Evaluation of A Pre-operative Computer Assisted Trajectory Planning System for Posterior Atlantoaxial Transarticular Screw Fixation Surgery

Tien-Han Li¹, Ying-Sian Chen¹, Andy Chien¹, Been-Der Yang¹, Yao-Hung Wang¹,², Dar-Ming Lai², Jaw-Lin Wang¹.
¹Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan, ²National Taiwan University Hospital, Taipei, Taiwan.

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Introduction: Posterior atlantoaxial transarticular screw (TAS) fixation is a commonly chosen surgical intervention for atlantoaxial joint instability caused by trauma or rheumatoid arthritis. However, in conventional TAS fixation surgery, the screw insertion path cannot be visually confirmed under intraoperative 2D fluoroscopy, many have regarded the procedure to be technically challenging and high complication rates have been reported. The commonly reported surgery related complications included malposition of screws, vertebral artery injuries, and neurologic deficits, which often lead to catastrophic consequences. In order to reduce the rate of complications and assisting surgeons to better perform the TAS fixation procedure, this paper reports the development of an innovative computerized technique to construct a customized individual cervical spine 3D model based on computer tomography (CT) images coupled with a computer-assisted trajectory planning system in order to determine and evaluate the optimal trajectory of screw pathway prior-, during- and post-surgery. The purposes of this study were firstly to evaluate the consistency between the preoperative computer-assisted planned pathway and the actual screw pathway and secondly to determine how the differences between virtually-planned trajectory and actual screw trajectory affects the relative resultant position of cervical C1 and C2.

Methods: The study included 19 patients that underwent TAS fixation surgery (mean age: 61.1 years, range: 35–71 years; 14 males and 5 females) at our institution and in total, 32 transarticular screws were inserted. A trajectory planning program designed by our lab, PunchMAX, utilizes Computerized Tomography (CT) images to render a 3D bone tissue model as well as the sagittal and transverse multi-planar reconstruction (MPR) views of the atlanto-occipital and cervical spine to guide the planning of optimal trajectory parameters for screw insertion pre-operatively (Figure 1). The program also produced a lateral Digitally Reconstructed Radiographs (DRR) to guide screw insertion for comparison with 2D Fluoroscopy intra-operatively. The entry point, horizontal angle, and the screw size were determined and simulated through the transverse MPR images and volume rendering of bone tissue model while the vertical angle was determined through the sagittal MPR images. Apart from the use of appropriate bony-landmarks to determine the most optimal trajectory pathway for the individual patients, the anatomical location of the vertebral artery and nerves were also considered to avoid inflicting collateral injuries. The pre-determined optimal trajectory parameters were firstly recorded and then compared with the actual screw trajectory parameters obtained based on the CT-images post-operatively. The screw trajectory parameters included the horizontal and vertical entry points as well as the vertical and horizontal angles. The horizontal and vertical entry points were defined as the horizontal and vertical distance between the screw and the lamina of C2 on the posterior view. The horizontal angle was measured from the center line of C2 to the screw trajectory on the screw path plane and the vertical angle was the angle on the lateral view between the screw path plane and the reference plane defined as the plane passing through the vertebral body of C2. Subsequently, relative position change of C1 and C2 was determined by comparing the relative C1-C2 positions at pre and post-operation. Two stages of the statistical analysis were employed. Firstly, a paired t-test was used to verify the consistency between the post-operative screw pathway and the planned pathway parameters. Secondly, The screw trajectory parameters identified to be significant was then entered for the linear regression analysis where the difference between the planned and actual screw trajectory were used as the independent variables in order to examine the relationship between the differential parameter/s and the relative positional change of C1 and C2 post-operatively. A p value of <0.05 was considered significant.

Results: Overall, no major bleeding or complications were encountered with the 32 inserted screws and with only one screw malposition identified (3.1%). Vertical angle was the only parameter found to be significantly different between the actual screw pathway and the virtually planned pathway (planned vertical angle=47.28°, actual angle=51.54°, p<0.01, Figure 2). The linear regression analysis revealed moderate positive correlation between the deviation of vertical angle and the relative C1-C2 positional shift along the X-axis (R=0.625, p<0.01) and Y-axis (R=0.522, p<0.01).

Discussion: The screw malposition rate of the conventional TAS fixation surgery which has been reported to be as high as 15% was found to be only 3.1% in the current study using our lab designed computerized 3D reconstruct and trajectory guided planning system. The result of this study demonstrated a good consistency between virtually planned screw trajectory pathway
and the actual screw pathway with the vertical angle being the only parameter found to be of significant difference. It is unclear why a steeper vertical angle often resulted in surgery but from a biomechanical perspective, a plausible explanation is that when the guided tube was initially inserted against the C2 vertebra, the slight force applied in allowing the initiation of the drilling to occur may cause some anterior rotation/tilt of C2 on C3 which may cause the vertical angle of the trajectory to become relatively steeper compared to the planned trajectory. Furthermore, the steeper angle of the actual screw trajectory leads to a C1 on C2 shearing and distraction effect as illustrated in Figure 3. Such movement may place increased strain on the facet joint capsule as well as altering the intervertebral disc loading capacities. It is outside the scope of the current study, however, the results here indicated that an altered vertical angle in surgery could potentially have more long term consequences due to the altered biomechanical properties of the C1/2 joint, despite the lack of major complications during surgery.

**Significance:** Lab developed computerized 3D modeling and computer assisted trajectory planning system is a highly effective means of achieving desired clinical outcome with a low associated complication rate. Furthermore, the system identified that an increase in the vertical screw trajectory angle may be associated with altered spinal biomechanics with potentially long term consequences.

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**References:**
Figure 1. Pre-operatively determined screw trajectory pathway illustrated here on the (a) volume rendering of bone tissue allows for easy identification of entry point, (b) transverse MPR plane showing C2 inferior articular process and lateral mass of C1 for virtual pathway planning, (c) sagittal MPR plane showing the pathway starting through the lamina and aiming toward the upper part of the anterior arch of C1 with the final exit site through the anterior cortex of the lateral mass of C1, (d)
Figure 2. Among all the parameters comparing the planned and actual screw trajectory, only the vertical angle was found to be significantly different ($p<0.01$).
Figure 3. The steeper angle ($\beta$) leads to a C1 on C2 shearing and distraction effect. The phenomenon could be explained by the direction of the applied force.