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# Biomechanical analysis on of anterior transpedicular screw-fixation after two-level cervical corpectomy using finite element method

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ABSTRACT

*Background:* Anterior cervical trans-pedicle screw fixation was introduced to overcome some of the disadvantages associated with anterior cervical corpectomy and fusion. In vitro biomechanical studies on the trans-pedicle screw fixation have shown excellent pull-out strength and favorable stability. Comprehensive biomechanical performance studies on the trans-pedicle screw fixation, however, are lacking.
*Methods:* The control computed tomography images (C2-T2) were obtained from a 22-year-old male volunteer. A three dimensional computational model of lower cervical spine (C3-T1) was developed using computed tomography scans from a 22 year old human subject. The models of intact C3-T1 (intact group), anterior cervical trans-pedicle screw fixation (trans-pedicle group), and anterior cervical corpectomy and fusion (traditional group) were analyzed with using a finite element software. A moment of 1 N·m and a compressive load of 73.6 N were loaded on the upper surface and upper facet joint surfaces of C3. Under six conditions, four parameters such as the range of motion, titanium mesh plant stress, end-plate stress, and bone-screw stress were measured and compared on two treatment groups.
*Findings:* Compared with the intact model, the range of motions for treatment groups were decreased. Compared with cervical corpectomy and fusion, the titanium plant, C4 upper end-plate and C7 lower end-plate stresses in trans-pedicle group were reduced. No significant difference was discovered on bone-screw stress between the two groups for lateral flexion and rotation, but bone-screw stress is smaller in trans-pedicle group when compared with traditional group. With exception of individual difference, trans-pedicle group had better biomechanical results than traditional group in range of motions, titanium mesh plant stress, end-plate stress and bone-screw stress.
*Interpretation:* The trans-pedicle method has better biomechanical properties than the anterior cervical corpectomy and fusion making it a viable alternative for cervical fixations.

## 1. Introduction

For multilevel anterior cervical spine surgery, the currently used screw-plating systems often lead to biomechanical instability and failure in the fixation construct. In a review of the current literature, nonunion rates after anterior cervical discectomy and fusion (ACDF) surgery and failure rates after anterior cervical corpectomy and fusion (ACCF) surgery are 15–50% and 30–75% (Koller et al., 2008b), respectively. The revision rate difference between ACDF and ACCF is 5–45% (Koller et al., 2008b). In order to increase structural rigidity, decrease failure rates, and reduce complications after anterior surgery, posterior lateral mass/pedicle screw fixation is often used as an adjunct. Anterior decompression cage stabilization with antero-posterior instrumentation is increasingly recognized as the mechanical standard of reference for multilevel corpectomies due to its excellent biomechanical characteristics (Hussain et al., 2011; Setzer et al., 2012). However, with the added posterior approach, the morbidity is increased.

Koller et al. introduced a new concept of cervical anterior transpedicular screw fixation (ATPS), with an anterior-only instrumentation to complete decompression, fusion, and pedicle screw implantation (Koller et al., 2008b). ATPS not only enforces primary construct stability, but also negates the need for posterior approach. Several studies

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have reported the successful clinical application of ATPS with transfixing of fibular grafts to cervical vertebrae or the use of a non-constrained single-hole plate (Ikenaga et al., 2012; Ma et al., 2013). The studies found excellent outcomes from ATPS as compared to posterior-only or anterior-posterior approaches. While ATPS system showed promising results in the clinical setting, there is a lack of literature studying its biomechanical characteristics. It is, thus, the aim of this study to analyze the biomechanical features of C5/6 anterior corpectomies with ATPS fixation using 3-D finite element analysis (FEA). A two-level screw-plating system matching the anterior multilevel decompression and fusion system designed by Zhao was used to reconstruct C5/6 corpectomy and fusion (Zhao et al., 2014b). Range of motion (RoM), end plate stresses, bone graft stresses, and bone-screw stresses were analyzed for a C4–7 corpectomy fusion model following ATPS fixation techniques and were compared with those of traditional ACCF.

## 2. Methods

A detailed geometrically accurate C3-T1 three-dimensional finite element (FE) model was reconstructed using the computed tomography (CT) data of a healthy 22-year-old male volunteer. The cortical bone, cancellous bone, end plates, annulus fibrosus (AF), nucleus pulposus (NP), posterior facets, anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), interspinous ligament, supraspinous ligament, transverse ligament, ligamentum flavum, and capsular ligaments were reconstructed in the model. According to Mercer et al., disc annulus was crescent shaped with the anterior disc thicker than the posterior disc (Mercer and Bogduk, 1999). The cervical physiologic lordosis which disappeared in supine CT scan was restored by modifying the intervertebral disc (IVD) position using Borden's method to measuring normal cervical lordosis (Borden et al., 1960). The intact model consists of 245,363 elements and 350,340 nodes. The model had been validated through comparing RoMs data with experimental data demonstrated by Pabjabi et al. and previous FE analysis described by Kallemeyn et al. (Kallemeyn et al., 2010; Panjabi et al., 2001) (see Table 2).

Two C3-T1 fusion models were built from the intact model. The ATPS model, a two level corpectomies procedure, was developed through implementation of pedicle screws from the left anterior body into the right pedicle bodies of C4–C7. The ACCF model, also a two level corpectomies procedure, was created by implanting body screws at C4 and C7 parallel to their respective end plates. The two-level corpectomies were performed by removing the C5 and C6 vertebral bodies and adjoining intervertebral discs. ALL and PLL from C4-T1 were removed. The titanium mesh with osseous materials was placed centrally between the C4 inferior and C7 superior end plates. An anterior titanium plate designed by Zhao et al., with a rigid screw trajectory was used from C4 to C7 (Zhao et al., 2014b). The interfaces at graft-end plate and screw-bone were rigid with tied nodes which mimics complete fusion. Various material properties used to reconstruct FE model by previous studies were referenced (Table 1) (Dong et al., 2007; Wang et al., 2008).

Moment loads of 1.0 N·m was applied over nodes on the C3 superior surface. Following load of 73.6 N was loaded to the superior surface of the C3 which imitates the weight of the head. The T1 inferior surface was constrained in the three planes. ATPS and ACCF models were analyzed for RoM, bone graft stresses, end plate stresses, and bone-screw stresses using ANSYS 14.0 software (ANSYS company, USA). Bone graft stresses and end plate stresses measure the compressive stresses between bone graft and end plate. Bone-screw stresses measure the Von Mises stresses in the vertebral bone near the screws (Fig. 1A–D show the stress distribution on ATPS model).

**Table 1**
Material properties of the spinal components.

| Structure | Young's modulus (Mpa) | Poisson's ratio (V) | Areas (mm2) | Element type |
|---|---|---|---|---|
| Cortical bone | 12,000 | 0.29 | / | Shell93 |
| Cancellous bone | 450 | 0.29 | / | Solid92 |
| End plate, cartilage | 10 | 0.3 | / | Shell93 |
| Fiber matrix's | 1.5–3 | 0.4 | / | Solid92 |
| Annulus fibrosus | 450 | 0.3 | 1 | Link10 |
| Nucleus pulposus | 1 | 0.49 | / | Solid92 |
| Titanium prosthesis | 110,000 | 0.32 | / | Solid92 |
| Anterior longitudinal ligament | 10 | 0.3 | 6 | Link10 |
| Posterior longitudinal ligament | 10 | 0.3 | 5 | Link10 |
| Capsular ligaments | 10 | 0.3 | 46 | Link10 |
| Ligamentum flavum | 1.5 | 0.3 | 5 | Link10 |
| Interspinous ligament | 20 | 0.3 | 10 | Link10 |
| Intertransverse ligament | 20 | 0.3 | 10 | Link10 |

## 3. Results

The relationship between pure moments applied at the C3 and the resulting rotations at the C3–C7 segments are shown in Table 2. The RoMs correlated well with experimental studies by Pabjabi et al. and the FE studies by Kallemeyn et al. (Dong et al., 2007; Panjabi et al., 2001). The ATPS model consists of 243,048 elements and 362,007 nodes; the ACCF model consists of 259,884 elements and 386,666 nodes (Figs. 1 and 2).

### 3.1. Range of motion

Relative to the intact model, there were reduction in RoM in ATPS and ACCF techniques models: flexion (−72.9%, −47.8%), extension (−57.9%, −23.7%), lateral flexion (−78.6%, −49.5%), axial rotation (−58.5%, −41. 0%) (Fig. 3). The smallest RoMs were found in ATPS model.

### 3.2. Titanium mesh graft stresses

For ATPS FE model, titanium mesh graft stresses was maximally loaded in extension and minimally loaded in flexion (Fig. 4). Compared with ACCF FE model, the titanium mesh graft stresses decreased in ATPS: flexion (−33.3%), extension (−23.2%), lateral flexion (−9.2%), axial rotation (−18.2%).

### 3.3. End plate stresses

Stresses in the C4 inferior and C7 superior end plates of the fusion models were higher than the corresponding end plate stresses of the intact model (Fig. 5). Stresses in the C7 superior end plate of ATPS model were lower than the stresses in the C4 inferior end plate. The end plate stresses were highest in extension and lowest in flexion. Compared with ACCF, the C4 inferior end plate stresses were reduced in ATPS fixation: flexion (−18.5%), extension (−23.1%), lateral flexion (−13.6%), and axial rotation (−22.0%). The C7 superior end plate stresses were also reduced in ATPS model as compared to the ACCF model: flexion (−31.8%), extension (−44.6%), lateral flexion (−54.0%), axial rotation (−55.2%).

### 3.4. Bone-screw interface stresses

Compared with vertebral body screw instrumentation model, ATPS model showed reduced flexion and extension stresses in bone adjacent to the screws, which was not significantly different in lateral flexion or