightly higher (p≤0.5, 32%) than the lumbar and S1 values, but otherwise the values were reasonably consistent across the vertebrae (Figure 2b).

Discussion: A large range of forces during cannulation and breaching was measured; this is experienced clinically but to our
knowledge has not been previously reported. Furthermore, the absolute and relative force and torque levels were previously unknown. Importantly, lateral breach forces in weak specimens can be less than cannulation forces in specimens with stronger bone. The information gathered in this experiment will be further analyzed to investigate a breach prediction algorithm, as well as to guide the development of a physical training simulator for the placement of pedicle screws. Computed tomography (CT) scans of the specimens will be analyzed to determine the bone properties of the specimens and the trajectories taken. A finite element analysis of the experimental bones, coupled with CT scans of younger patients, will allow our findings to be extended to patients with stronger bone. Effective training simulators will enhance the learning experience outside of the operating room, thus creating a more efficient learning environment which can reduce the risk of complications, reduce surgery time, and enhance patient safety.

**Significance:** Providing residents with training outside the OR will improve patient safety. Measuring pedicle cannulation and breach forces will aid with resident training and with developing a physical simulator system for pedicle screw placement.

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