INTRODUCTION:
Pelvic ring fractures are a relatively common form of orthopaedic trauma. While mechanical stability may be restored by the insertion of iliosacral screws, the proximity of the ideal screw trajectory to the fifth lumbar and first sacral nerve roots (S1), as well as the spinal canal make nervous tissue injury a potential hazard. Fluoroscopy has typically been used to ensure proper screw placement by inserting guide wires followed by the screw. However, this approach may produce less than satisfactory results, as nerve root damage has been reported in as many as 18% of cases. To avoid this surgical complication, Moed et al. [1] introduced a novel technique for determination of the proximity to a neural structure based on the electromyographic (EMG) response evoked by passing a small current between the tip of the drill-bit and a reference electrode.

In order to evoke an EMG response small current pulses (<50 mA, 0.2 ms) delivered at 3 Hz are passed between the tip of the drill-bit and the reference electrode (anode) to stimulate action potential propagation from the nervous tissue towards the muscles they innervate. The threshold current required to induce a 20 mV EMG response serves as a measure of the distance between the tip of the drill bit and the neural structure intraoperatively. The location of the anode relative to the drill bit determines the path that current flows through the body and the potential at any point on the nervous structure. The efficacy of the nerve monitoring technique is clearly dependent on the anode location. However, due to the subtle anatomical intricacies of the nervous structure and the complex effects of a three dimensional anatomical model of varying conductivity, a computational study of anode sites is necessary to determine optimal electrode location. A three dimensional finite element model has the potential to provide this information through a comprehensive investigation of the current density observed in the first sacral nerve root using different anode configurations.

In order to evaluate the importance of reference (anode) location in this procedure, a three dimensional finite element model was constructed from computed tomography data to evaluate the effectiveness of five anode locations.

METHODS:
The finite element model (FEM) was created from ninety-three axial computed tomography (CT) slices from the level of the fourth lumbar vertebrae to the diaphysis of the femur obtained from a healthy female subject with 0.08 cm x 0.08 cm x 0.25 cm resolution. The voxel data was segmented by tissue type in a commercially available software package (Amina 3.1, Mercury Computer Systems Inc., Chelmsford, MA). These data were used to create tissue surfaces, which were combined to construct a solid tetrahedral mesh in the same software environment. The mesh was imported into the FEM solver (Algor V16, Algor Inc., Pittsburgh, PA), for analysis. Due to the limited bandwidth of the signal, frequency dependent conductivity changes were ignored and the governing equation solved by the FEM reduces to Laplace’s equation.

The current density in the S1 nerve root was studied in two basic configurations. First, five anode locations (see Fig. 1) were examined with the cathode in the normal final resting position (station III). The five anode locations depicted were contralateral anterior superior iliac spine (CASIS), the ipsilateral anterior superior iliac spine (IASIS), the dorsal and ventral midlines (DM, VM) at the level of the umbilicus, and 2 cm anterior to the insertion site. Second, with the anode in position VM, the screw insertion path was examined at four stations: station I: the sacroiliac joint; station II: prior to the tip of the drill-bit crossing anteromedial to the nerve root; station III: the normal final screw resting position; station IV: the drill-bit tip approaching the contralateral nerve root. The current density in the contralateral nerve root was also examined with the drill in station IV and both VM and CASIS anode locations. In both configurations the anode was placed at a minimum distance of 5 mm from S1 and assigned the ground potential. The constant current stimulus (7.28 mA) stimulus was generated in elements located at the end of the 6.5 mm diameter drill-bit.

RESULTS SECTION:
With the cathode in station III the peak current density $J_{\text{max}}$ magnitude in the ipsilateral S1 nerve root increased as the anode moved counter clockwise away from the insertion site, producing a maximum response when the anode is in position DM. Relative to this peak, the other locations were attenuated by 25.5%, 22.6%, 66.8% and 86.6% respectively for the VM, CASIS, IASIS, and insertion site positions. Simulations of the drill-bit motion along the insertion path, with anode location VM, indicate that moving from station I to II increased the peak $J_{\text{max}}$ by (76.6%). Continuing from stage II to III and then III to IV decreased the peak $J_{\text{max}}$ by 16.8% and 3.1% respectively. Placing the drill-bit at station IV and moving the anode from the VM to the CASIS anode location had a small effect on $J_{\text{max}}$ in the ipsilateral S1 nerve root but increased the peak current density in the contralateral nerve root by 32.2%.

DISCUSSION:
For a given stimulus level, higher current density levels in the nerve root will lead to a lower threshold for evoking an EMG response. With the drill in station III, this initial study indicates that the CASIS, VM, and DM anode locations provide responses suitable for monitoring the spinal nerve root during iliosacral screw insertion. The attenuated responses seen with the IASIS and insertion site anode locations make their clinical implementation risky since a much larger current threshold would be needed to evoke a response, potentially leading to an artificially large inferred drill-bit to nerve root distance.

As the drill-bit moves towards its final position the simulation results indicate a rise in current density as the nerve root is approached (station I to II), followed by decreases as the drill moves past (station II to III, and II to IV). Thus the current threshold will rise as the nerve is passed, but the impact is minimal since the risk to the ipsilateral root no longer exists. However, there is an additional hazard, should insertion continue, to the contralateral root. The FEM showed that moving the anode to the CASIS location substantially increased current density in the contralateral nerve root thus supporting the a case for moving the anode to the CASIS location once the drill-bit has crossed the midline is beneficial to monitoring the contralateral nerve.

REFERENCES: