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Original Investigation

The C2-Pars Interarticularis Screw as an Alternative in Atlanto-Axial Stabilization. A Biomechanical Comparison of Established Techniques

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ABSTRACT

AIM: To compare four different atlantoaxial stabilization techniques.

MATERIAL and METHODS: Eight human cervical spines (segments C0-C3) were tested in flexion/extension, lateral bending and axial rotation. Range of Motion (ROM) at a 1.5 Nm load was recorded. After native testing, the Harms (HARMS), pars screw (PARS), intralaminar screw (INTRA) and anterior transarticular screw (ATA) constructs were applied in a random order.

RESULTS: FLEXION/EXTENSION: mean ROM (±SD) in native state was 15.9° (± 7.6°); HARMS 3.6° (± 2.0°); INTRA 5.5° (± 2.7°); PARS 2.8° (± 1.6°); ATA 3.7° (± 1.3°). A significant difference was found for all techniques compared to the native spine.

LATERAL BENDING: ROM in native state was 3.2° (± 1.9°); HARMS 1.4° (± 0.4°); INTRA 2.5° (± 1.4°); PARS 1.3° (± 0.7°); ATA 0.9° (± 0.6°). There were no significant differences compared to native spine, although ATA and PARS showed a strong tendency. INTRA had a significantly higher ROM than ATA.

AXIAL ROTATION: ROM in native state was 15.7° (± 6.6°); HARMS 1.5° (± 0.7); INTRA 2.7° (± 2.1°); PARS 1.7° (± 0.7); ATA 1.1° (± 0.3°). All instrumentation techniques significantly reduced ROM; there was no significant difference between the techniques.

All instrumentation techniques were able to reduce ROM for most of the motions. The differences between the techniques were small. Nevertheless, the intralaminar screw showed deficits in lateral bending.

CONCLUSION: Screw positioning seems to be of minor influence on stability in atlantoaxial stabilization. Therefore, the pars screw is a sound alternative to the established techniques from a biomechanical point of view. Anatomical considerations for screw placement should be kept in mind as a superior priority.

KEYWORDS: Atlanto-Axial stabilization, Biomechanical comparison, C2-Pars interarticularis screw, Intralaminar screw, Anterior transarticular screw fixation

INTRODUCTION

The atlanto-axial joint complex plays an important role in cervical spine mobility. About 50% of axial rotation and 12% of flexion-extension motion are provided by the first two vertebrae (28). In cases of severe instability caused by trauma, inflammatory disease or neoplasm, surgical stabilization is indicated.

Several different methods have been proposed for surgical stabilization of the atlanto-axial complex. The most common methods are posterior transarticular screw fixation according

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to Magerl (12), or posterior stabilization with a screw-rod system according to Goel/Harms (7,9). Posterior cervical screw-rod instrumentation via posterior cervical pedicle screws (pCPSs) requires an anchor in the occipitocervical and cervicothoracic instrumentation final at C2 (20).

Transarticular screw fixation of atlantoaxial joint stabilization was described in 1987 by Magerl and Seeman (19). The goal of rigit fixation over wiring with onlay bone grafting is to gain higher fusion rates, thus reducing malaligment that occurs after operation and to reduce the period of a patient's postoperative immobilization with a brace. However, significant risks related with transarticular screw fixation of AA, such as screw malposition or vertebral artery injury, can be fatal, and as such cannot be ignored (2).

Due to the proximity of vital anatomical structures, such as the vertebral artery, the upper cervical myelon, spinal nerves and the small dimension of atlas and axis, these techniques are regarded as demanding. Furthermore, a high rate of anatomical variants have been described, which sometimes raises the need for an alternative screw placement, especially in the axis vertebra (C2).

The success of Margel's method depends on the anatomic alignment of the C1-2 joint to send the screw safely to the target and to accomplish sufficent fixation in both C1 and C2. Additionally, this technique can be almost impossible when the patients anatomy is improper, such as for morbidly obese patients with a thick back- neck or inflated cervicothoracic kyphosis (2).

Pedicle screw fixation is a milestone of posterior C2 fixation and it is mostly preferred when a direct C1 fixation is not essential with a posterior fixation of C2. Although problems in obtaining the desired screw route are thought to be less than with transarticular screw insertion, the injury risk to a vertebral artery is reported parallel to that reported with transarticular screws, which is mainly a consequence of variant vertebral artery anatomy.While the screw malposition rate for a C2 pedicle screw is reported as 7%, the vertebral artery injury rate is between 4-6 % with transarticular screw placement, which is almost the same as with C2 pedicle screws (2,8).

Examples of such alternative screw trajectories are the intralaminar screw placement in C2 introduced by Wright et al. (29), or an anterior transarticular screw fixation via an anterior retropharyngeal approach (18).

Another alternative screw placement in C2 is sometimes referred to as a "pars" or "isthmus" screw and uses the same entry point and trajectory as the Magerl screw without crossing the C1/2 facet joint. A drawback of this technique may be the very short length of the screw, which might have a negative impact on construct stability.

Either standard or short C2 pedicle screws can be used for posterior, atlantoaxial (AA) fusions of the cervical spine. What is the impact of the pedicle screw length in C1-2 atlantoaxial fusion construct? Xu et al. used 12 cadaveric spines to compare short (16 mm) and standard (26 mm) C2 pedicle screws in a C1-2 posterior fusion construct. They focused on an in vitro biomechanical comparison of standard versus short C2 pedicle screws to perform posterior C1-C2 AA fusions. Both standard and short C2 pedicle screws allow for equally rigid fixation of the C1 lateral mass-C2 AA fusions. Sim et al. compared a short C2 pedicle screw (14-16 mm) to a standard long C2 pedicle screw (24-28 mm) in a C1-C2 AA fixation study (25). Both studies found no statistical difference between long and short pedicle screws in regard to range of motion and neutral zones (33).

All these techniques can be categorized as posterior and anterior techniques or transarticular screw and internal fixator techniques. The common advantage of internal fixator techniques is the preservation of the facet joint, which is obligatory for functional recovery after implant removal. Disadvantages are the high cost of the implants as well as the generally more difficult technically procedures.

Beside the differences in handling and implant cost, the different screw positions may have an impact on construct stability. Most of the mentioned techniques have been compared in several biomechanical studies (Table I). However, to the best of our knowledge, there is still very limited information regarding the pars screw and anterior transarticular screw fixation.

Objectives

The aim of this study was to compare four different atlantoaxial stabilization techniques:

1. Goel/Harms technique (in the results section abbreviated as HARMS) as a standard technique, as well as:
2. Anterior transarticular screw (ATA),
3. Intralaminar screw (INTRA) and
4. Pars interarticularis screw (PARS) as alternative techniques.

A comparison of the pars screw vs. anterior transarticular screw has never been done before. A comparison between pars screw vs. intralaminar screw vs. the Goel/Harms construct has been studied only once (4). Thus, a confirmation of their data is missing.

Hypotheses

Our hypotheses were:

1. Atlantoaxial stabilization with a pars screw in C2 is able to reduce atlantoaxial Range of Motion (ROM) under physiologic loading conditions to the same extent as a Goel/Harms construct or an anterior transarticular screw fixation.
2. The pars screw technique is able to reduce ROM to a greater extent than the intralaminar screw position according to Wright (31).

■ MATERIAL and METHODS

Specimens and specimen preparation

The tests were performed using eight fresh frozen human spine specimens (C0-C3), originating from a U.S. American population of voluntary body donors, which were acquired via

Table I: Biomechanical Research on the Proposed Techniques

Publication	C2-Pedicle screws (Goel/Harms)	C2-Pars/Isthmus- screw	C2-intralaminar screw (Wright)	Anterior-transarticular
Härtl, 2006 (10)			X (vs. lateral mass screws and Magerl)	
Dmitriev, 2009 (4)	X	X	X	
Sim/Lee/Park, 2011 (25)	X	X ("short pedicle screw")		
Lapsiwala, 2006 (16)	X		X	X
Kim/Lim, 2004 (14)	X			X
Hong/Takigawa, 2011 (11)		X	X (+ additional group w/ laminar decortication)	

an institutionalized supplier of body donations (ScienceCare, Phoenix, AZ, USA). Prior to acquisition, anonymized patient files were screened for malignant diseases or bone metabolism pathologies that might affect the biomechanical properties of the specimens.

Prior to inclusion, every specimen was screened using spiral CT and bone mineral density (BMD) that was measured using QCT (Toshiba Aquilion32, Toshiba Corp., Tokyo, Japan) in the vertebral body of C2 and C3, excluding cortical structures. The calculated BMD was averaged over these two vertebrae.

After thawing of the specimens in a 25°C water bath, muscles and other soft tissue were removed while preserving intervertebral discs, facet capsules and ligamentous structures. The occipital bone (C0) and the distal half of C3 were embedded in Polymethylmethacrylat (PMMA; Technovit 3040, Heraeus Kulzer GmbH, Wehrheim/Taunus, Germany) to improve fixation in the spine tester.

Surgical procedures and implant type

Goel/Harms method

Posterior atlantoaxial stabilization according to Goel/Harms necessitates the use of an internal fixator (7,9). The screws are inserted into the lateral masses of C1 and into the pedicles of C2.

The entry point for the C1 lateral mass screw is just below the posterior lamina of the posterior arch, right in the middle of the lateral mass. The screw was directed 10° medially and 10° cranially.

The C2 pedicle screw was inserted similar to the Judet technique for osteosynthesis of a hangman's fracture (24). Entry point was right in the middle of the lateral mass of C2, with a screw trajectory of about 25° cranially and 15-25° medially. Screw length was 30-35 mm. Figure 2A, B show a CT hologram of an instrumented cervical spine specimen with the Harms type screw configuration.

The following constructs (intralaminar and pars screw constructs) are variants, derived from the Goel/Harms construct. They only differ in the positioning of the C2-screw, which was done because of the frequent need for alternative pathways due to the course of the vertebral artery. The C1 screw was always left in place.

Posterior intralaminar screw construct

This construct, later on referred to as INTRA, is based on the Goel/Harms construct. The C1 screw positioning is the same as in the Goel/Harms construct, therefore this screw was left in place.

The entry point for the C2 screws were at the junction between the C2 lamina and C2 spinous process, with one screw entering slightly cranially and the contralateral screw entering slightly caudally to avoid interference. The trajectory was oriented towards the pathway of the lamina, with a slight tendency posteriorly to avoid entering the spinal canal as per Wright et al. (31). Screw length was about 30 mm.

Figure 3A, B show a CT hologram of an instrumented cervical spine specimen with the intralaminar screw configuration.

C2-pars-screw construct

This construct, later on referred to as PARS, is also based on the Goel/Harms construct.

The entry point and trajectory of the C2 screw were similar to the posterior transarticular screw fixation according to Magerl (12). The entry point was located at the lower edge of the C2 articular process, about 2-3 mm above the C2/3 facet joint line and about 3 mm lateral of the medial border of the C2 pedicle, which was located using a small dissector. In the original Magerl technique, the screw direction is strictly parallel to the sagittal plane, with an upward angulation aiming at the C1 lateral mass. Since there is no need to cross the C1/2 joint when using an internal fixator, the upward angulation was reduced to adapt to a possibly interfering high-riding vertebral artery, resulting in a shorter screw length, which ranged from 15-20 mm.

Figure 4A, B shows a CT hologram of an instrumented cervical spine specimen with the pars type screw configuration.

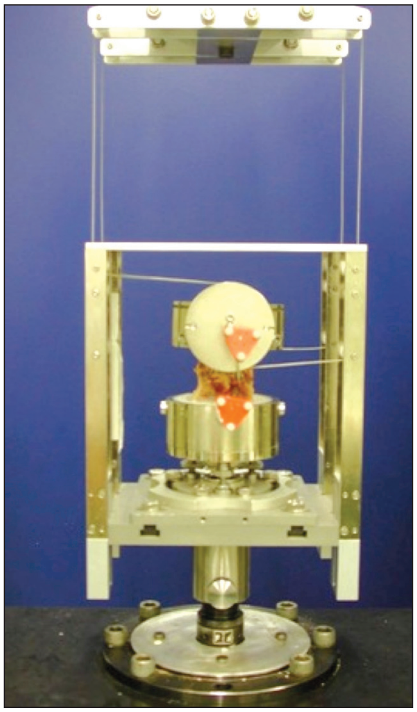

Figure 1: The test setup with a cervical spine specimen mounted for flexion/ extension.

Anterior transarticular screw fixation

Anterior transarticular screw fixation was performed according to Lesoin et al. (18).

In a clinical setting, this approach is similar to that for anterior odontoid screw fixation. The entry point for the screw was in a groove beneath the articular surface of C2, about 8-10 mm from the midline. The trajectory was directed about 25° laterally, aiming at lateral mass of C1. The length of the screw was around 25-30 mm.

Figure 5A, B show a CT hologram of an instrumented cervical spine specimen with an anterior transarticular screw configuration.

Implant Type

In this study, we used a polyaxial internal fixator system (Synapse®, Synthes GmbH, Oberdorf, Switzerland) for all posterior fixation techniques. Screw diameter was 3.5 mm.

For anterior transarticular screw fixation, we used standard titanium, self-tapping 3.5 mm non-cannulated cortical bone screws (Synthes GmbH, Oberdorf, Switzerland).

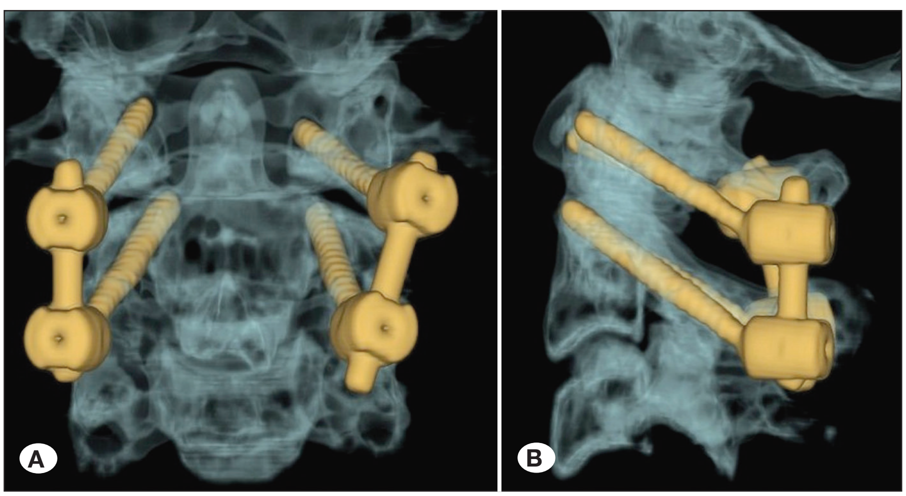

Figure 2: A) CT holographic visualisation of a cervical spine specimen with Harms type instrumentation in a-p view, **B)** lateral view.

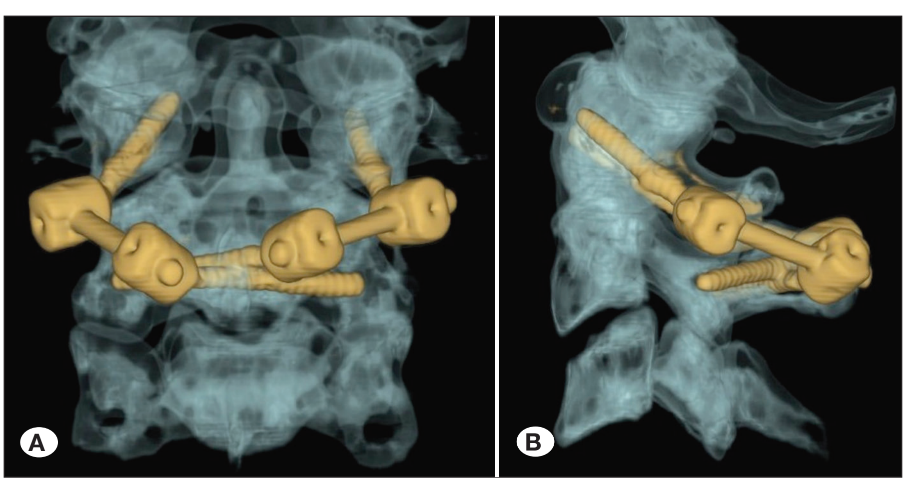

Figure 3: A) CT holographic visualisation of a cervical spine specimen with translaminar screw instrumentation in C2; a-p view, **B)** lateral view.

Test protocol and biomechanical methodology

All specimens were subjected to three-dimensional flexibility testing in a custom-made spine tester, which allowed for unconstrained loading in flexion, extension, lateral bending and axial rotation (Figure 1). The load was applied by transforming the axial force of a materials testing machine (Zwick Z005, Zwick GmbH, Ulm, Germany) via a cable and pulley system into a torque moment, similar to the setups described by Crawford et al. and Kandziora et al. (3,13).

After testing in native state as a baseline, every specimen was tested with every one of the four different stabilization methods. To minimize a possible bias from repetitive testing, the stabilization methods were applied in a randomized order.

The load was applied adding up to a maximum load of 1.5 Nm, as recommended by Wilke et al. (29). The loading rate was 0.1 Nm/s. The load application was repeated three times, with the first two cycles serving as preconditioning cycles and the third cycle as the relevant test cycle. The weight of the upper potting device added up to 5 N. An additional axial preload was not applied. Tests were performed with loading in flexion/extension, lateral bending and axial rotation load, with every specimen being tested in the same loading order.

Angular motions between C1 and C2 were recorded by an infrared motion tracking and analysis system (Vicon Inc., Oxford, UK). The accuracy found in prior tests and was about 100 µm and 0.1° (30).

Primary endpoint was the Range of Motion in degrees.

Load-displacement diagrams were evaluated for sigmoid curves, indicating a differentiable neutral and elastic zone. Elastic zone stiffness was recorded.

Data management and statistics

The angulation between C1 and C2 was visualized in a load displacement diagram. The six different loading steps were identified and the values were manually recorded into an Excel file.

Statistical analysis was done with the statistical software PASW (SPSS) 16.0 for Windows (IBM, Armonk, USA). After screening for a normal distribution of the values, a repeated measures ANOVA was used to detect statistical significance. A level of significance was assumed for a p-value of < 0.05. This was followed by a post-hoc Bonferroni analysis in case of significance.

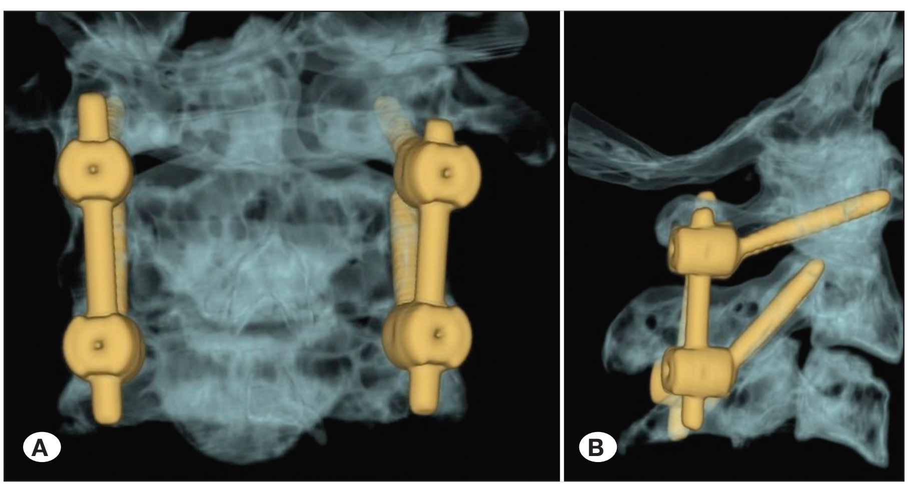

Figure 4: A) CT holographic visualisation of a cervical spine specimen with pars screw instrumentation in C2; a-p view, **B)** lateral view. Note the C2 screw tip, which is proximal to the superior facet joint of C2, but does not cross.

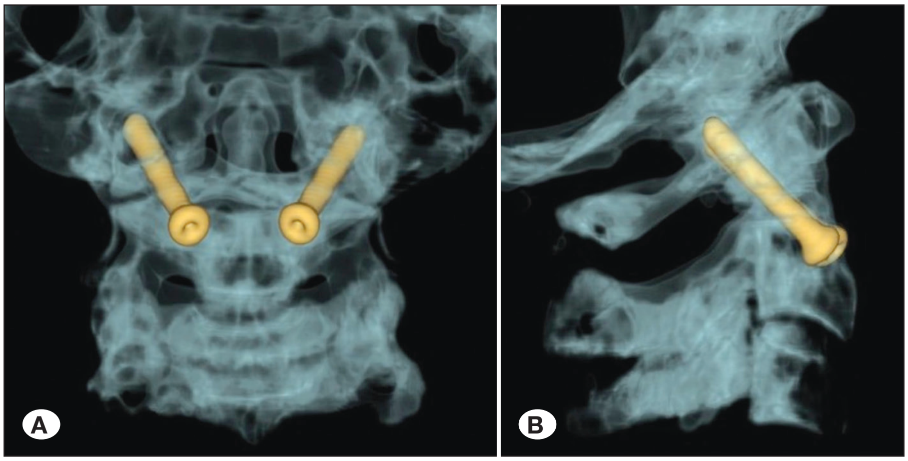

Figure 5: A) CT holographic visualisation of a cervical spine specimen with anterior transarticular screw instrumentation in C2; a-p view, **B)** lateral view.

RESULTS

Population

The average age of the donors was 62.9 years (57-66), and the male-to-female ratio was 4:4. Average BMD was 289.81 mg/cm³. The obtained specimen showed no osteolytic or traumatic defects and no signs of gross degeneration.

Flexion/Extension

Figure 6 and 7 shows the results of the ROM and stiffness measurements in flexion/extension respectively as a percentage of the native specimen. Absolute ROM values are listed in Table II.

Mean ROM was highest for the native state (15.9°). Regarding the instrumented specimen, the INTRA configuration had the highest ROM (5.5°), followed by HARMS (3.7°), ATA (3.7°) and PARS showing the lowest ROM (2.8°).

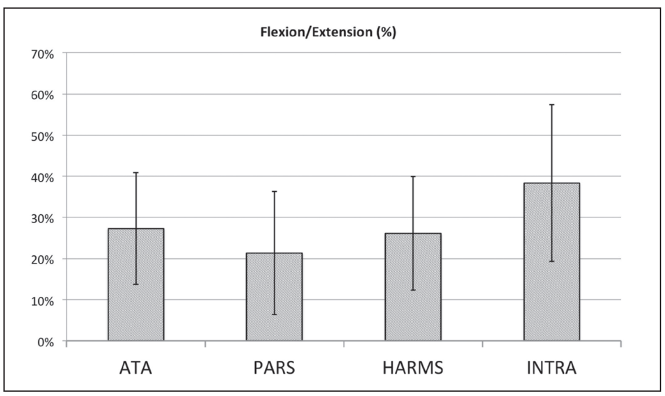

Figure 6: Results of testing in flexion/extension. Displayed are the ROM values as a percentage of the native specimen (native spine = 100%; ± standard deviation, SD). The differences between the four surgical techniques are small.

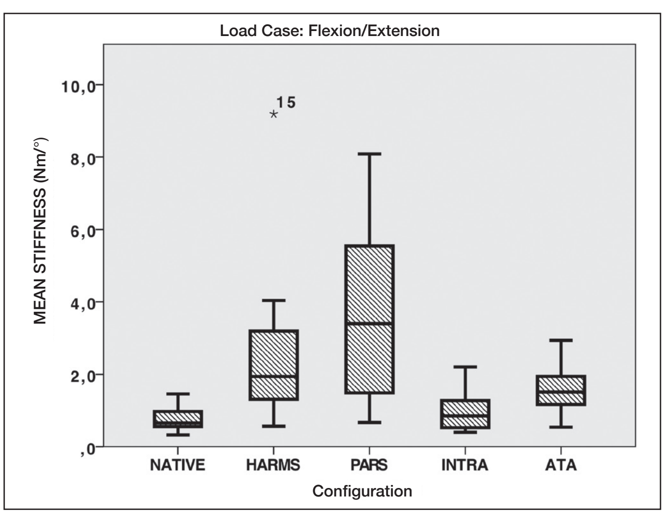

Figure 7: Results of testing in lateral bending. Displayed are the ROM values as a percentage of the native specimen (native spine = 100%; ± standard deviation, SD). The intralaminar screw technique was not able to stabilize the spinal segment superior to the native state.

The difference between native spine and instrumented spine was significant for all techniques ($p < 0.05$).

Comparing the instrumentation techniques, there were no significant differences. Nevertheless, the comparison between HARMS and INTRA showed a strong tendency ($p = 0.053$).

Elastic zone stiffness was highest in the PARS group, with the lowest stiffness for the native spine. Significant differences were measured between native and PARS ($p = 0.002$) and PARS vs. INTRA ($p = 0.011$).

Lateral Bending

Load case lateral bending results are displayed in Figures 8, 9 and Table III.

For lateral bending, native spine was the least stable configuration (mean ROM: 3.2°). The least stable instrumented configuration was INTRA (mean ROM: 2.5°), followed by HARMS (1.4°), PARS (1.3°) and ATA (0.9°).

There were no significant differences between native spine and the instrumented specimens. The comparison between native and PARS showed a strong tendency ($p = 0.054$). Between the instrumentation techniques, there was a significant difference between ATA and INTRA ($p = 0.045$).

Table II: ROM Flexion/Extension

Configuration	Mean ROM	Standard Deviation
	(degrees)	
Native	15.9	7.6
Goel/Harms	3.7*,#	1.3
Intralaminar screw	5.5*	2.7
Pars screw	2.8*	1.6
Anterior transarticular screw	3.7*	1.3

**significant difference to native specimen, #significant difference to intralaminar screw technique.*

Table III: ROM Lateral Bending

Configuration	Mean ROM	Standard Deviation
	(degrees)	
Native	3.2	1.9
Goel/Harms	1.4	0.4
Intralaminar screw	2.5	1.4
Pars screw	1.3	0.7
Anterior transarticular screw	0.9#	0.6

**significant difference to native specimen, #significant difference to intralaminar screw technique.*

Elastic zone stiffness was highest for ATA, followed by HARMS and PARS. The INTRA configuration was just slightly above native spine. Significant differences were found between native, and ATA (p = 0.007), and INTRA, and ATA (p = 0.017).

Axial rotation

Load case axial rotation results are displayed in Figures 10, 11 and Table IV.

In axial rotation, again, native spine showed the highest ROM with a mean value of 15.7°. The instrumentation techniques reduced ROM significantly ($p < 0.001$) with INTRA allowing 2.7°, PARS 1.7°, HARMS 1.5° and ATA 1.1°. There was no significant difference between the different techniques ($p > 0.05$).

Table IV: ROM Axial Rotation

Configuration	Mean ROM	Standard Deviation
	(degrees)	
Native	15.7	6.6
Goel/Harms	1.5*	0.7
Intralaminar screw	2.7*	2.1
Pars screw	1.7*	0.7
Anterior transarticular screw	1.1*	0.3

**significant difference to native specimen, #significant difference to intralaminar screw technique.*

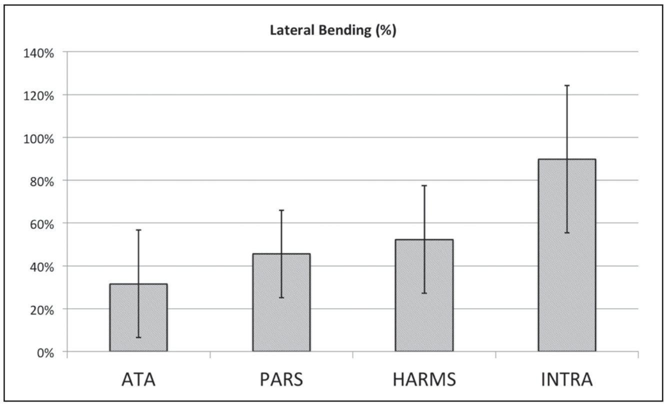

Figure 8: Results of testing in axial rotation. Displayed are the ROM values as a percentage of the native specimen (native spine = 100%; ±standard deviation, SD). The differences between the four surgical techniques are small.

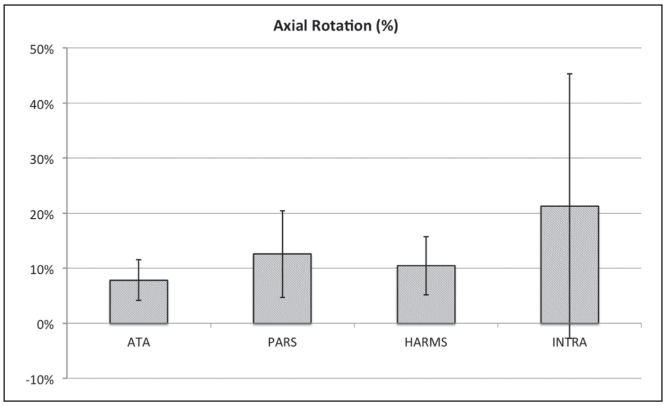

Figure 10: Results of testing in lateral bending. Displayed are the mean stiffness values ±95% confidence interval. A significant difference was seen between ATA and native/intralaminar screw, respectively.

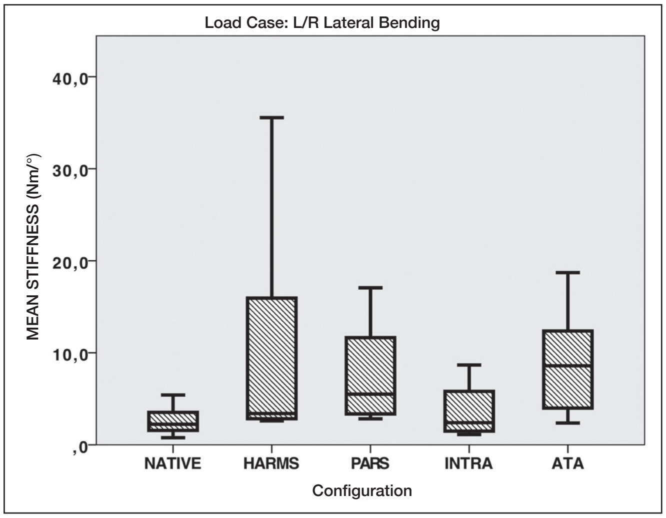

Figure 9: Results of testing in Flexion/Extension. Displayed are the mean stiffness values. The differences between the four surgical techniques are small, compared to the native spine.

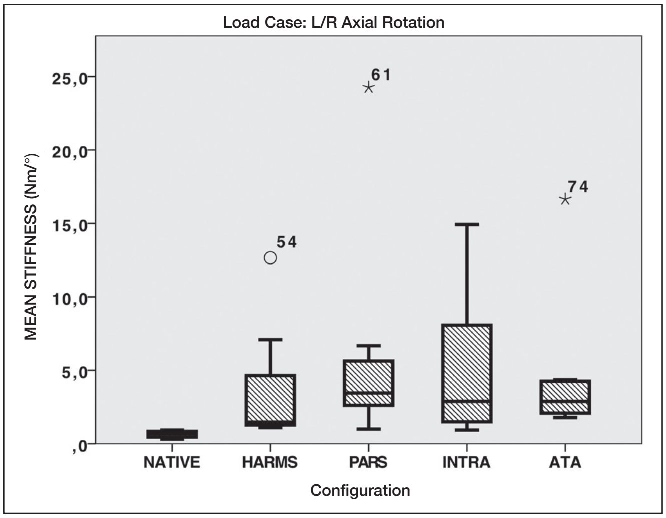

Figure 11: Results of testing in axial rotation. Displayed are the mean stiffness values. Intralaminar, pars and anterior transarticular screw showed similar results, the harms configuration had slightly lower values. Significant differences were measured between native and intralaminar/anterior transarticular screw, respectively.

Elastic zone stiffness values were quite similar for INTRA, PARS and the ATA screw. The HARMS configuration showed some little lower stiffness values with the native spine being the least stiff. Significant differences were found between native and intralaminar screw (p=0.043), and native, and anterior transarticular screw (p = 0.023).

DISCUSSION

The causes of AA instability may be due to trauma, malignancy, congenital malformation or inflammatory diseases. C1-2 reduction followed by stabilization is the gold standard for treatment of AA subluxation clinically and radiographically. There are several current approaches for internal fixation, which are usually done through a posterior approach (9).

Complicated AA anatomy can create difficulties that arise in proper screw positioning. As screw malposition can cause VA injury, which is known as the most devastating complication of screw malposition (6).

In our study, the investigated fixation techniques were all able to stabilize the atlanto-axial joint complex. The differences between the techniques were small (1.35° between highest and lowest average in flexion). Since the clinically relevant effect size for stabilizing methods on vertebral segments is still unknown, the value of these small differences is unclear.

Nevertheless, there were some statistically significant differences, such as a slightly inferior stabilization of the intralaminar screw fixation especially in flexion/extension and lateral bending. Regarding these results and the tendency towards a higher ROM for intralaminar screw fixation in the other load cases, we would favor one of the other three techniques from a biomechanical point of view, or at least, use it in a hybrid construct.

C2 translaminar screws have become popular because they reduce the risk from screw malposition complications, especially VA injury (8). Unfortunately, biomechanical analysis suggests that these screws do not provide adequate rigid fixation with a higher rate of pseudoarthrosis clinically. These screws can only be used in patients when posterior decompression is not required for C2. Additionally, the rod placement of these screws together with a C1 lateral mass or pedicle screws is challenging, which leads to the limitations of this technique (2,16).

Several studies have previously biomechanically tested intralaminar screw placements. Lehman et al. tested a pars screw, pedicle screw and intralaminar screw in a screw pull out and insertional torque setup (17). They found that pedicle screws provided the best anchorage. Intralaminar screws exceeded pars screws in both parameters, but without a significant difference. In a subsequent study from the same group using a 3D-spine tester, Dmitriev et al. found better stability in the intralaminar screws compared to a pars screw in axial rotation and significantly lower stability for the intralaminar screw compared to a pars screw in lateral bending (4). A comparison of intralaminar vs. pedicle screws found no difference.

These results are partly conclusive and partly contradictory to our results. The major difference occurs in axial rotation, where Dmitriev et al. found much higher values (ca. 7° ROM) for the pars screw, whereas both studies showed a weak performance for the intralaminar screw in lateral bending. A reason for these differences might be the slightly alternative screw pathways used in these studies. In another study, Benke et al. compared C2-intralaminar to transpedicular screw placement in a C2-C6 subaxial construct (1). Similar to our results, they found significant lower rigidity for intralaminar screw placement in lateral bending. On the other hand, in axial rotation, the intralaminar screw technique was significantly stiffer in their study; however, in our study, we did not see this difference.

Another comparison of intralaminar and pars screw in an odontoid resection model was conducted by Hong and Takigawa (11). They found significant superior stability for pars screws in lateral bending and axial rotation, which is partially concordant with our results, showing a tendency toward the inferior stability of the intralaminar screws in nearly all loading directions.

Anterior transarticular screw fixation was intensively tested by Lapsiwala et al. in an odontoid resection model (16). This study compared against a Goel/Harms construct as well as a C2 intralaminar construct. Their results showed an opposite behavior for flexion extension, with the translaminar screw being the stiffest construct and an anterior transarticular screw the floppiest. In lateral bending, the results were similar to ours, with the translaminar screw being the weakest construct. Resistance against axial rotation was highest with a Goel/Harms construct and the translaminar screws, and lowest with anterior transarticular screws. Unfortunately, a statistical comparison was not done between these three techniques.

Xu et al. studied 60 patients to compare VA injury risk associated with percutaneous anterior transarticular and posterior transarticular screws. They found that percutaneous ATA fixation includes less anatomic risk of VA injury than percutaneous PTA fixation (32).

Koller et al. suggest that although the anterior transarticular fixation technique is neglected in the literature, it is a sound alternative to the equally-demanding posterior transarticular fixation. We also think there is still insufficient information about the ATA technique and its performance in comparison with posterior fixation techniques. Our study is the first to compare the pars screw vs. anterior transarticular screw fixations (15).

Härtl et al. compared intralaminar screw placement with an additional interlaminar bone graft against a Magerl-Gallie construct and a C1-3 internal fixator with a lateral mass screw (10). They also found a significantly higher ROM for the intralaminar screw placement, especially in lateral bending.

In 2013, Su et al. studied 15 cadaveric spines to compare the strength of three different types of C2 fixation. C2 pedicle screws had significantly increased stiffness (pullout strength) compared with bilateral short C2 pars screws. Bilateral pedicle screws, bilateral pars screws and hybrid of unilateral pars screw with contralateral pedicle screw combinations all showed the ability to limit range of motion and significantly decreased after cyclical testing in flexion-extension, lateral bending, and axial rotation. They concluded that in situations with anatomical limitations like a high-riding or medialized vertebral artery, the unilateral C2 pedicle screw along with a contralateral short pars screw is a viable biomechanical option that may be as stable as a bilateral pedicle screw construct (26).

With data from over 1,000 AA instrumentation cases, a meta-analysis by Elliott et al. found that the combination of C1 lateral mass screws with C2 pars or pedicle screws provided perfect stabilization and arthrodesis rates (95-99%) without any halo vest immobilization requirement. In comparison, C2 pedicle screws over C2 pars screws had only a slightly higher rate of successful arthrodesis.The review of over 3,000 cases demonstrated that the rate of VA injury with C-2 pedicle screws was approximately 0.3% and no VA injury occurred with shorter pars screws. There were also a higher proportion of screw malpositions identified radiographically for pedicle screws than for pars screws, which is not significant statistically. These findings suggest that C-2 pars screws may be slightly safer than pedicle screws (6).

To summarize all the biomechanical results in our study, one can state that all the techniques provide high stability. The Goel/Harms technique, as a gold standard, sets a benchmark. Anterior transarticular screw fixation and the pars interarticularis screw do not perform worse. Therefore, our hypothesis of a similar stabilizing effect from the pars interarticularis screw was met.

For the intralaminar screw, emerging data suggests inferior stabilizing properties. Thus, our second hypothesis was also met. Ex post, this might be easily explained by the C2-screws' entry points, which are very close to each other and to the instantaneous axis of rotation for C1-2 lateral bending. Nevertheless, it is doubtful whether this small ROM difference of some 1-2° will have any clinical effect, since clinical applications of the intralaminar screw technique also show good results (21,22).

It is important to recognize the difference between the C2 pedicle and pars interarticularis (isthmus), which are anatomically disparate structures. Ebraheim et al. described the C2 pedicle as a dense bone that connects the inferior articular fascet to the C2 vertebral body, and C2 pars as a trabecular bone between superior and inferior articular processes. The distinction between these two different structures is much more significant for confrontation with situations such as a high-riding or medialized vertebral artery, in which a long C2 pedicle screw places the vertebral artery at risk (5,26).

C2 pedicular screw placement has a more superior and medial trajectory according to transarticular screw placement, which decreases the risk of VA injury (18,27); however, several studies have also found that the anatomical risk of VA injury does not significantly differ between these two techniques (4,7). The risk of vertebral artery injury with pedicle screws is for the most part similar to that reported with transarticular screws, which is as a consequence of abnormal vertebral artery anatomy, although problems with obtaining the desired screw trajectory are thought to be less than with transarticular screw placement (2,8).

Given the anatomical history of VA, there are two anatomic variations associated with VA injury: the first is high-riding VA (HRVA), which increases the risk of VA injury during C1-2 transarticular screw fixation, (1,3,9,13); and the other is a narrow pedicle that increases VA injury risk in C2 pedicle screwing (27).

The prevalence of HRVA and a narrow C2 pedicle has been reported to be 14.5%–18% and 9.5%–32%, respectively (7,29,30).

In C2 vertebra posterior instrumentation, the surgeon should be accustomed with all techniques. In the event that anatomical difficulties are encountered, such as an inordinately narrow pedicle to place the screw or the presence of abnormal VA, the surgeon should be able to choose the safest procedure for the patient (23). Several authors have stated that preoperative computed tomography evaluation to identify VA variations would be helpful for deciding upon the best fixation method to avoid VA injury (2,29).

■ CONCLUSION

Of the investigated instrumentation techniques, all had the potential to sufficiently stabilize the atlanto-axial complex. Since the differences between the techniques are small, the decision to utilize either screw type should be made only after punctilious review of each patient's anatomy on computed tomography imaging to avoid risks from the presence of anatomical variants, such as a high-riding vertebral artery or due to the dimension of the pedicles.

Preferring to stabilize the AA region with C2 pedicle screws achieved better rigid fixation for patients with unfavorable body habitus and for those with an irreducible C1-2 complex. We believe that the low-risk of pars screws in terms of VA injury makes it a good alternative to pedicle screwing and also in terms of the need for pedicle screw revision.

It is our opinion that a pars screw can be the alternative to pedicle screws. It's the best choice for C2 when considering anatomical variations, such as in cases of posterior decompression or unfavorable body habitus. Considering the advantages compared to alternatives, utilizing a pars screw should be kept in mind.

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