Research Square

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Biomechanical Evaluation of Lag Screw versus Cerclage Cable for Treatment of Diaphyseal Femur Fractures

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Abstract

Background

Diaphyseal femur fractures are commonly treated with intramedullary nailing; however, plate fixation is required when deformity, existing implants, or limited bone stock preclude nail use. Long lateral locking plates often require adjunct fixation to achieve anatomic reduction. Lag screws provide compression but may be unreliable in osteoporotic bone, whereas cerclage cables offer circumferential fixation independent of bone density. This study compared the biomechanical performance of anatomic fixation of a long spiral oblique femur fracture using either a single lag screw or a single cerclage cable augmented by a lateral plate.

Methods

Ten synthetic femora were osteotomized at the mid-diaphysis. Five specimens were reduced and fixed with a bicortical lag screw and five with a cerclage cable. All specimens received a lateral 4.5-mm LC-DC neutralization plate with a standardized screw configuration. Constructs underwent cyclic axial loading, and fracture-site micromotion was recorded using optical motion capture. Stiffness was calculated from the linear portion of the load–displacement curve. Mean and maximal interfragmentary displacement were recorded. Statistical analysis included independent-samples t-tests and one-way ANOVA.

Results

Mean stiffness was similar between lag screw (996.6 ± 138.8 N/mm) and cerclage constructs (988.9 ± 156.8 N/mm; $p = 0.12$). Mean displacement did not differ between groups (lag screw: 0.56 ± 0.36 mm; cerclage: 0.49 ± 0.66 mm; $p = 0.84$). Maximal displacement ranged from 0.7 to 1.8 mm with no group difference ($p = 0.87$). Significant stiffness differences were observed among constructs of the same type ($p < 0.0001$).

Conclusions

Both lag screw and cerclage cable fixation provided comparable axial stability and resistance to micromotion in a laterally plated synthetic femur model. Cerclage cables may be a viable alternative when lag screw use is limited. Construct variability highlights the importance of surgical technique.

Background

The femur is one of the most commonly fractured long bones, and advances in intramedullary nailing techniques have markedly improved the management of many diaphyseal injuries. Nevertheless, certain clinical scenarios necessitate plate fixation rather than intramedullary techniques. These include the

presence of pre-existing implants or deformity that prevents nail passage and limited proximal or distal bone stock in the setting of existing arthroplasty components[1,2]. In such cases, assuming the prosthesis is well fixed, the standard approach typically involves a long lateral distal femur locking plate. A variety of proximal fixation methods may be used proximally, including unicortical screws, bicortical screws, and cerclage cables[3–7].

Achieving anatomic reduction is critical in these scenarios to minimize the stress borne by the implants and reduce the risk of construct failure[8]. Traditionally, this has been achieved with a lag screw combined with a neutralization plate. However, the effectiveness of lag screw fixation is dependent upon adequate bone mineral density, and patients with osteoporotic bone are at higher risk for screw loosening and failure under cyclic loading[9]. Cerclage cables are an attractive option for maintaining reduction in osteoporotic bone, given that they generate fixation through circumferential friction rather than relying on the bone-screw interface[10].

Previous investigations into the biomechanical properties of lag screws and cerclage cables have been in isolation[11], without the presence of a lateral femoral locking plate[12], or in the setting of a Vancouver B1 fracture rather than true diaphyseal femur fractures[13]. Consequently, limited evidence exists regarding their comparative biomechanical performance when used as adjuncts to lateral plate fixation in diaphyseal injury patterns.

The purpose of this study was to determine whether cerclage cable fixation provides axial stability and resistance to micromotion comparable to a bicortical lag screw when used as adjunct fixation to a lateral plate.

Methods

Ten synthetic femurs (Sawbones, Model # SKU 3406-7, Vashon, WA) were utilized for primary analysis during this study. An oblique osteotomy was made in the femoral diaphysis 14 centimeters distal to the vastus ridge using an oscillating saw (Stryker, Kalamazoo, MI). The fracture was reduced anatomically and clamped with pointed reduction clamps. In five specimens, the osteotomy was secured using a 3.5mm lag screw placed via lag-by-technique, while the osteotomy in the remaining five specimens was secured with a 1.7mm cerclage cable which was tensioned and crimped per manufacturer instructions (J&J Medtech, Paoli, PA). A 4.5mm LC-DC neutralization plate (J&J Medtech, Paoli, PA) was secured on the lateral femur (Fig. 1). The number of screws and screw configuration were standardized across all specimens. Specimens were then potted distally in rectangular 3D printed bases using polyester resin. Each specimen was oriented so that its femoral mechanical axis was aligned with the vertical axis (Fig. 2).

Mechanical Testing

By using a customized jig, the base of each specimen was secured firmly onto the testing surface of an MTS universal testing machine (858 Mini-Bionix, MTS, Eden Prairie, MN). A customized metal bar attached to the MTS was placed in direct contact with the top of each femoral head.

For the first pair of screw vs cerclage, after 5 Newtons of preload, 600 cycles of sinusoidal cyclical loading (1 Hz), from 5 to 2000 Newtons (N), were applied in the vertical direction (from the head of the femur to the intercondylar notch of the distal femur). For the second pair of screw vs cerclage, 660 cycles of sinusoidal cyclical loading (1 Hz), from 5 to 2200 Newtons (N), were applied. For the third pair of screw vs cerclage, 720 cycles of sinusoidal cyclical loading (1 Hz), from 5 to 2400 Newtons (N), were applied. For the fourth and fifth pair of screw vs cerclage, 780 cycles of sinusoidal cyclical loading (1 Hz), from 5 to 2600 Newtons (N), were applied. Stiffness comparisons were standardized to the first 600 cycles to allow direct comparison across all constructs. A 1 cm actuator displacement threshold was set as the failure criterion. For each test, load (N) and displacement (mm) were collected continuously by the MTS software. Stiffness (N/mm) during loading was determined from the slope of the elastic region of load-deformation curve for each cycle.

Motion Capture

Two retroreflective markers (19 mm diameter) were taped onto both ends of the fracture site without interfering with the nearby cerclage or the lag screw for each specimen before mechanical testing. A third marker was used on the proximal side as an offset to help identify the other two markers (Fig. 3). Marker positions and gap distance between the two main markers were recorded with a calibrated motion capture system (Eagle cameras, Motion Analysis Corporation) at 200 Hz before and during each mechanical testing. Construct stability was assessed by both mean interfragmentary displacement during cyclic loading and maximal displacement from initial reduction, as measured by the motion capture system. The change of fracture gap distance (mm) was calculated as the average gap distance before testing compared to the average gap distance throughout the testing. Maximal displacement at the fracture gap was calculated as the marker gap distance (mm) prior to testing compared to the moment of maximal marker gap distance during cyclic testing. Axial loading was selected as the primary testing mode given its dominant role during early weight-bearing following plate fixation of diaphyseal femur fractures.

Statistical Analysis

Descriptive analysis and calculations were performed in Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). The remaining statistical analysis procedures were performed using JMP Pro 17 (SAS Institute Inc.). Independent samples t-tests were used to examine differences in overall displacements between the two constructs (cerclage vs. screw). One-way analysis of variance (ANOVA) test was conducted to examine stiffness for the first 600 cycles, divided by screw and cerclage. ANOVA with Tukey post hoc comparisons were also used to investigate differences in stiffness for the first 600 cycles for each of the 10 constructs tested with post hoc testing.

Results

All ten constructs (five cerclage plus plate, five lag screw plus plate) completed cyclic axial loading without catastrophic failure or meeting the displacement safety stop. Group-level analysis demonstrated no statistically significant difference in mean stiffness between lag screw (996.6 ± 138.8 N/mm) and cerclage constructs (988.9 ± 156.8 N/mm) over the first 600 cycles ($p = 0.12$) (Fig. 4). Likewise, mean interfragmentary displacement measured via optical motion capture did not differ significantly between groups (lag screw: 0.56 ± 0.36 mm; cerclage: 0.49 ± 0.66 mm; $p = 0.84$) (Fig. 5). Across all constructs, interfragmentary displacement remained below 2 mm during cyclic axial loading (Table 1).

Table 1

Change in gap distance and maximal displacement during cyclical loading of individual constructs. Constructs include cerclage plus plate (C01 - C05) and lag screw plus plate (S01 - S05) fixation. Displacement was measured using an optical motion capture system as the change in fracture gap distance from the initial reduction position. Mean displacement represents the average gap change throughout cyclic loading, while maximal displacement represents the greatest observed change from the pre-load position.

Measurement	C01	S01	C02	S02	C03	S03	C04	S04	C05	S05
Average gap distance before testing (mm)	46.0	50.3	43.8	48.8	45.4	43.0	39.8	49.4	38.0	37.3
Average gap distance during cyclical testing (mm)	45.3	49.7	43.6	48.4	44.9	41.9	38.4	48.8	38.3	37.2
Change of gap distance (mm)	0.7	0.6	0.2	0.4	0.5	1.1	1.4	0.6	-0.3	0.1
Maximal displacement (mm)	1.0	0.9	0.8	0.7	1.0	1.4	1.8	1.4	0.7	0.7

When constructs were analyzed individually, no significant change in stiffness was observed over time within each specimen ($F(599) = 0.0573$, $p > 0.05$). Although fixation type did not influence group-level stiffness, stiffness varied significantly between individual constructs despite standardized instrumentation ($p < 0.0001$) (Table 2). Construct-specific stiffness values are illustrated in Fig. 6.

Table 2

Comparison of difference in stiffness between constructs. Constructs include cerclage plus plate (C01 - C05) and lag screw plus plate (S01 - S05) fixation.

Comparisons		Difference	Lower CL	Upper CL	p-Value
C05	C02	473.4	468.3	478.5	< .0001*
C05	S01	419.7	414.6	424.8	< .0001*
C05	S02	404.3	399.2	409.4	< .0001*
S03	C02	388.8	383.6	393.9	< .0001*
S03	S01	335.0	329.9	340.1	< .0001*
C05	C03	321.2	316.1	326.3	< .0001*
S03	S02	319.6	314.5	324.7	< .0001*
S05	C02	314.2	309.1	319.3	< .0001*
S04	C02	296.2	291.1	301.3	< .0001*
C05	C04	262.5	257.4	267.6	< .0001*
S05	S01	260.5	255.3	265.6	< .0001*
C01	C02	245.4	240.3	250.6	< .0001*
S05	S02	245.1	240.0	250.2	< .0001*
S04	S01	242.5	237.4	247.6	< .0001*
S03	C03	236.5	231.4	241.6	< .0001*
C05	C01	228.0	222.9	233.1	< .0001*
S04	S02	227.1	222.0	232.2	< .0001*
C04	C02	210.9	205.8	216.0	< .0001*
C01	S01	191.7	186.6	196.8	< .0001*
S03	C04	177.8	172.7	182.9	< .0001*
C05	S04	177.2	172.1	182.3	< .0001*
C01	S02	176.3	171.2	181.4	< .0001*
S05	C03	162.0	156.9	167.1	< .0001*
C05	S05	159.3	154.1	164.4	< .0001*
C04	S01	157.2	152.1	162.3	< .0001*
C03	C02	152.2	147.1	157.3	< .0001*

Comparisons		Difference	Lower CL	Upper CL	p-Value
S04	C03	144.0	138.9	149.1	< .0001*
S03	C01	143.3	138.2	148.4	< .0001*
C04	S02	141.8	136.7	146.9	< .0001*
S05	C04	103.2	98.1	108.3	< .0001*
C03	S01	98.5	93.4	103.6	< .0001*
C01	C03	93.2	88.1	98.3	< .0001*
S03	S04	92.5	87.4	97.6	< .0001*
S04	C04	85.3	80.2	90.4	< .0001*
C05	S03	84.7	79.6	89.8	< .0001*
C03	S02	83.1	78.0	88.2	< .0001*
S03	S05	74.6	69.5	79.7	< .0001*
S02	C02	69.1	64.0	74.2	< .0001*
S05	C01	68.7	63.6	73.8	< .0001*
C04	C03	58.7	53.6	63.8	< .0001*
S01	C02	53.7	48.6	58.8	< .0001*
S04	C01	50.8	45.7	55.9	< .0001*
C01	C04	34.5	29.4	39.6	< .0001*
S05	S04	17.9	12.8	23.0	< .0001*
S02	S01	15.4	10.3	20.5	< .0001*

The change in fracture gap distance relative to the pre-load position was minimal across all constructs, with mean displacement values ranging from − 0.3 mm to 1.4 mm (Fig. 6). The maximal displacement observed during cyclic loading ranged from 0.7 mm to 1.8 mm across all specimens. Among cerclage constructs, maximal displacement values ranged from 0.8 mm (C03) to 1.8mm (C04). Among lag screw constructs, maximal displacement values ranged from 0.7 mm (S02) to 1.4 mm (S03 and S04). Group-level comparison of maximal displacement revealed no statistically significant difference between cerclage (mean ± SD: 1.06 ± 0.41 mm) and lag screw constructs (1.02 ± 0.34 mm) ($p = 0.87$). Mean and maximal displacement values for each construct are presented together in Fig. 7.

Discussion

Diaphyseal femur fractures – particularly in patients with existing implants such as arthroplasty components or prior intramedullary implants – pose unique challenges as these implants may preclude intramedullary nailing and necessitate plate-based fixation. The rising number of total hip and knee arthroplasties performed annually suggests that the incidence of interprosthetic femur fractures is also likely to increase[14]. Conventional treatment options include open reduction and internal with a long lateral distal femur locking plate and lag screw or cerclage cable, combined medial and lateral plating, adding allograft struts for augmented fixation, and combined retrograde intramedullary nail with a lateral distal femur locking plate when feasible. Fracture patterns that permit anatomic reduction may be managed with a lag screw or cerclage cable in conjunction with a spanning lateral distal femur locking plate.

To our knowledge, no prior study has directly compared lag screw and cerclage fixation in the setting of a laterally plated diaphyseal fracture model using high-resolution optical motion capture to quantify interfragmentary micromotion. In this biomechanical model of a plated diaphyseal femur fracture, cerclage cable augmentation provided axial stiffness and resistance to interfragmentary micromotion comparable to a bicortical lag screw. These findings support cerclage cables as a mechanically viable option to lag screws when used in conjunction with a lateral neutralization plating, particularly when screw placement is limited by bone quality, implant interference, or fracture morphology. Both adjunct fixation strategies maintained reduction and demonstrated similar axial construct stability under cyclic loading. When lag screw placement is constrained by implant position, fracture morphology, or bone quality, cerclage cable fixation may be used without compromising axial stability in this model. Clinically, this similar stability may give surgeons greater flexibility in intraoperative decision-making in the setting of poor bone quality, implant interference, or fracture morphology which precludes lag screw placement.

Notably, construct stiffness varied substantially between individual specimens despite standardized reduction and fixation techniques. This finding suggests that factors such as reduction accuracy, plate contouring, clamp placement, and adjunct fixation technique may influence axial construct behavior as much as the choice of lag screw versus cerclage.

The limitations of this study include the use of synthetic femora rather than cadaveric, lack of testing under torsional or bending forces, and inability to account for the dynamic stability provided by soft tissues. Furthermore, synthetic femora more closely resemble non-osteoporotic bone. With the growing incidence of osteoporotic related fractures, this limits the generalizability of our findings, as the limitations of the bone-screw interface may be more pronounced in osteoporotic models. Future studies with human osteoporotic cadaveric models, longer cyclic protocols, and torsional or bending loads may better approximate clinical conditions and inform construct optimization.

Conclusions

In summary, both cerclage cable and lag screw augmentation provided comparable axial stability in this laterally plated diaphyseal femur fracture model. Given their similar biomechanical performance, either

technique may be appropriate when applied with precise surgical execution, allowing the choice of fixation strategy to be tailored to patient anatomy, bone quality, and intraoperative constraints.

Declarations

Funding:

none

Ethics: not applicable (synthetic bones)

Consent: not applicable

Competing interests: none

Data availability: available from corresponding author upon reasonable request

Author Contribution

JK prepared the manuscript and helped with data acquisitionAW prepared the manuscript and helped with data acquisition MP and CC helped with statistical analysis and data curationJE helped with conceptualizationJH supervised the project and assisted with editing the manuscript. All authors reviewed the manuscript

Data Availability

available from corresponding author upon reasonable request

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Figures



Figure 1

Anterior and lateral view of the synthetic femur constructs used for biomechanical testing. A standardized oblique osteotomy was performed 14 cm distal to the vastus ridge. Fractures were anatomically reduced and stabilized with a 4.5 mm LC-DC neutralization plate. Five specimens were fixed with a 3.5 mm lag screw, and five with a 1.7 mm cerclage cable, per manufacturer specifications. Constructs were embedded in polymethylmethacrylate for testing.

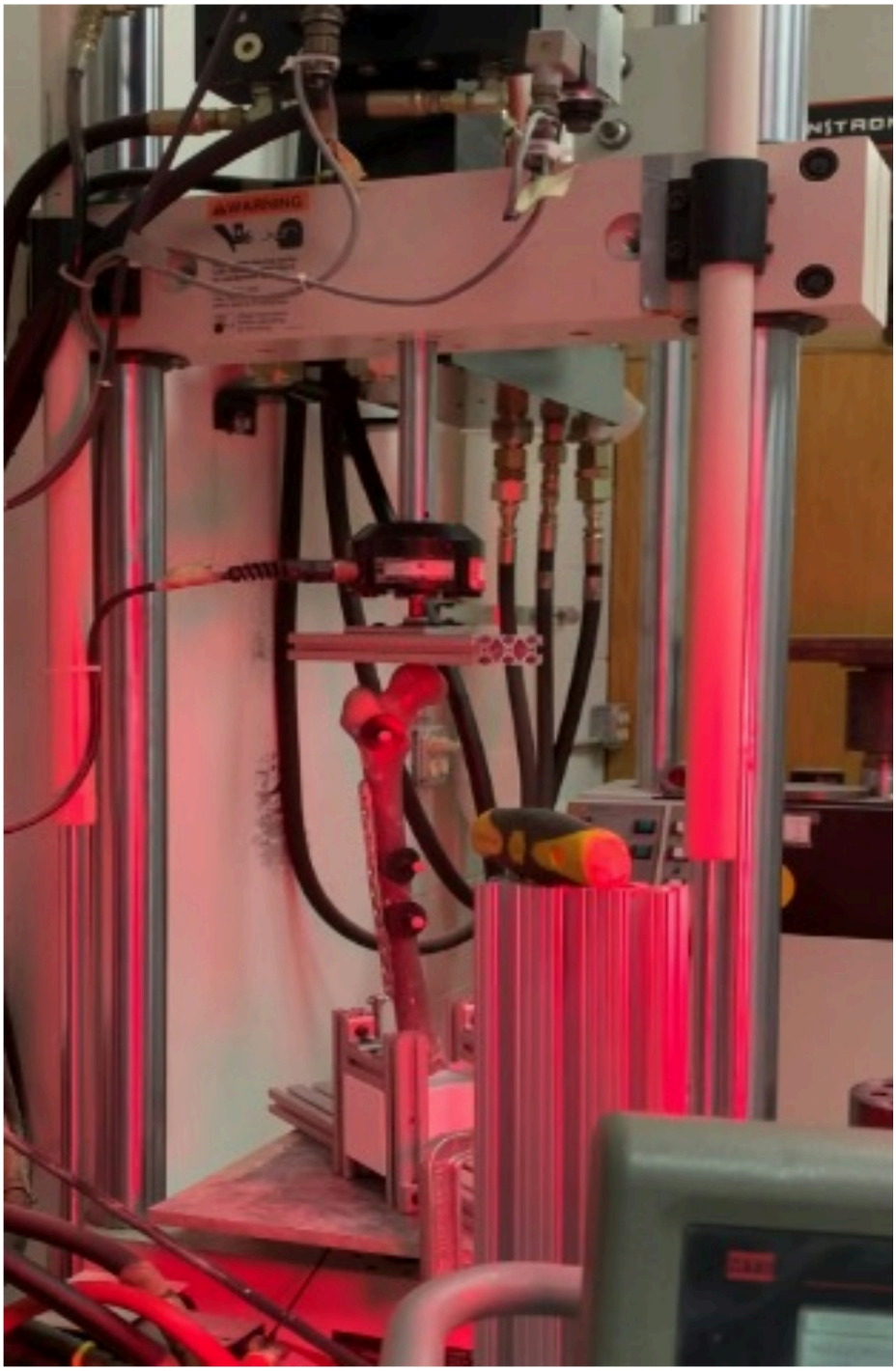


Figure 2

Motion capture analysis setup. Each femoral specimen was securely mounted on the testing surface of an MTS universal testing machine (858 Mini-Bionix, MTS, Eden Prairie, MN). A custom metal bar attached to the MTS was positioned in direct contact with the superior aspect of the femoral head to facilitate controlled loading.



Figure 3

Calibrated motion capture system. Two retroreflective markers were placed on the specimen before mechanical testing, with a third proximal marker serving as a reference to track the primary markers. Marker positions and the distance between the two main markers were recorded using a calibrated motion capture system.

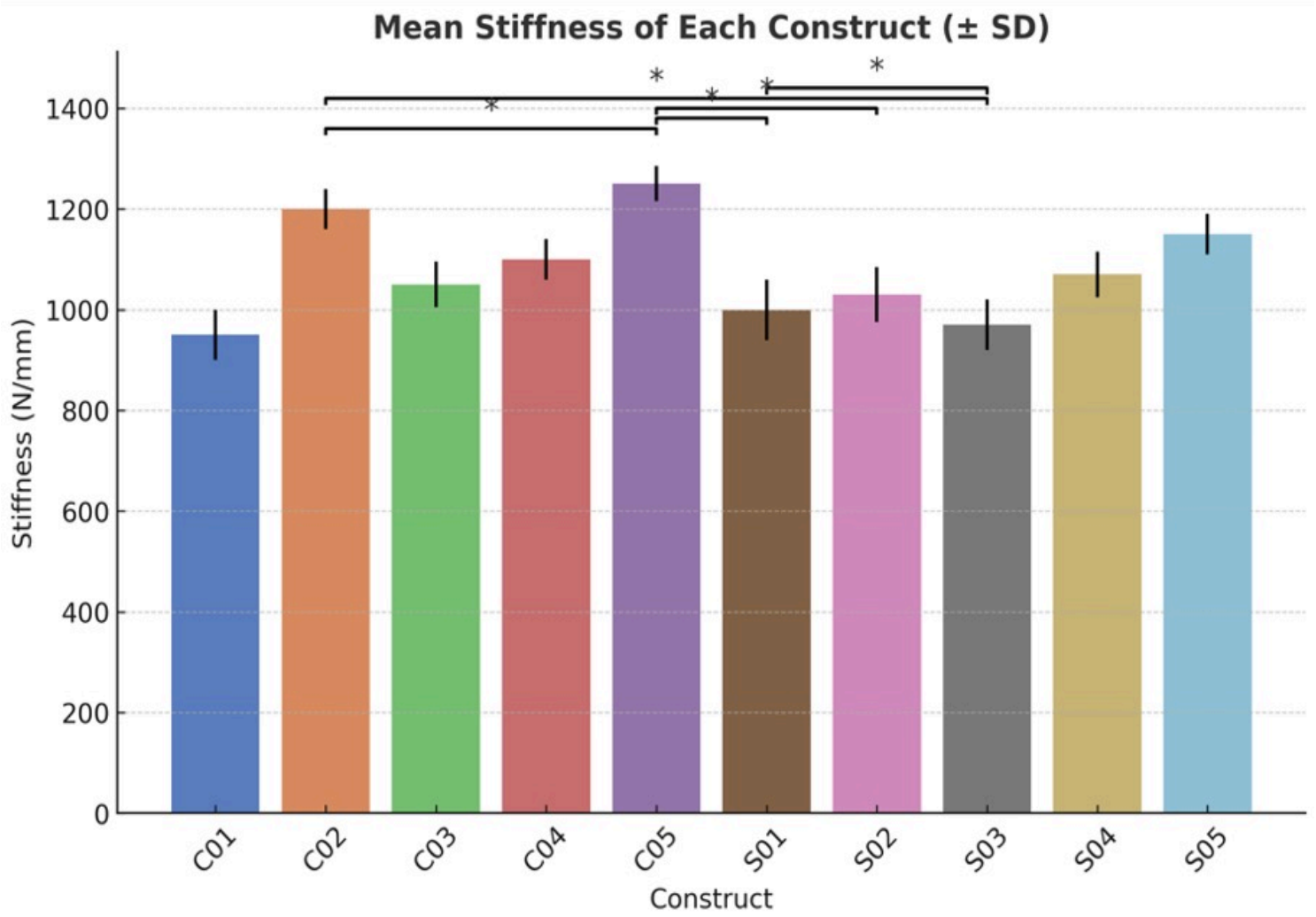


Figure 4

Mean stiffness of individual constructs (± SD) during the first 600 cycles of cyclic axial loading. Constructs include cerclage plus plate (C01 - C05) and lag screw plus plate (S01 - S05). Stiffness values were calculated from the linear region of the load-displacement curve. Statistical significance between constructs was determined using one-way ANOVA with Tukey post hoc testing ($p < 0.05$), indicated by asterisks.

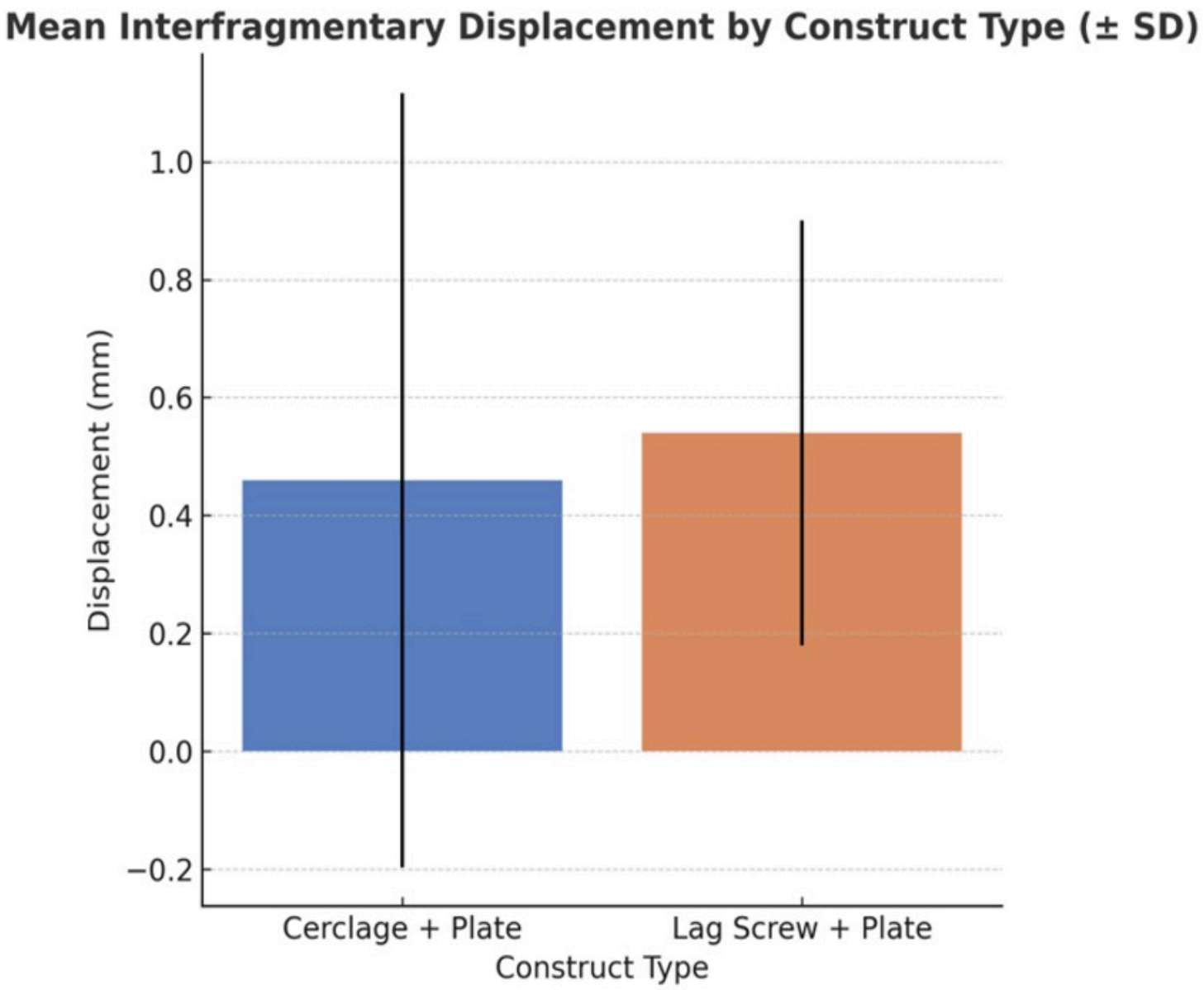


Figure 5

Mean interfragmentary displacement (± SD) during cyclic axial loading for cerclage plus plate and lag screw plus plate constructs. Displacement was measured using an optical motion capture system as the change in fracture gap distance from the initial reduction position. No significant difference was found between groups (p = 0.84).

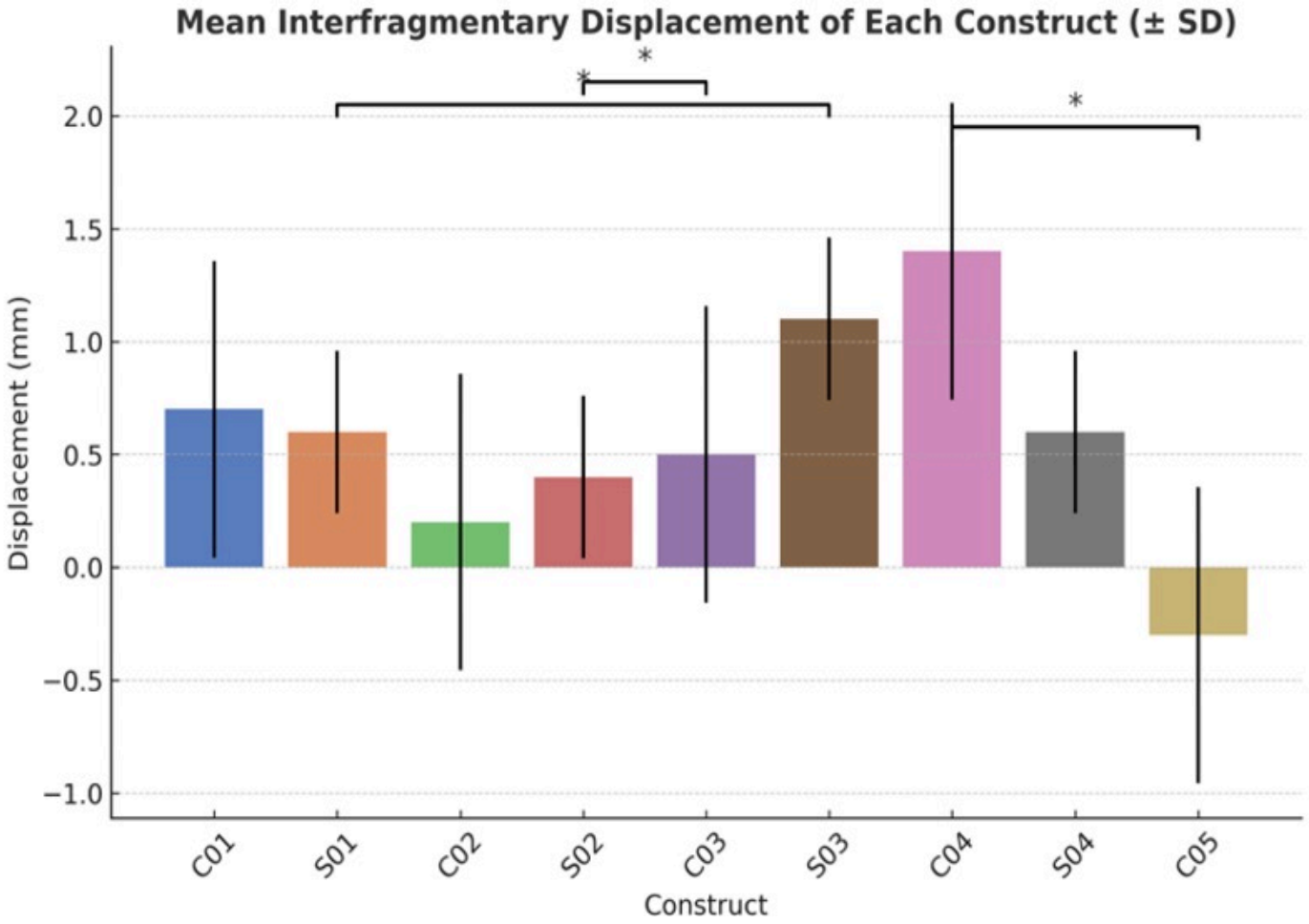


Figure 6

Mean interfragmentary displacement (± SD) for each construct during cyclic axial loading. Constructs include cerclage plus plate (C01 - C05) and lag screw plus plate (S01 - S05) fixation. Displacement was measured using an optical motion capture system as the change in fracture gap distance from the initial reduction position. Statistical significance between individual constructs was determined using one-way ANOVA with Tukey post hoc testing ($p < 0.05$) and is indicated by asterisks.

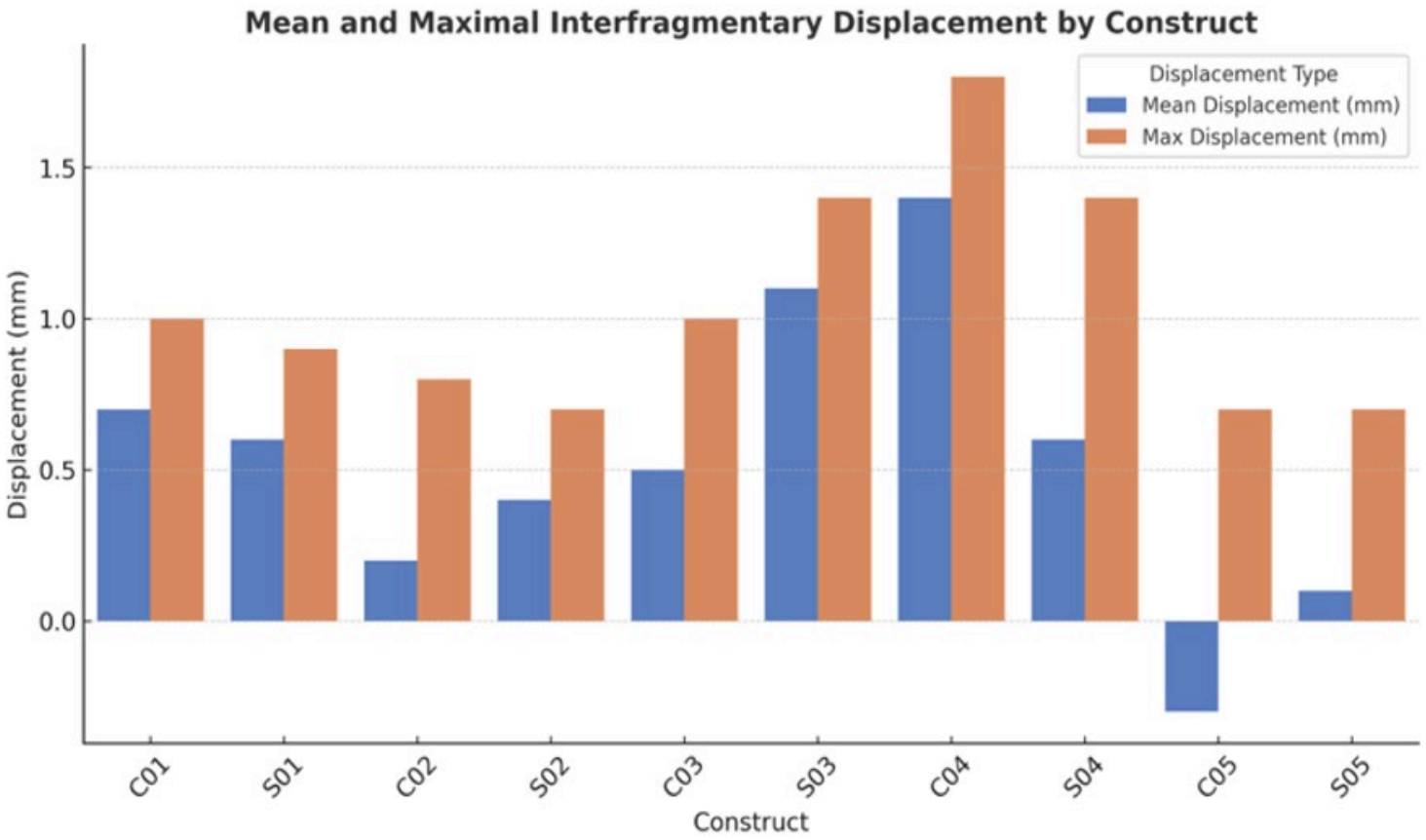


Figure 7

Mean and maximal interfragmentary displacement for each construct during cyclic axial loading. Constructs include cerclage plus plate (C01 - C05) and lag screw plus plate (S01 - S05) fixation. Displacement was measured using an optical motion capture system as the change in fracture gap distance from the initial reduction position. Mean displacement represents the average gap change throughout cyclic loading, while maximal displacement represents the greatest observed change from the pre-load position.