Atlantoaxial instability: biomechanical evaluation of T-Plate versus transarticular screw fixation

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FINAL APPROVAL OF THESIS
Master of Science in Biomedical Sciences

Atlantoaxial Instability: Biomechanical Evaluation of T-plate Versus Transarticular Screw Fixation

Submitted by

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In partial fulfillment of the requirements for the degree of Master of Science in Biomedical Sciences

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2005
ACKNOWLEDGMENTS

It is a pleasure to thank the many people who made this thesis possible.

I am grateful to my advisors Dr. Nabil A. Ebraheim and Dr. Vijay K. Goel for their comprehensive help and support during my entire program.

I would like to thank Dr. Ashok Biyani for his recommendations and to Dr. Koichi Sayrio and Dr. Richard Yeasting for their assistance on the experimental procedures.

Finally, I wish to thank my family for their support and loving environment. To them I dedicate this thesis.
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INTRODUCTION

Cervical spine C1-C2 motion segment is the most technically challenging for the spine surgeon. Atlantoaxial instability is treated surgically by different techniques. The most used technique is the transarticular screw fixation, with great risk for injury of the vertebral artery.

Posterior fusion at C1-C2 segment is indicated in fractures, degenerative osteoarthritis, rheumatoid arthritis, metastasis, ligamentous injuries, congenital anomalies, infections and tumors. Atlantoaxial instability can cause severe neurological injury or death.

Posterior wiring is the standard cervical stabilization technique since the late 1800s. Wires provide provisional alignment and stability until a formal arthrodesis occurs. Simple wiring is effective with little risk of neurovascular injury for most of the cases.

Unstable posterior cervical injuries without posterior element fractures are excellently repaired by standard interspinous wiring techniques.

The method of choice for C1-C2 instability is the posterior sublaminar wiring technique. Studies by Brooks and Jenkins (1978) reveal that posterior wiring technique of Gallie requires adequate bone quality of the C1 and C2 laminae and the bone graft for sufficient stability. Anterior translation of atlas on axis is not adequately controlled with the posterior wiring technique while rotation is minimally controlled.
In Gallie’s wire fixation, a single sublaminar wire is doubled and passed under the posterior arch of C1. The loop is secured to the spinous process of C2, while the two wire ends are tightened posteriorly over a corticocancellous bone graft compressing the graft onto the C1 and C2 laminae.

Studies by Kanat and Aydin (1999) reveal that Brooks C1- C2 arthrodesis is accomplished by the passage of two sublaminar wires at C1 and C2 that are tied individually and separately over bilateral struts of bone graft.

In recent years, Rodriguez et al (1991), Mimatsu et al (1992), Fidler et al (1994), Dickman and Sonntag (1995 b), Farey et al (1999), Kanat and Aydin (1999) described several new posterior wiring techniques have been described. These techniques differ in number of sublaminar wires, wire position, graft position, and bone graft shape and position. All these technique are associated with potential risks associated with the use of sublaminar wires.


Many spine surgeons consider this technique the gold standard for posterior fusions of C1-C2 as was revealed by studies done by Dickman (1995), Coric (1996),

Transarticular screw fixation is technically demanding and requires considerable experience. There are numerous reports of screws penetrating the vertebral artery, sometimes with fatal consequences as was revealed by studies done by Dickman (1995 a), Farey (1999), and Goel (1999). The Magerl technique is biomechanically superior to wiring techniques in load to failure and stiffness as well. The superiority of Magerl technique is due to the longer screw utilized for this technique, which provides additional rotational stability.

The present study was undertaken to biomechanically compare the stiffness of two different constructs for posterior fusion between C1 and C2. The purpose of our study was to compare the pullout strength of the T plate fixation with the pullout strength of transarticular screw fixation. In one construct a “Synthes” T plate was used. This plate was fixated with three screws on C1 vertebral arch and only one screw on C2. The purpose of this study was to determine whether non-bone graft fixation with T plate could provide strength levels equivalent to transarticular screw fixation and to compare the stiffness of these two constructs. This technique, using a T plate for atlantoaxial fusion, would avoid complications and a challenging surgical technique such as Magerl transarticular fixation. Our hypothesis is that this fixation is biomechanically as strong as transarticular screw fixation.
LITERATURE

The treatment of cervical spine instability has evolved from the use of minimal fixation to the development of various surgical techniques. The benefits of internal fixation include rigid stabilization, maintenance of alignment, minimal postoperative immobilization, and enhanced fusion rates. The advantages of newer techniques do not imply that the use of the simple wiring technique has become obsolete. Wiring technique is still commonly used for posterior cervical fusion.

The use of posterior internal fixation in the cervical spine is expanding. This review of the literature focuses on various posterior internal fixation methods of the C1-C2 cervical spine, the technique, the indications and the potential complications. C1-C2 fusion can be performed posterior with transarticular screw fixation, clamp fixation, and the various wires with bone graft techniques. Indications for posterior atlantoaxial arthrodesis include instability due to fracture, ligament disruption, and congenital abnormalities.

Posterior atlantoaxial arthrodesis is indicated in cases of instability to reduce deformity, to provide pain relief, and to minimize the risk of potential neural damage. Posterior atlantoaxial arthrodesis is accomplished by 4 types of methods and their variations:

1) Wire fixation of Brooks or Gallie techniques
2) Transarticular screw fixation of Magerl, Magerl and Seeman
3) Interlaminar clamps by Halifax technique
4) C1-C2 screw–rod fixation
Stabilization of the atlantoaxial articulation presents special problems due to the unique anatomical and functional characteristics of the upper cervical vertebra. The majority of rotational movement occurs at C1-C2, the cervical stabilization limit rotational movement of the neck.

C1-C2 instability is visualized with plain films: open view mouth. In case of a suspected abnormality of the dens, a CT reconstruction in the frontal plane is useful. MRI imaging is very useful for defining the relationship of the spinal cord and adjacent soft tissue, but visualizes poorly the bone structures. Flexion-extension films are potentially dangerous in case of C1-C2 malalignments.

Wiring Fixations of C1-C2

The sublaminar wiring technique for C1-C2 fixation is the oldest method for atlantoaxial stabilization. It is generally effective and appropriate for patients whose subluxations are reducible and without compromise of the spinal canal. Stauffer (1988) thought that the amount of C1-C2 displacement and the ability to achieve reduction preoperatively are important factors for the safety of wiring technique. If the reduction results in a decrease of displacement, then successful sublaminar wires can be expected. Another factor considered was the sufficient space between the occiput and the posterior ring of C1. A small space may reduce the area for wire passage and increase the incidence of neural injury. Another considered factor was the determination of the bone integrity of posterior arch of C1. Posterior atlantoaxial arthrodesis may be performed using either Gallie or Brooks techniques.
In Gallie’s wire fixation, a single sublaminar wire is doubled and passed under the posterior arch of C1. The loop is secured to the spinous process of C2, while the two wire ends are tightened posteriorly over a corticocancellous bone graft compressing the graft onto the C1 and C2 laminae. Kanat (1999) revealed that Brooks C1- C2 arthrodesis technique describes passage of two sublaminar wires at C1 and C2 that are tied individually and separately over bilateral struts of bone graft. The Brooks technique has greater rotational stability when compared with Gallie technique. Most authors recommend the Gallie technique for most flexion injuries and Brooks fusion for extension injuries and in cases that need more rigid fixation. In a modified Gallie fusion a wire is passed beneath the arch of C1 from inferior to superior. The bone graft is fitted between the posterior elements of C1 and C2. The loop wire is passed beneath the C2 spinous process, and the wires tightened over the bone graft.

Sublaminar wiring is frequently used for atlantoaxial subluxation secondary to ligamentous laxity or for odontoid fractures. It cannot be used in cases of fractures or neoplasms of the posterior elements of atlas or axis. It cannot be used in cases of hypertrophy of soft tissue within the spinal canal where spinal canal narrowing poses a great risk of spinal cord injury. The C1- C2 wiring techniques described in the literature are similar but differ in the wiring passage modalities and the bone graft positions. The interspinous method was described by Dickman in 1991 and represents a synthesis of Brooks and Gallie techniques. The wiring passage is similar to Gallie technique and the graft is wedged between the posterior elements of C1 and C2 and the wires are tightened. The advantage of this construct is the avoidance of the sublaminar wiring passage beneath C2, which is the major risk of the Brooks fusion. Although wiring technique is
safe, easy and effective for cervical fixation, other fixations for C1-C2 are gaining more popularity in the literature.

*C1-C2 Transarticular Screw Fixation*

Stabilization of C1-C2 may be accomplished by bilateral placement of screws into the C2 pedicle, directed across the C1-C2 joint toward the lateral mass of C1. This technique is useful for patients with atlantoaxial instability with spinal canal compromise and for patients with fractures or neoplasms of the posterior elements of C1-C2, cases which preclude wiring technique or Halifax clamps fixation. Magerl (1979) described transarticular technique as a stable fixation of C1-C2, which does not depend on the integrity of the posterior arch of C1. Magerl transarticular fixation requires a thorough knowledge of atlantoaxial anatomy and a precise technique for safe and successful results.

Transarticular instrumentation of Magerl is considered the gold standard technique for posterior fusions of C1-C2 as was mentioned by studied done by Grob (1991), Jeanneret (1992), Dickman (1995), Silveri (1998), Blauth (1999), Campanelli (1999), Crawford (1999), Kanat (1999), and Mitchell (1999). The screws are inserted at the inferior aspect of the laminae approximately 2 mm cranial and lateral of the medial border of the caudal articular process of C2. A drill guide and fluoroscopic imaging are used as the screw is passed across the facet joint into the lateral mass of C1. Transarticular screw fixation requires considerable experience. There are numerous reports of screws penetrating the vertebral artery, sometimes with fatal consequences as
was revealed by studies done by Coric (1996), Campanelli (1999), Farey (1999), and Goel (1999).

Several biomechanical studies have compared the transarticular screws technique with wiring techniques (the Gallie type and the Brooks type). Hanley (1992) found that the Brooks technique was twice as stiff in extension and flexion and five times as stiff in rotation compared with the Gallie technique and simple midline wiring. Naderi (1998) studied biomechanically in vitro combinations of cable-graft-screw at C1-C2. Spinal stiffness increases after spinal instrumentation with two transarticular screws plus a posterior wire-graft compared with a wire-graft alone. The transarticular screws prevented lateral bending and axial rotation better than the posterior wire-graft. The wire-graft prevented flexion and extension better than the screws. Increasing the number of fixation points often significantly decreased the rotation and translation. Axes of rotation shifted from their normal location toward the hardware. Naderi (1998) studied one-point fixation technique compared to three-point fixations using transarticular screws and concluded that it is mechanically advantageous to include as many fixation points as possible for the treatment of atlantoaxial instability. Montesano (1991) and Grob (1992) compared in vitro different posterior atlantoaxial fusions: the two wire techniques (Gallie type and Brooks type) to the transarticular screw method (Magerl technique). Each fixation technique decreased motion in all directions significantly when compared to the intact and injured spines. They found that the Gallie technique was associated with significantly more motion in flexion, extension, axial rotation, and lateral bending than Brooks and Magerl technique. The Magerl technique tended to allow the least rotation. Magerl (1987) and Grob (1992) did not report any vertebral artery injury. The fusion rate
with transarticular screw placement is very high for all bilateral screw placements. Transarticular screw fixation is advantageous in prevention of postoperative translational movements that may occur with the Gallie and Brooks techniques, allowing early mobilization of the patient with major cervical injuries. If the posterior elements of C1 are intact, a Gallie-type or Books-type fusion is added to the transarticular screw fixation to strengthen the stability of the construct. For the successful placement of transarticular screws, knowledge of the anatomy of the C1-C2 region is mandatory; the relationship of the C2 transverse foramen to the C1-C2 facet joint, lateral spinal cord, and vertebral artery determine the correct trajectory for the screw. CT images determine whether the patient’s anatomy support the placement of the screws.

Complications may result due to malpositioning or breakage of the screw. A trajectory too lateral may result in vertebral artery injury. A screw trajectory too medial may result in injury to the spinal cord with disastrous consequences.

**Halifax Clamps**

Another atlantoaxial arthrodesis procedure is the interlaminar clamps technique. Halifax clamps are small laminar hooks connected by a threaded screw. Moskovich (1991) reported an 80% fusion rate within 12 weeks using interlaminar clamps with interposed bone graft. Unsuccessful unions were due to incorrect use of the device intraoperatively. The major advantage of this technique according to the authors is the reduced risk of dural penetration and wire cut out. Interlaminar clamps with interposed bone graft allow a construct with immediate stability. The limitation of this technique is the technical challenges at the time of application and the potential for rotational dislocation. The
author thought that creation of a locking technique would enhance the safety of the system. Halifax clamps should be placed from C1 to C3 for more stability and less dislodgement when compared with placements of the clamps on C1-C2 as was revealed by Holness (1984) and Cybulski (1988). Halifax clamps cannot be used in cases with fractures of the posterior elements. It cannot be used in patients with a narrowed spinal canal because the hooks intrude into the spinal canal and spinal cord compression may occur as the hooks are placed.

Comparing the Brooks, Gallie and Magerl methods, studies show the biomechanical inferiority of the Gallie method; the Magerl technique is the stiffest in rotational strength. Brooks, Magerl and Halifax fixations provide similar biomechanical levels of fixation in flexion and extension. However, the transarticular screw fixation provides the most stable configuration in lateral bending and axial rotation. Brooks and Halifax methods provide greater rotational and translational stiffness than Gallie construct but present greater technical difficulties for the surgeon, as was revealed by Hajek (1993). Gallie fusion is the simplest construct for posterior atlantoaxial instability but provide the least stability to the fixation.

*Posterior C1-C2 Fusion with Screw-Rod Fixation*
Fixation by transarticular screws combined with posterior wiring and structural bone graft leads to excellent fusion rates but the technique is very demanding and poses a great risk of vertebral artery injury. A bilateral insertion of screws in lateral mass of C1 and into the pedicle of C2 followed by rod fixation was described lately to avoid the limitations of transarticular fixation with wiring and bone graft. This technique does not require structural bone graft or wiring. A retrospective study by Harms (2001) revealed
that satisfactory screw placements were obtained in all patients. No vertebral artery or
dural laceration was noted. The trajectory for the insertion of C2 screws was guided by
anatomic landmarks, without continuous fluoroscopy. Integrity of the posterior arch of
C1 is not necessary for stable fixation. This technique seems reliable and effective and
should be considered as an efficient alternative to the traditional fixations of the
atlantoaxial complex.
MANUSCRIPT I

Atlantoaxial instability: biomechanical evaluation of T-plate fixation versus transarticular screw fixation

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Atlantoaxial instability: biomechanical evaluation of T-plate fixation versus transarticular screw fixation

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Abstract

**Background context.** Magerl transarticular screw fixation has yielded serious complications such as hardware failure, hypoglosal nerve injury and vertebral artery laceration minimizing its widespread acceptance.

**Purpose.** Our objective is to evaluate a new technique using a T plate for the atlantoaxial fusion in comparison with the Magerl technique.

**Study design.** Pullout tests are being performed on cadaverous specimens to compare the fixation strength of T-plate fixation versus Magerl technique.

**Methods.** The study is being performed on eighteen intact, embalmed cadaverous specimens (C1-C2). A Synthes T plate is being placed posterior on C1-C2 on nine specimens. A Magerl transarticular screw fixation is being placed on the other nine specimens to compare the strength of these two fixations. Pullout tests are being performed on a MTS machine, at a constant displacement rate of 20 mm/minute, to evaluate the fixation strength.

**Results.** The mean failure load for the T plate fixation (mean=318.83 N, SD=46.61N) is lower than for the transarticular fixation (mean =520.07 N, SD=194.51 N). The test was significant, t (8.916)= -3.018, p=0.015

**Conclusion.** Posterior cervical plating may offer a reasonable alternative for the clinical situations in which the patient’s anatomy does not support the placement of the transarticular screws. The simplicity of the T-plate and the safe placement of the screws are the main advantage of the T-plate construct versus the transarticular screw fixation. The study demonstrated minimal risk of neurovascular injury. The thin diameter of the
posterior arches of C1 precludes insertion of longer screws. A modification in plate design would allow insertion of the C2 screws into the pedicle, increasing the strength of the construct. Although analyses of the data shows that the mean axial pullout of the posterior T-plate is 62% of the mean pullout strength for the transarticular fixation, the T-plate construct might provide the same stability in the physiological range of motion.

Keywords: cervical spine, T-plate, transarticular screw, biomechanics, cadaveric.
Introduction.

Cervical spine C1-C2 motion segment is the most technically challenging for the spine surgeon. C1-C2 fractures, degenerative osteoarthritis, rheumatoid arthritis, metastasis, ligamentous injuries, congenital anomalies, infections and tumors cause alantoaxial instability, which is treated surgically by different techniques. The most used technique is the transarticular screw fixation, with great risk for injury of the vertebral artery. Posterior wiring techniques (posterior wiring technique of Gallie, Brooks atlantoaxial arthrodesis technique) were considered the standard cervical stabilization technique since the late 1800s. Wires provided provisional alignment and stability until a formal arthrodesis occurred. In recent years, several new posterior wiring techniques have been described by McGraw (1973), Salmon (1977), Brooks (1978), Dickman (1991), Rodriguex (1991), Mimatsu (1992), Fidler (1994) and Kanat (1999). These techniques differ in number of sublaminar wires, wire position, graft position, and bone shape.

Many spine surgeons consider this technique the gold standard for posterior fusions of C1-C2 as was shown by studies done by Blauth (1999), Campanelli (1999), Crawford (1999), Dickman (1995), Grob (1991), Jeanneret (1992), Kanat (1999), Mitchell (1999), Silveri (1998). It also shows negligible pseudarthrosis rates in large clinical studies as was revealed by Grob (1992) and Dickman (1995). Transarticular screw fixation is technically demanding and requires considerable experience. There are numerous reports of screws penetrating the vertebral artery, sometimes with fatal consequences as was revealed by studies done by Campanelli (1999), Coric (1999), Farey (1999), and Goel (1999). Therefore, there is concern about the widely use of transarticular fixation and many authors try to find new techniques or to improve the classical Magerl technique.

Biomechanical studies show that bone-mineral density, osteoporosis, cortical fixation, screw orientation and screw thread area all affect the screw pullout. Pullout testing is considered to be a good predictor of pedicle screw strength although pure pullout is not the mode of failure seen in clinical situations as was revealed by studies done by Abshire (2001).

No previous studies investigated pullout strength of the posterior T plate fixation on C-C2. This technique aims to be a valuable technique for the posterior spinal fusion of C1-C2. The present study was undertaken to biomechanically compare the pullout strength of Magerl fixation versus this new technique using T plate. This T plate was fixated with three screws on C1 vertebral arch and one screw on C2. The purpose of this study is to determine whether non-bone graft fixation with T plate could provide
stability levels equivalent to transarticular screw fixation and to compare the stiffness of these two constructs. The T-plate fixation for atlantoaxial fusion would avoid complications and a challenging surgical technique such as Magerl transarticular fixation. Our hypothesis is that this fixation is biomechanically as strong as transarticular screw fixation.
Methods.

Eighteen human adult cervical spines were harvested from embalmed cadavers. The donors were eight females and ten males with an age range of 73 – 101 years, with a mean of 84.38 years (standard deviation 6.31 years). The cervical spines were harvested from cadavers in the Anatomy Department. The spines were cleaned of all soft tissue.

The study was completed on eighteen intact, embalmed cadaverous specimens (C1-C2). Each specimen was stripped of soft tissue leaving the ligamentous structures intact.

The anterolateral part of C1-C2 was affixed in polyester resin to provide an interface to the MTS machine. Metallic screws were inserted into anterolateral parts of C1 and C2 vertebrae prior to pouring the polyester resin to secure the fixation between the vertebral bodies and the resin.

The specimens were placed in ventrolateral position and the anterior part of C1-C2 was affixed in polyester resin to provide an interface to the MTS machine. The specimens were potted in a potting mixture composed of Bondo Body Filler, Fiberglass Resin and cream hardener.
Description of posterior cervical plating (T plate):

A Synthes T plate with locking screws was placed on C1-C2 specimen. The plate was placed posterior on C1-C2. One aspect of this new technique of posterior cervical plating is the safe placement of screws into the lateral mass and C1 posterior arch with a screw length sufficient for maximal fixation. Computed tomography should be recommended to determine the location and orientation of the neural foramen and the vertebral artery. The T-plate posterior cervical plating technique consists of placement of three screws on the posterior arch of the atlas and one screw on atlas. Medial screw on atlas with a length of 10 mm is oriented medially approximately at 20°. (Figure 1)

Figure 1: C1-C2 specimen affixed with “Synthes” T-plate
Midscrew on atlas 10 mm length is oriented perpendicularly on the posterior arch. Lateral screw 16 mm length is placed in the middle of the lateral mass on C1. On axial projection, the lateral screw on atlas diverges from the parasagittal plane at approximately 20°. A typical screw length of approximately 16 mm for the lateral mass was considered safe without extracortical protrusion. All the screws were mono-cortical (unicortical) and did not penetrate the posterior wall of spinal canal, resulting in a safe technique. For the placement of the screw on axis we suggested that the starting point be 2 mm- 3mm superior to the inferior articular process and the direction towards the pedicle (to get enough depth for the stability of the fixation). The more medial starting point requires a divergence of approximately 25° to traverse the middle of the pedicle. Laterally, the screws are placed parallel to the superior facet. The atlas screw placement typically results in a longer average screw length of approximately 20 mm. The advantage of this device is that it does not require or depend on structural bone graft and as opposed to wire techniques and no instruments are passed into the spinal canal.
Description of Magerl technique:

A transarticular screw fixation at C1-C2 (Magerl technique) was placed on C1-C2 specimens. (Figure 2)

Figure 2: Magerl transarticular screw, holding device and C1-C2 human cadaveric specimen

Transarticular screws were inserted according to this clinically established method. Specimens showing subluxation were excluded, using in this study only the specimens without any subluxation. The screw trajectory should cross the C1–C2 facet and end at the anterior arch of the atlas. The anatomy of individual patients may require that the entry point for transarticular screw placement to be modified to avoid intercepting the vertebral artery. The entry point of the screw was 2 to 3 mm above the caudal edge of the C2 inferior facet and 2-3 mm lateral to the medial border of the C2-C3 facet. Using 50
cm long, 1.2 mm diameter, end-threaded K-wire, a cannulated cortical screw was inserted. (Figure3)

Figure 3: C1-C2 specimen with transarticular fixation placed in the MTS system

Placing the screws too ventral could penetrate C1 anteriorly and enter the pharynx; rostrally placed screws could cross the occipitoatlantal joint and injure the hypoglossal nerve; lateral placed screws could injure the vertebral arteries, and medial screws could injure the spinal cord.
Pullout tests were performed on a MTS machine, at a constant displacement rate of 20 mm/minute, to evaluate the fixation strength. All biomechanical testing were performed on a biaxial materials testing machine (858 Bionix Testing System). (Figure 4a, b)

**Figure 4a- Pullout test for the “Synthes” T-plate**

![Pullout test for the “Synthes” T-plate](image1)

**Figure 4b- Pullout test for the transarticular fixation**

![Pullout test for the transarticular fixation](image2)
The load and displacement until failure were recorded on a computer-based data acquisition system. Using independent $t$-test, statistically analyzes were performed to determine the difference between the strength for the Synthes T plate fixation compared with the strength of the transarticular screw fixation.
Results.

In nine cervical specimens, “Synthes” T plate fixation was tested by recording the axial load to failure after pullout tests. Another nine specimens were tested for Magerl fixation strength using pullout tests also.

Results indicate a mean axial failure load for the T plate fixation tested specimens, versus transarticular fixation.

An independent-samples t test was conducted to evaluate the failure load of C1-C2 fixation for the T plate compared to the failure load of the transarticular screw fixation. The mean pullout force of the T-plate fixation was 318.83 N with a standard deviation of 46.61 N and the mean pullout force of the transarticular fixation was 520.07 N with a standard deviation of 194.51 N. The test was significant, $t(8.916)= -3.018$, $p = 0.015$. The results were opposite to the research hypothesis. The 95% confidence interval for the T plate fixation was 218.89 to 418.779 and the 95% confidence interval for the Magerl transarticular fixation was 420.129 to 620.015. The observed power for these two techniques was 0.809.

Figure 5 shows the distribution for the 2 groups (error bars - one standard deviations above and below the mean) for the failure load of each group (t plate and transarticular screw fixation).
Figure 5. Error bars for the failure load for each group: T plate fixation vs. Magerl transarticular screw fixation.

The details of the pullout forces for the T-plate fixation versus Magerl transarticular screw fixation are shown in Table I.
Table 1. The results of pullout force

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<th>Specimen ID for the transarticular screw</th>
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<td>Mean for T-plate pullout</td>
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<td>Mean for transarticular pullout</td>
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</tr>
<tr>
<td>Standard deviation</td>
<td>46.61N</td>
<td>Standard deviation</td>
<td>194.51 N</td>
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Discussion.


Transarticular screw fixation requires considerable experience. There are numerous reports of screws penetrating the vertebral artery, sometimes with fatal consequences as revealed retrospective studies done by Coric (1996), Campanelli (1999), Farey (1999), and Goel (1999).

Several biomechanical studies have compared the transarticular screws technique with wiring techniques. Hanley and Harvell (1992) found that the Brooks technique was twice as stiff in extension and flexion and five times as stiff in rotation compared with the Gallie technique and simple midline wiring.

Studies by Naderi (1998) revealed that spinal stiffness increases after instrumentation with two transarticular screws plus a posterior wire-graft compared with a wire-graft alone. The transarticular screws prevented lateral bending and axial rotation better than the posterior cable-graft. The wire-graft prevented flexion and extension better than the screws. Increasing the number of fixation points often significantly decreased the rotation and translation. Axes of rotation shifted from their normal location toward the hardware. Naderi (1998) studied one-point fixation technique compared to three-point fixations using transarticular screws and concluded that it is mechanically advantageous to include as many fixation points as possible for the treatment of atlantoaxial instability.
Montesano (1991) and Grob (1992) compared in vitro different posterior atlantoaxial fusions: the two wire techniques (Gallie and Brooks type) to the transarticular screw method (Magerl technique). Each fixation technique decreased motion in all directions significantly when compared to the intact and injured spines. They found that the Gallie technique was associated with significantly more motion in flexion, extension, axial rotation, and lateral bending than Brooks and Magerl technique. The Magerl technique tended to allow the least rotation.

Magerl (1987) and Grob (1992) did not report any vertebral artery injury. The fusion rate with transarticular screw placement is very high for all bilateral screw placements. Transarticular screw fixation (Magerl) is advantageous in prevention of postoperative translational movements that may occur with the Gallie and Brooks techniques, allowing early mobilization of the patient with major cervical injuries. When it is possible, a Gallie- or Books-type fusion is added to the transarticular screw fixation to strengthen the stability of the construct.

Studies that compare the Brooks, Gallie and Magerl methods, show the biomechanical inferiority of the Gallie method; the Magerl technique is the stiffest in rotational strength. Knowledge of the anatomy of the C1-C2 region is mandatory for the successful placement of transarticular screws; the relationship of the C2 transverse foramen to the C1-C2 facet joint, lateral spinal cord, and vertebral artery determine the correct trajectory for the screw. CT images determine whether the patient’s anatomy support the placement of the transarticular screws.
Posterior cervical plating offers a reasonable alternative for the transarticular screw fixation due to the safe placement of the screws. In patients in whom the anatomy of C1-C2 contraindicates the use of the transarticular screw fixation, T-plate fixation might be a reasonable alternative.

Analyses of the data in this study demonstrate that the mean axial pullout strength of the posterior T-plate fixation is 62% of the mean pullout strength for the transarticular fixation.

The comparison between the T-plate fixation and transarticular screw fixation is justified by the fact that in a clinical case both the T-plate and the transarticular screw will be bilaterally placed with interposed bone graft. Pullout tests were done unilaterally for both the T-plate fixation and the transarticular screw fixation. The cervical spine chosen for testing were obtained from the Medical College of Ohio, Department of Anatomy. There are several studies done by McKoy (2000), Mummaneni (2002) and Sarzier (2002) that used embalmed cadaveric specimens for pullout tests.

The technique of posterior T-plate fixation requires attention to anatomical details. Proper screw placement requires identification of the proper starting point for screw insertion and correct screw trajectory. A preoperative CT scan to study the relationship of the neural foramen, vertebral artery, and lateral masses would be important in the T-plate technique.

All the screws for the T-plate were unicortical. There weren’t statistically significant different between screws inserted with bicortical versus unicortical purchase as was demonstrated by Silveri (1998). Plate systems are known to fail by screw pullout
from bone, screw and plate breakage so our testing method simulated one of the failure modes met in a clinical case. Transarticular screws may fail by screw pullout in rare cases of severe osteoporosis because of the high strength of the fixation.

Our testing methods had to account for a number of uncontrolled variables: of bone mineral density and spine specimens’ morphology. The same spine surgeon inserted all the screws to eliminate variability of technique insertion.

A decision had to be made as to what screw length to use for the T-plate technique. We selected a medium size screw that would fit into the fixation without penetrating the cortex. According to spine morphology, screw length would vary from specimen to specimen, but we decided to use the same screw length for the purpose of evaluating T-plate fixation.

For the transarticular fixation we used 50 mm screw length for all the tested specimens. We chose this length due to the use of a holding device (about 10 mm width) for pullout tests. Ebraheim (2000) study suggest that the mean optimal transarticular C1-C2 screw length may be 38 mm but the determination of the accurate optimal screw length should be made on an individual basis.

In this investigation we found that mean axial pullout strength of the posterior T-plate fixation is 62% of the mean pullout strength for the transarticular fixation (p < 0.05). Although the T-plate technique has only 62% of the mean axial pullout strength of the Magerl technique as shown by the pullout tests, the T-plate might still provide the same stability in the physiological range of motion. This would require new tests to be done on fresh- frozen cadaveric specimens using the Optotack system. This technique
could be a worthwhile technique if it is proved that the T-plate fixation has the same range of motion as the transarticular fixation. The study of this T-plate technique has evaluated the internal fixation for fusion of C1-C2 spine using Synthes T plate.
Conclusion.

The T-plate technique of internal fixation of the cervical spine shows that the T-plate fixation provided a 38 % decrease in the pullout strength when compared with the traditional transarticular fixation described by Magerl. (P = 0.035). Our study confirms the safety of the T-plate fixation when compared with the transarticular fixation. A more stable T-plate fixation could be obtained using a longer screw for the C2 fixation. Further anatomical studies need to determine the optimal screw length. A different plate design could also improve the pullout strength of the fixation.

Motion studies on fresh specimens are necessary to provide information about the range of motion of these two compared fixations. Further studies are necessary to evaluate these hypotheses.
References


Legends.

**Figure 1**: C1-C2 specimen affixed with “Synthes” T-plate

**Figure 2**: Magerl transarticular screw, holding device and C1-C2 human cadaveric specimen

**Figure 3**: C1-C2 specimen with transarticular fixation placed in the MTS system

**Figure 4a**: Pullout test for the “Synthes” T-plate

**Figure 4b**: Pullout test for the transarticular fixation

**Figure 5**: Error bars for the failure load for each group: T plate fixation vs. Magerl transarticular screw fixation.
DISCUSSION/SUMMARY

Magerl’s transarticular instrumentation is considered the gold standard technique for posterior fusion of C1-C2. The main problem with the transarticular screw fixation is that requires considerable experience, is very challenging technique for the spine surgeon and has a high risk of neurovascular injury. Coric (1996), Campanelli (1999), Farey (1999) and Goel (1999) reported screws penetrating the vertebral artery, sometimes with fatal consequences.

Magerl (1987) and Grob (1992) did not report any vertebral artery injury. The fusion rate with transarticular screw placement is very high for all bilateral screw placements. Several biomechanical studies have compared the transarticular screws technique with the wiring techniques. Transarticular screw fixation is advantageous in prevention of postoperative translational movements that may occur with the Gallie and Brooks techniques, allowing early mobilization of the patient with major cervical injuries. When possible, a Gallie- or Brooks –type fusion is added to the transarticular screw fixation to strengthen the stability of the construct.

Studies that compare the Brooks, Gallie and Magerl methods, show the biomechanical inferiority of the Gallie method; the Magerl technique is the stiffest in rotational strength. A thorough knowledge of the anatomy of C1-C2 anatomy region is mandatory for the successful placement of transarticular screws. CT images determine whether the patient’s anatomy support the placement of the transarticular screws.
Posterior cervical plating offers a reasonable alternative for the clinical situations in which wiring technique is ineffective. The wiring technique is useful only if the posterior arch of C1 and C2 are intact and the spinal cord must be monitored during the passage of sublaminar wires.

Posterior cervical plating offers an alternative for transarticular screw fixation in cases where the patient’s anatomy does not support the placement of the transarticular screws. The simplicity of the T-plate fixation with the immediate access to the posterior arch of C1 for the screws insertion is the main advantage of the T-plate construct versus the transarticular screw fixation. The study demonstrated the safe placement of the screws with minimal risk of injury of vertebral artery, hypoglossal nerve or spinal cord. Further analyses should evaluate the anatomy of the cervical spine C1-C2 to determine the optimal screw length. An anatomical study using CT scan should be performed to measure the dimensions of C1 posterior arch and to conclude about the mean optimal screw size.

The comparison between the T-plate fixation and transarticular screw fixation is justified by the fact that in a clinical case both the T-plate and the transarticular screw will be bilaterally placed with interposed bone graft.

Several studies done by McKoy (2000), Mummaneni (2002) and Sarzier (2002) used embalmed cadaveric specimens for pullout tests as we used in this study. The T-plate design should be modified, according to the measurements done with the CT scan, to allow insertion of the C2 screw into the pedicle, increasing the strength of the fixation.
A 20 mm screw length for the C2 pedicle screw insertion is considered the optimal length.

Analyses of the data in this study demonstrate that the mean axial pullout strength of the posterior T-plate fixation is 62% of the mean pullout strength for the transarticular fixation.

The T-plate technique proved to have less strength than Magerl technique, according to the pullout test results, but might still provide the same stability in the physiological range of motion. This would require new tests on fresh-frozen cadaveric specimens using the Optotrack system. This technique could be a worthwhile technique if it is proved that the T-plate fixation has the same range of motion as the transarticular fixation. Combining the T-plate concept with the wiring technique and bone graft would increase the strength of the construct. The T-plate–wiring construct may provide the same strength as the Magerl fixation and the instrumentation would be much safer and easier when compared with the Magerl fixation.

A change in the plate design could make possible the use of the locking system, increasing the strength of the T-plate system.

The technique of posterior T-plate fixation requires attention to anatomical details. Proper screw placement requires identification of the proper starting point for screw insertion, correct screw trajectory and the optimal screw length according to CT scan anatomical studies.

All the screws for the T-plate were unicortical. Plate systems are known to fail by screw pullout from bone, screw and plate breakage so our testing method simulated one
of the failure modes met in a clinical case. Transarticular screws may fail by screw pullout in rare cases of severe osteoporosis because of the high strength of the fixation. Our testing methods had to account for a number of uncontrolled variables, like bone mineral density and spine specimens’ morphology. The same spine surgeon inserted all the screws to eliminate variability of technique.

A decision had to be made as to what screw length to use for the T-plate technique. We selected a medium size screw that would fit into the fixation without penetrating the cortex. According to spine morphology, screw length would vary from specimen to specimen, but we decided to use the same screw length for the purpose of evaluating T-plate fixation.

For the transarticular fixation we used 50 mm screw length for all the tested specimens. We chose this length due to the use of a holding device (about 10 mm width) for pullout tests. Ebraheim (2000) study suggest that the mean optimal transarticular C1-C2 screw length may be 38 mm but the determination of the accurate optimal screw length should be made on an individual basis.

The T-plate technique of internal fixation of the cervical spine shows that the T-plate fixation provided 38% less pullout strength when compared with the traditional transarticular screw fixation described by Magerl (p = 0.035). Our study confirms the safety of the T-plate fixation when compared with the transarticular fixation. There is minimal risk of neurovascular injuries.

A more stable T-plate fixation could be obtained using a longer screw for the C2 fixation. Further anatomical studies need to determine the optimal screw length.
Motion studies on fresh specimens should be undertaken to provide information about the range of motion of these two compared fixations. A different plate design could also improve the pullout strength of the fixation.
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ABSTRACT

Background context. Transarticular fixation has yielded serious complications such as hardware failure, hypoglosal nerve injury and vertebral artery laceration lowering its widespread acceptance.

Purpose. Our objective was to evaluate the T plate construct for the atlantoaxial fusion in comparison with the Magerl technique.

Study design. Pullout tests were performed on cadaverous specimens to compare the fixation strength of T-plate fixation versus Magerl technique.

Methods. The study was performed on 18 intact specimens. Pullout tests were performed on a MTS machine.

Results. The mean failure load for the T plate fixation (mean=318.83 N, SD=46.61N) is lower than for the transarticular fixation (mean =520.07 N, SD=194.51 N).

Conclusion. Posterior cervical plating offers a reasonable alternative for the clinical situations in which the placement of the transarticular screws is contraindicated. The safe placement of the screws is the main advantage of the T-plate construct versus the transarticular screw fixation. Ongoing research will evaluate the optimal screw length placed on C1 and C2 for the T-plate fixation.

Key words: cervical spine, T–plate, transarticular screw, biomechanic, cadaveric