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Cadaveric Biomechanical Comparison of Cervical Transarticular Facet Screw Fixation Versus Lateral Mass Screw Fixation: Range of Motion and Construct Stiffness Analysis

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Abstract

Background: Posterior cervical fixation is widely used to stabilize the cervical spine in conditions such as trauma, degenerative disease, and instability. Among the commonly employed techniques, lateral mass screw fixation has been widely accepted due to its safety and ease of insertion. However, transarticular facet screw fixation has been proposed as an alternative technique that may provide superior biomechanical stability. Comparative biomechanical data evaluating these two fixation methods remain limited. ***Aim:*** To biomechanically compare cervical transarticular facet screw fixation with lateral mass screw fixation in terms of range of motion and construct stiffness using cadaveric cervical spine specimens. ***Materials and Methods:*** This cadaveric experimental biomechanical comparative study included 80 human cervical spine specimens, divided equally into two groups: transarticular facet screw fixation (TAFSF, n=40) and lateral mass screw fixation (LMSF, n=40). After instrumentation, the specimens were mounted on a biomechanical testing apparatus and subjected to controlled loading conditions simulating physiological cervical spine movements. Range of motion (ROM) was measured in flexion–extension, lateral bending, and axial rotation. Construct stiffness, intervertebral translation, facet joint gapping, and resistance to displacement were also evaluated. Statistical analysis was performed using the independent t-test and chi-square test, with $p < 0.05$ considered statistically significant. ***Results:*** Baseline specimen characteristics were comparable between groups. Following instrumentation, the global ROM was significantly lower in the TAFSF group (12.8 ± 2.9°) compared with the LMSF group (15.6 ± 3.1°) ($p < 0.001$). Transarticular fixation demonstrated significantly greater reduction in ROM relative to the intact spine (76.4% vs 69.1%, $p < 0.001$). Construct stiffness was significantly higher in the TAFSF group (1.92 ± 0.41 Nm/°) compared with the LMSF group (1.53 ± 0.39 Nm/°, $p < 0.001$). Peak intervertebral translation, facet joint gapping, and displacement under shear loading were significantly lower in the TAFSF group, indicating improved biomechanical stability. The load required to produce translational displacement and construct failure load were also significantly higher in the TAFSF group. ***Conclusion:*** Transarticular facet screw fixation demonstrated superior biomechanical stability, greater construct stiffness, and more effective reduction of cervical spine motion compared with lateral mass screw fixation. These findings suggest that transarticular fixation may provide a mechanically stronger construct for posterior cervical stabilization.

Keywords: Cervical spine fixation. Transarticular facet screw. Lateral mass screw.

INTRODUCTION

The cervical spine is a highly mobile and complex anatomical structure responsible for supporting the head while allowing a wide range of movements including flexion, extension, lateral bending, and axial rotation. However, due to its mobility and relatively delicate structure, the cervical spine is susceptible to instability caused by trauma, degenerative disorders, tumors, infections, and congenital abnormalities. Cervical spinal instability may lead to neurological deficits, chronic pain, and progressive deformity if not treated appropriately. Surgical stabilization using posterior fixation techniques is often required to restore spinal alignment, maintain stability, and protect neural structures.[1]

Posterior cervical fixation techniques have evolved significantly over the last several decades with the goal of providing strong biomechanical stability while minimizing surgical complications. Among the commonly used posterior stabilization methods are lateral mass screw fixation and transarticular facet screw fixation. Lateral mass screw fixation, popularized by Roy-Camille and later modified by Magerl and Anderson, has become one of the most widely used techniques for posterior cervical stabilization due to its relative safety and reproducibility. This technique involves placement of screws into the lateral masses of the cervical vertebrae and provides adequate stabilization for many cervical spine pathologies.[2]

Despite its widespread use, lateral mass screw fixation may have certain biomechanical limitations, especially in cases requiring higher construct rigidity. The fixation strength largely depends on bone quality and the limited purchase within the lateral mass. In contrast, transarticular facet screw fixation, which involves screw placement across the facet joint into the adjacent vertebra, has been proposed as an alternative technique that may offer greater biomechanical stability. By crossing the facet joint, the transarticular screw engages multiple cortical surfaces, potentially providing stronger fixation and improved resistance to motion.[3]

Biomechanical evaluation of spinal fixation constructs is essential to determine the stability provided by different surgical techniques. Cadaveric biomechanical studies are commonly used to simulate physiological loading conditions and assess parameters such as range of motion (ROM), construct stiffness, and resistance to displacement. These studies allow objective comparison of fixation techniques without exposing patients to experimental procedures. Several studies have suggested that transarticular facet screws may provide superior rotational stability and increased stiffness compared with traditional lateral mass screws, particularly in multilevel constructs.[4]

AIM

To biomechanically compare cervical transarticular facet screw fixation with lateral mass screw fixation in terms of range of motion and construct stiffness using cadaveric cervical spine specimens.

OBJECTIVES

1. To evaluate the range of motion (ROM) of cervical spine segments stabilized with transarticular facet screw fixation and lateral mass screw fixation.
2. To compare the construct stiffness provided by transarticular facet screws and lateral mass screws under simulated physiological loading conditions.
3. To determine the biomechanical stability and resistance to displacement between the two fixation techniques.

MATERIALS AND METHODS

Source of Data

The data for the present study were obtained from human cadaveric cervical spine specimens collected from the Department of Anatomy of a tertiary care teaching institution. Biomechanical testing measurements including range of motion and construct stiffness were recorded from these cadaveric specimens after application of the fixation techniques.

Study Design

The study was conducted as a cadaveric experimental biomechanical comparative study designed to analyze the mechanical stability of two different cervical spine fixation techniques.

Study Location

The study was carried out in the Department of Neurosurgery and Department of Anatomy in collaboration with the Biomechanics Laboratory of a tertiary care medical college.

Study Duration

The study was conducted over a period of 12 months, which included specimen preparation, instrumentation, biomechanical testing, and data analysis.

Sample Size

A total of 80 cadaveric cervical spine specimens were included in the study.

The specimens were divided into two groups:

- Group A: Cervical Transarticular Facet Screw Fixation (40 specimens)
- Group B: Cervical Lateral Mass Screw Fixation (40 specimens)

Inclusion Criteria

- Intact adult human cadaveric cervical spine specimens (C3–C7).
- Specimens without visible deformity or prior surgical intervention.
- Specimens with preserved bone integrity and normal anatomical alignment.

Exclusion Criteria

- Specimens showing evidence of fractures or traumatic injury.
- Specimens with severe degenerative changes or osteoporosis.
- Specimens with congenital deformities or structural abnormalities.
- Specimens damaged during preparation or instrumentation.

Procedure and Methodology

Cadaveric cervical spine segments (C3–C7) were carefully dissected while preserving the ligaments, facet joints, and intervertebral discs. All surrounding soft tissues were removed while maintaining the structural integrity of the spinal column.

The specimens were randomly allocated into two groups. In Group A, transarticular facet screws were inserted across the cervical facet joints following standard anatomical landmarks and surgical techniques. The screws were placed across the inferior articular process of the superior vertebra into the superior articular process of the inferior vertebra to stabilize the segment.

In Group B, lateral mass screws were inserted into the lateral masses of the cervical vertebrae using the standard Roy-Camille technique. The screws were placed with appropriate angulation to avoid injury to the vertebral artery and neural structures.

Following instrumentation, each specimen was mounted on a biomechanical testing apparatus capable of applying controlled loads to simulate physiological spinal movements. Controlled forces were applied to evaluate spinal motion in flexion, extension, lateral bending, and axial rotation.

The range of motion (ROM) of each specimen was measured under standardized loading conditions before and after fixation. Construct stiffness was determined by analyzing the resistance of the fixation constructs to applied forces.

Sample Processing

Each cadaveric specimen was inspected and cleaned prior to instrumentation. Specimens were stored at controlled temperatures to prevent tissue degradation. Before biomechanical testing, specimens were thawed at room temperature and carefully mounted onto the testing frame. All instrumentation procedures were performed by experienced spine surgeons to ensure accuracy and consistency.

Statistical Methods

The collected data were entered into Microsoft Excel and analyzed using SPSS statistical software version 25.
Descriptive statistics such as mean and standard deviation were calculated for range of motion and stiffness values. The comparison between the two groups was performed using the independent sample t-test for continuous variables.
A p-value less than 0.05 was considered statistically significant.

Data Collection

Data were collected using a standardized recording sheet. The parameters recorded included:

- Range of motion in flexion, extension, lateral bending, and axial rotation.
- Construct stiffness under applied loads.
- Displacement measurements during loading

All measurements were recorded in a structured data sheet for statistical analysis and comparison between the two fixation techniques.

RESULTS

Table 1: Baseline specimen profile and primary biomechanical outcomes (N = 80)

Groups: Transarticular Facet Screw Fixation (TAFSF) **n=40** vs Lateral Mass Screw Fixation (LMSF) **n=40**

Variable	TAFSF (n=40)	LMSF (n=40)	Test of significance	Effect size (95% CI)	P value
Age (years)	58.3 ± 8.7	57.1 ± 9.1	Independent t-test	Mean diff = **1.20** (−2.76 to 5.16)	0.548
BMD (g/cm²)	0.84 ± 0.11	0.82 ± 0.12	Independent t-test	Mean diff = **0.02** (−0.03 to 0.07)	0.440
Male sex	23 (57.5%)	21 (52.5%)	Chi-square test	OR = **1.22** (0.51 to 2.96)	0.653
Osteopenia present	11 (27.5%)	14 (35.0%)	Chi-square test	OR = **0.70** (0.27 to 1.82)	0.469
Instrumented levels: C4–C6	26 (65.0%)	24 (60.0%)	Chi-square test	OR = **1.24** (0.50 to 3.07)	0.644
Baseline intact ROM (°)	53.7 ± 6.4	54.2 ± 6.1	Independent t-test	Mean diff = **−0.50** (−3.28 to 2.28)	0.722
Global ROM after fixation (°)	12.8 ± 2.9	15.6 ± 3.1	Independent t-test	Mean diff = **−2.80** (−4.14 to −1.46)	<0.001*
Global ROM reduction vs intact (%)	76.4 ± 7.8	69.1 ± 8.3	Independent t-test	Mean diff = **7.30** (3.71 to 10.89)	<0.001*
Overall construct stiffness (Nm/°)	1.92 ± 0.41	1.53 ± 0.39	Independent t-test	Mean diff = **0.39** (0.21 to 0.57)	<0.001*

*Statistically significant at $p < 0.05$.

Table 1 presents the baseline characteristics of cadaveric cervical spine specimens and the primary biomechanical outcomes comparing **Transarticular Facet Screw Fixation (TAFSF)** and **Lateral Mass Screw Fixation (LMSF)** groups, each comprising 40 specimens. The mean age of specimens was comparable between the two groups, with 58.3 ± 8.7 years in the TAFSF group and 57.1 ± 9.1 years in the LMSF group, and the difference was not statistically significant (p = 0.548).

Similarly, bone mineral density (BMD) values were comparable between groups (0.84 ± 0.11 g/cm² vs 0.82 ± 0.12 g/cm²; p = 0.440), indicating similar bone quality across specimens. The gender distribution also showed no statistically significant difference, with male specimens accounting for 57.5% in the TAFSF group and 52.5% in the LMSF group (p = 0.653). Osteopenia was present in 27.5% of specimens in the TAFSF group compared to 35.0% in the LMSF group, which was also statistically non-significant (p = 0.469). The majority of instrumented segments involved the **C4–C6 levels**, observed in 65.0% of TAFSF specimens and 60.0% of LMSF specimens (p = 0.644). Baseline intact cervical range of motion (ROM) was similar between groups (53.7 ± 6.4° vs 54.2 ± 6.1°; p = 0.722), confirming comparable pre-instrumentation mobility. However, after fixation, the global ROM was significantly lower in the TAFSF group (12.8 ± 2.9°) compared with the LMSF group (15.6 ± 3.1°), demonstrating significantly greater restriction of motion with the transarticular technique (p < 0.001). Consequently, the percentage reduction in ROM relative to the intact state was significantly greater in the TAFSF group (76.4 ± 7.8%) compared with the LMSF group (69.1 ± 8.3%), indicating superior motion-limiting capability (p < 0.001). Additionally, the overall construct stiffness was significantly higher in the TAFSF group (1.92 ± 0.41 Nm/°) than in the LMSF group (1.53 ± 0.39 Nm/°), suggesting greater biomechanical rigidity provided by transarticular fixation (p < 0.001). Overall, the baseline characteristics were comparable between the groups, while the biomechanical outcomes favored the transarticular facet screw construct in terms of stability and stiffness.

Table 2: Range of motion (ROM) comparison between constructs (N = 80)

(Outcome: **ROM (°)** measured under standardized loading)

ROM Parameter	TAFSF (n=40) Mean ± SD	LMSF (n=40) Mean ± SD	Test of significance	Mean difference (TAFSF − LMSF) with 95% CI	P value
Flexion–Extension ROM (°)	5.2 ± 1.4	6.7 ± 1.6	Independent t-test	**−1.50** (−2.17 to −0.83)	<0.001*
Lateral Bending ROM (°)	3.9 ± 1.2	4.8 ± 1.3	Independent t-test	**−0.90** (−1.46 to −0.34)	0.002*
Axial Rotation ROM (°)	3.7 ± 1.1	5.0 ± 1.4	Independent t-test	**−1.30** (−1.86 to −0.74)	<0.001*
Neutral Zone ROM (°)	2.1 ± 0.7	2.7 ± 0.8	Independent t-test	**−0.60** (−0.93 to −0.27)	0.001*
Total ROM (sum of planes) (°)	12.8 ± 2.9	15.6 ± 3.1	Independent t-test	**−2.80** (−4.14 to −1.46)	<0.001*

*Statistically significant at p < 0.05.

Table 2 compares the range of motion (ROM) of cervical spine segments following stabilization using transarticular facet screw fixation and lateral mass screw fixation under standardized biomechanical loading conditions. In the flexion–extension plane, the TAFSF group demonstrated significantly lower motion (5.2 ± 1.4°) compared with the LMSF group (6.7 ± 1.6°), with a mean difference of −1.50° (95% CI: −2.17 to −0.83), indicating superior motion restriction with transarticular fixation (p < 0.001). Similarly, lateral bending ROM was significantly reduced in the TAFSF group (3.9 ± 1.2°) compared with the LMSF group (4.8 ± 1.3°), with a mean difference of −0.90° (95% CI: −1.46 to −0.34) (p = 0.002). In axial rotation, the TAFSF construct also demonstrated significantly less motion (3.7 ± 1.1°) compared with the LMSF construct (5.0 ± 1.4°), with a mean difference of −1.30° (95% CI: −1.86 to −0.74) (p < 0.001). The neutral zone ROM, which reflects the region of minimal resistance during spinal motion, was also significantly smaller in the TAFSF group (2.1 ± 0.7°) compared with the LMSF group (2.7 ± 0.8°), suggesting improved segmental stability with the transarticular fixation technique (p = 0.001). When the overall ROM across all motion planes was considered, the total ROM was significantly lower in the TAFSF group (12.8 ± 2.9°) compared with the LMSF group (15.6 ± 3.1°), with a mean difference of −2.80° (95% CI: −4.14 to −1.46) (p < 0.001).

Table 3: Construct stiffness comparison under physiological loading (N = 80)

(Outcome: **Stiffness (Nm/°)**)

Stiffness Parameter	TAFSF (n=40) Mean ± SD	LMSF (n=40) Mean ± SD	Test of significance	Mean difference (TAFSF − LMSF) with 95% CI	P value
Flexion–Extension stiffness (Nm/°)	1.88 ± 0.46	1.49 ± 0.42	Independent t-test	**0.39** (0.19 to 0.59)	<0.001*
Lateral Bending stiffness (Nm/°)	1.95 ± 0.43	1.58 ± 0.41	Independent t-test	**0.37** (0.18 to 0.56)	<0.001*
Axial Rotation stiffness (Nm/°)	2.05 ± 0.47	1.62 ± 0.44	Independent t-test	**0.43** (0.23 to 0.63)	<0.001*
Overall construct stiffness (Nm/°)	1.92 ± 0.41	1.53 ± 0.39	Independent t-test	**0.39** (0.21 to 0.57)	<0.001*

*Statistically significant at p < 0.05.

Table 3 illustrates the comparison of construct stiffness between the two fixation techniques under simulated physiological loading conditions. The stiffness in the flexion–extension plane was significantly higher in the TAFSF group (1.88 ± 0.46 Nm/°) compared with the LMSF group (1.49 ± 0.42 Nm/°), with a mean difference of 0.39 Nm/° (95% CI: 0.19 to 0.59) ($p < 0.001$). Similarly, lateral bending stiffness was greater in the TAFSF group (1.95 ± 0.43 Nm/°) compared with the LMSF group (1.58 ± 0.41 Nm/°), showing a statistically significant difference of 0.37 Nm/° (95% CI: 0.18 to 0.56) ($p < 0.001$). In the axial rotation plane, which is considered a critical movement affecting cervical spine stability, the TAFSF construct demonstrated significantly higher stiffness (2.05 ± 0.47 Nm/°) compared with the LMSF construct (1.62 ± 0.44 Nm/°), with a mean difference of 0.43 Nm/° (95% CI: 0.23 to 0.63) ($p < 0.001$). When overall stiffness was evaluated across all motion planes, the TAFSF group exhibited significantly higher overall construct stiffness (1.92 ± 0.41 Nm/°) compared with the LMSF group (1.53 ± 0.39 Nm/°), with a mean difference of 0.39 Nm/° (95% CI: 0.21 to 0.57) ($p < 0.001$).

Table 4: Biomechanical stability and resistance to displacement (N = 80)
(Metrics of translation/gapping/displacement and cyclic integrity)

Stability / Displacement Parameter	TAFSF (n=40)	LMSF (n=40)	Test of significance	Effect size (95% CI)	P value
Peak intervertebral translation at 2 Nm (mm)	0.62 ± 0.18	0.81 ± 0.22	Independent t-test	Mean diff = **−0.19** (−0.28 to −0.10)	<0.001*
Facet joint gapping during rotation (mm)	0.28 ± 0.11	0.41 ± 0.14	Independent t-test	Mean diff = **−0.13** (−0.19 to −0.07)	<0.001*
Displacement at 50 N shear load (mm)	0.74 ± 0.21	0.93 ± 0.25	Independent t-test	Mean diff = **−0.19** (−0.29 to −0.09)	<0.001*
Load required for 2 mm translation (N)	214.7 ± 42.6	183.9 ± 39.8	Independent t-test	Mean diff = **30.8** (12.45 to 49.15)	0.001*
Construct failure load (N)	386.2 ± 61.4	341.7 ± 58.9	Independent t-test	Mean diff = **44.5** (17.72 to 71.28)	0.001*
Screw backout during cyclic loading	2 (5.0%)	7 (17.5%)	Chi-square test	OR = **0.25** (0.05 to 1.28)	0.077

*Statistically significant at $p < 0.05$.

Table 4 presents the comparison of biomechanical stability and resistance to displacement between the two fixation techniques. The peak intervertebral translation under a 2 Nm load was significantly lower in the TAFSF group (0.62 ± 0.18 mm) compared with the LMSF group (0.81 ± 0.22 mm), with a mean difference of −0.19 mm (95% CI: −0.28 to −0.10) ($p < 0.001$), indicating improved segmental stability with the transarticular construct. Similarly, facet joint gapping during rotational loading was significantly smaller in the TAFSF group (0.28 ± 0.11 mm) compared with the LMSF group (0.41 ± 0.14 mm), demonstrating stronger resistance to joint separation ($p < 0.001$). The displacement observed under a 50 N shear load was also significantly lower in the TAFSF group (0.74 ± 0.21 mm) compared with the LMSF group (0.93 ± 0.25 mm), further supporting the superior mechanical stability of the transarticular fixation technique ($p < 0.001$). In terms of resistance to translational forces, the load required to produce 2 mm translation was significantly higher in the TAFSF group (214.7 ± 42.6 N) than in the LMSF group (183.9 ± 39.8 N), indicating stronger resistance to displacement ($p = 0.001$). Additionally, the construct failure load was significantly greater in the TAFSF group (386.2 ± 61.4 N) compared with the LMSF group (341.7 ± 58.9 N) ($p = 0.001$), suggesting a higher load-bearing capacity of the transarticular construct. Screw backout during cyclic loading occurred in 5.0% of specimens in the TAFSF group compared with 17.5% in the LMSF group; however, this difference did not reach statistical significance ($p = 0.077$).

DISCUSSION

Baseline Characteristics and Primary Biomechanical Outcomes (Table 1): In the present cadaveric biomechanical study, the baseline characteristics of specimens were comparable between the transarticular facet screw fixation (TAFSF) and lateral mass screw fixation (LMSF) groups, ensuring the validity of the biomechanical comparison. The mean age of specimens in the TAFSF group was 58.3 ± 8.7 years compared with 57.1 ± 9.1 years in the LMSF group, with no statistically significant difference ($p = 0.548$). Similar demographic comparability has been reported in cadaveric biomechanical studies evaluating posterior cervical fixation constructs. Liu et al. (2020)[5] reported comparable specimen characteristics when evaluating different cervical fixation techniques, emphasizing the importance of balanced baseline parameters to minimize bias in biomechanical assessments.

Bone mineral density (BMD), an important determinant of screw purchase and fixation strength, was also comparable between the groups in the present study (0.84 ± 0.11 g/cm² vs 0.82 ± 0.12 g/cm²; $p = 0.440$). Similar findings were reported by Du et al. (2020)[2], who demonstrated that bone quality significantly influences fixation stability but reported comparable BMD values across cadaveric groups in biomechanical experiments. Likewise, the proportion of osteopenic specimens in the present study (27.5% vs 35.0%) did not differ significantly between groups (p = 0.469), which is consistent with observations by Ansaripour et al. (2022)[3], who noted that osteopenia can influence fixation strength but balanced specimen distribution ensures reliable comparative results.

The distribution of instrumented cervical levels was also comparable between groups, with C4–C6 segments accounting for the majority of instrumentation (65.0% vs 60.0%). Similar cervical levels are commonly studied in biomechanical research due to their high mobility and frequent involvement in degenerative pathology, as reported by Erbulut et al. (2022)[4].

Baseline intact cervical spine motion was nearly identical between groups (53.7 ± 6.4° vs 54.2 ± 6.1°; p = 0.722), indicating that the specimens had comparable pre-instrumentation biomechanical properties. However, following fixation, global ROM was significantly lower in the TAFSF group (12.8 ± 2.9°) compared with the LMSF group (15.6 ± 3.1°) (p < 0.001). These findings suggest that transarticular fixation provides greater restriction of cervical spine motion. Similar results were reported by Liu et al. (2020)[5], who demonstrated that transarticular fixation techniques significantly reduce segmental motion compared with conventional lateral mass constructs.

Furthermore, the percentage reduction in ROM relative to the intact spine was significantly greater in the TAFSF group (76.4%) compared with the LMSF group (69.1%), highlighting the enhanced motion-limiting capability of transarticular screws. This observation is consistent with the biomechanical analysis performed by Koller et al. (2021)[6], who reported superior motion control with facet-based fixation techniques due to the engagement of multiple cortical surfaces across the facet joint.

The present study also demonstrated significantly greater overall construct stiffness in the TAFSF group (1.92 ± 0.41 Nm/°) compared with the LMSF group (1.53 ± 0.39 Nm/°) (p < 0.001). These findings align with the study by Oitment et al. (2022)[7], who reported that transarticular screw constructs exhibit greater rigidity due to improved load sharing across the posterior column of the cervical spine.

Range of Motion Comparison (Table 2): The results of the present study demonstrate that transarticular facet screw fixation significantly reduces cervical spine motion across all planes compared with lateral mass screw fixation. In the flexion–extension plane, ROM in the TAFSF group was 5.2 ± 1.4° compared with 6.7 ± 1.6° in the LMSF group (p < 0.001). Similar findings were reported by Zhang et al. (2021)[8], who demonstrated that facet-based fixation techniques provide superior resistance to flexion–extension movements due to direct stabilization of the facet joint complex.

In lateral bending, ROM was also significantly lower in the TAFSF group (3.9 ± 1.2°) compared with the LMSF group (4.8 ± 1.3°, p = 0.002). This reduction in lateral bending motion has been attributed to the ability of transarticular screws to stabilize both adjacent vertebrae across the facet joint, thereby limiting coronal plane motion. Similar biomechanical findings were reported by Liu et al. (2020)[5], who observed improved stability in lateral bending with facet-based constructs.

The present study also demonstrated significantly lower axial rotation ROM in the TAFSF group (3.7 ± 1.1°) compared with the LMSF group (5.0 ± 1.4°, p < 0.001). Axial rotational stability is particularly important in cervical fixation constructs, and previous studies have suggested that transarticular screws provide superior rotational stability. Erbulut et al. (2022)[4] described this biomechanical advantage in screw-based atlantoaxial fixation techniques.

Additionally, the neutral zone ROM, which reflects the initial range of spinal motion with minimal resistance, was significantly smaller in the TAFSF group (2.1 ± 0.7°) compared with the LMSF group (2.7 ± 0.8°, p = 0.001). Reduction in neutral zone motion is an important indicator of improved spinal stability. Similar results were reported by Zhang et al. (2021)[8], who demonstrated that facet-based fixation significantly reduces the neutral zone, thereby enhancing biomechanical stability.

Construct Stiffness Comparison (Table 3): Construct stiffness is a key biomechanical parameter that reflects the resistance of a spinal fixation construct to applied loads. In the present study, transarticular fixation demonstrated significantly greater stiffness across all motion planes compared with lateral mass fixation.

In the flexion–extension plane, stiffness was 1.88 ± 0.46 Nm/° in the TAFSF group compared with 1.49 ± 0.42 Nm/° in the LMSF group (p < 0.001). Similar observations were reported by Oitment et al. (2022)[7], who demonstrated improved mechanical rigidity with facet-based fixation constructs.

Similarly, lateral bending stiffness was significantly greater in the TAFSF group (1.95 ± 0.43 Nm/°) compared with the LMSF group (1.58 ± 0.41 Nm/°, p < 0.001). The engagement of the facet joint by the transarticular screw likely contributes to improved resistance against lateral bending forces.

The axial rotation stiffness was also significantly greater in the TAFSF group (2.05 ± 0.47 Nm/°) compared with the LMSF group (1.62 ± 0.44 Nm/°, p < 0.001). Previous biomechanical studies have highlighted axial rotational stability as a key advantage of transarticular fixation techniques. Niu et al. (2024)[9] reported improved torsional stability in cervical screw-based constructs using finite element analysis.

Biomechanical Stability and Resistance to Displacement (Table 4): The present study also evaluated the biomechanical stability and resistance to displacement of the fixation constructs. The peak intervertebral translation under a 2 Nm load was significantly lower in the TAFSF group (0.62 ± 0.18 mm) compared with the LMSF group (0.81 ± 0.22 mm, $p < 0.001$). Similar findings were reported by Huang et al. (2021)[10], who demonstrated that advanced screw constructs can significantly reduce segmental translation in cervical fixation models.

Facet joint gapping during rotational loading was also significantly lower in the TAFSF group (0.28 ± 0.11 mm) compared with the LMSF group (0.41 ± 0.14 mm, $p < 0.001$), indicating improved facet joint stability.

Additionally, displacement under 50 N shear load was significantly smaller in the TAFSF group (0.74 ± 0.21 mm) compared with the LMSF group (0.93 ± 0.25 mm, $p < 0.001$), indicating greater resistance to shear forces.

The load required to produce 2 mm translation was significantly higher in the TAFSF group (214.7 ± 42.6 N) compared with the LMSF group (183.9 ± 39.8 N, $p = 0.001$), demonstrating superior resistance to translational forces. Likewise, the construct failure load was significantly higher in the TAFSF group (386.2 ± 61.4 N) compared with the LMSF group (341.7 ± 58.9 N, $p = 0.001$), suggesting stronger structural integrity of the transarticular fixation construct.

Although screw backout during cyclic loading occurred less frequently in the TAFSF group (5.0%) compared with the LMSF group (17.5%), the difference did not reach statistical significance ($p = 0.077$). Similar observations have been reported by Zhang et al. (2021)[8], who noted that screw loosening rates may vary but biomechanical stability is generally superior in facet-based fixation techniques.

CONCLUSION

The present cadaveric biomechanical study compared transarticular facet screw fixation (TAFSF) and lateral mass screw fixation (LMSF) in the cervical spine with respect to range of motion, construct stiffness, and resistance to displacement. The findings demonstrated that both fixation techniques were effective in stabilizing the cervical spine; however, transarticular facet screw fixation provided significantly greater biomechanical stability compared with lateral mass screw fixation.

The baseline characteristics of the specimens, including age, bone mineral density, gender distribution, and instrumented levels, were comparable between the two groups, ensuring a reliable comparison of biomechanical outcomes. After instrumentation, the transarticular fixation construct significantly reduced cervical spine motion across all planes of movement, including flexion–extension, lateral bending, and axial rotation. The total range of motion after fixation was significantly lower in the TAFSF group compared with the LMSF group, indicating superior restriction of spinal motion. Furthermore, the percentage reduction in range of motion relative to the intact cervical spine was significantly greater in the transarticular fixation group, highlighting its enhanced motion-limiting capability. Construct stiffness analysis also demonstrated that transarticular facet screw fixation produced significantly higher stiffness values across all loading conditions compared with lateral mass screw fixation. Increased construct stiffness reflects greater resistance to deformation under physiological loading, which may contribute to improved postoperative spinal stability.

The study also showed that transarticular fixation provided greater resistance to translational forces and shear loads. Parameters such as peak intervertebral translation, facet joint gapping, and displacement under shear load were significantly lower in the transarticular fixation group, suggesting stronger biomechanical stability of the construct. Additionally, the load required to produce translational displacement and the construct failure load were significantly higher in the transarticular fixation group, further confirming the superior mechanical strength of this fixation technique.

Although screw backout was observed less frequently in the transarticular group compared with the lateral mass screw group, this difference did not reach statistical significance. Nevertheless, the overall biomechanical findings consistently favored transarticular facet screw fixation in terms of rigidity and stability.

In conclusion, the results of this cadaveric biomechanical analysis indicate that transarticular facet screw fixation provides superior biomechanical stability, greater construct stiffness, and more effective restriction of cervical spine motion compared with lateral mass screw fixation. These findings suggest that transarticular fixation may be a biomechanically advantageous technique for posterior cervical stabilization in appropriate clinical scenarios. However, clinical studies are required to further evaluate the surgical safety, long-term outcomes, and complication profile associated with this technique.

LIMITATIONS OF THE STUDY

1. The study was conducted using cadaveric specimens, which may not fully replicate the complex physiological conditions present in living patients.
2. Muscle forces and dynamic physiological loading could not be simulated accurately in the cadaveric biomechanical testing environment.
3. The study evaluated short-term mechanical stability and did not assess long-term biological factors such as bone healing, fusion rates, or implant loosening.

4. Variations in bone mineral density and specimen preservation may influence fixation strength despite efforts to standardize specimens.
5. Only single-level instrumentation and specific cervical segments were evaluated, which may limit generalization to multilevel constructs.
6. The study focused primarily on biomechanical parameters and did not assess potential surgical complications such as vertebral artery injury or neural injury associated with screw placement.
7. The sample size, although adequate for biomechanical comparison, may still be limited for detecting rare mechanical failures.
8. Clinical outcomes such as pain relief, neurological recovery, and functional improvement could not be evaluated in this experimental study.

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