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Unicortical Locking Screws Provide Comparable Rigidity to Bicortical Compression Screws in Clavicle Plate Fixation Constructs

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Clavicle fracture; Mid-shaft; Unicortical; Bicortical; Screw fixation

1. Abstract

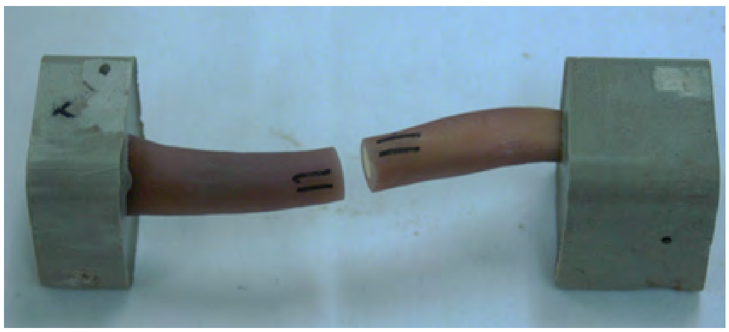
Clavicle fixation carries neurovascular injury risk. The purpose of this study was to compare bicortical compression and unicortical locked clavicle fixation constructs biomechnically. Ten 4th-generation composite transverse mid-shaft clavicle osteotomy specimens were assigned to two groups and each clavicle was fixed with an eight-hole 2nd generation 3.5 mm locking pelvic reconstruction plate placed superiorly. Group one included five fixed with bicortical compression screws and group two included five fixed with unicortical locking screws. All were tested on a 4-axis servo-hydraulic testing frame in three modes: axial rotation, anterior/posterior bending, and cephalad/caudad bending. Mean construct stiffness for AP bending was 1.255 ± 0.058 Nm/deg (group 1) and 1.442 ± 0.065 Nm/deg (group 2); (p=0.001). Mean construct stiffness for axial rotation was 0.701 ± 0.08 Nm/deg (1) and 0.726 ± 0.03 Nm/deg (2); (p=0.581). Mean construct stiffness for cephalad bending was 0.889 ± 0.064 Nm/deg (1) and 0.880 ± 0.044 Nm/deg (2); (p=0.807). Mean construct stiffness for caudal bending was 2.523 ± 0.29 Nm/deg (1) and 2.774 ± 0.25 Nm/deg (2); (p=0.182). With transverse clavicle fractures, unicortical locking fixation provided comparable rigidity to bicortical compression fixation in axial rotation, cephalad bending, and caudal bending; it provided greater rigidity in AP bending

2. Introduction

The clavicle is among the more unique bones in the human body when considering anatomy and function. It serves as a strut for the upper extremity and is the only bony connection between the upper extremity and the axial skeleton. Loads on the upper extremity are transmitted to the thorax through the clavicle. Combined with its superficial location, these factors make the clavicle the most fractured human bone [1,2]. Middle third clavicle fractures account for approximately 80% (of clavicle fractures) and have traditionally been treated non-operatively based on Neer's work [3]. However, Hill, et al reviewed non-operatively treated displaced mid-shaft clavicle fracture outcomes and found patients often fared poorly [4]. They subsequently recommended operative fixation for displaced mid-shaft clavicle fractures. In a randomized clinical trial, the Canadian Orthopaedic Trauma Society found operative fixation of displaced adult mid-shaft clavicle fractures resulted in improved functional outcomes and lower rates of nonunion as well as malunion when compared with non-operative treatment [5]. Unfortunately, the orthopedic and vascular literature contains reports of limb-threatening complications associated with plate-screw constructs for mid-shaft clavicle fractures [6,7]. Unicortical screw fixation may reduce vascular injury risk to subclavian vessels near mid-shaft fractures. However, it is unclear if unicortical screw and plate fixation is adequate. We hypothesized 3.5 mm pelvic reconstruction plates with unicortical screw fixation would provide comparable stability to more traditional bicortical compression screw constructs.

3. Materials and Methods

Ten 4th generation composite clavicles (Sawbones, Pacific Research Laboratories, Vashon, WA) with manufactured mid-shaft osteotomies were randomly assigned to one of two groups [Figure A1]. Each clavicle was reduced and repaired using standard orthopaedic trauma techniques by a single author (C.H.) under the supervision of two attending orthopaedic surgeons (E.F., M.M.). Each specimen was repaired with a contoured eight-hole 2nd generation 3.5 mm locking pelvic reconstruction plate (DePuy Synthes, Raynham, PA) on the superior surface [Figure A2]. Group one specimens were fixed with standard bicortical compression screws and a 1.5 Nm torque-limiting driver. Group two specimens were fixed with unicortical locking screws and the 1.5 Nm torque-limiting driver. Plates were contoured identically with standard hand-held plate benders. Four screws were placed on each side of the osteotomy. All specimens were identically potted in liquid molding plastic and tested for stiffness on a 4-axis MTS servohydraulic machine under displacement control in three loading modes: axial rotation, anterior/posterior bending, and cephalad/caudad bending [Figure A3]. The testing protocol included a single warm-up loop followed by three loops of continuous data acquisition at 100Hz. The displacement control range was determined from scouting (a trial loop) and was set to ±8.0° for axial rotation, ±7.2° for anterior/posterior bending, and +7.2° to -3.6° for cephalad/caudad bending respectively. Specimens were first tested in AP bending mode. For AP bending the proximal end of the specimen was statically fixed to the testing machine while the distal end was placed in a custom-built actuated fixture to allow the specimen to bend around the osteotomy while minimizing shear. Specimens were then rotated 180º to test cephalad/caudad bending using the same fixtures. Lastly, we tested axial rotation by applying axial torque through the piston actuator. Data were grouped by screw type for descriptive statistics. The data were analyzed using the two-sample t-test. Significance was set as a p value of ≤ 0.05.



Appendix A

Figure A1. Sawbones 4th generation composite clavicle with mid-shaft osteotomy.

Figure A2. Sawbones 4th generation composite clavicle with manufactured mid-shaft osteotomy repaired using contoured Synthes eight-hole 2nd generation 3.5mm locking pelvic reconstruction plate on the superior surface.

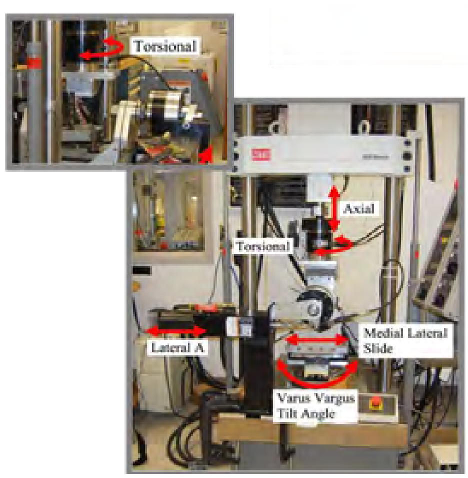


Figure A3. 4-axis MTS servohydraulic machine.

Table 1. CO2em (CO2 emission), NOx (NOx production), NOxc (NOx concentration at exit gas), Dump (Wastewater dumping), Fixable CO2, GWPR (global warming protection ratio), GDP (GDP ratio 2021/1991) of 13 countries.

Country	CO2 emit	NOx	NOxcon	Wdunp	FixabllCO2	GWPR	GDP
	Hmilt	Hmillt	g/kWh		Hills		2021/1991
World	510	16.5				1.3	
China	196.4	4.25	1.6	Do	100	1	51.1
India	24.6	1	1.6	Do	32	0.76	11.1
Indonesia	5	0.2	1.6	Do	19	0.3	
USA	51	2	0.5	No	95	0.53	3.7
Japan	12	0	0	No	3.8	3.3	1.1
Russia	19.6	0.63			32	0.61	
Germany	7.6	1	1	No	2.2	2.2	4.3
UK	4	0.16	1.3	No	2.4	1.2	3.3
Italy	3.5	0.14	0.5	No	3	1.2	
France	0.12			No	6.4	0.4	
Canada	5.6	0.22	1.3	No	199	0.06	
Iran	6.3	0.025			1.6	3	
Turky	4	0.16			7.6	0.5	

Table 2. Prediction of CO2em (CO2 emission), NOx (NOx production), NOxc (NOx concentration at exit gas), Dump (Wastewater dumping), Fixable CO2, GWPR (global warming protection ratio), GDP (GDP ratio 2025/1991) at 2025 of 13 countries.

Country	CO2 emit	NOx	NOxc	Wdunp	FixabllCO2	GWPR	GDP
	Hmilt	Hmillt	g/kWh		Hills		2025/1991
World	510	16.5			510	1	
China	196.4	4.25	1.6	Do	100	1	55
India	24.6	1	1.6	Do	32	0.76	15
Indonesia	5	0.2	1.6	Do	19	0.3	
USA	51	2	1.6	Do	95	0.53	10
Japan	8	0.5	.1.6	Do	8	1	10
Russia	19.6	0.63			32	0.61	
Germany	5.5	0.3	1.6	Do	2.2	1	10
UK	3	0.2	1.6	Do	2.4	1	10
Italy	2.5	0.14	1.6	Do	3	1	
France	0.12		1.6	Do	6.4	0.4	
Canada	5.6	0.22	1.6	Do	199	0.06	
Iran	6.3	0.025			1.6	3	
Turky	4	0.16			7.6	0.5	

4. Results

The mean steady-state construct stiffness for axial rotation, cephalad bending, and caudal bending was similar between groups one and two but differed significantly in AP bending [Figure 1]. The mean steady-state construct stiffness for AP bending was 1.255±0.058 Nm/deg for group one and 1.442±0.065 Nm/deg for group two; the difference was significant (p=0.0013). The mean steady-state construct stiffness for axial rotation was 0.701±0.08 Nm/deg for group one and 0.726±0.03 Nm/deg for group two; the difference was not significant (p=0.581). The mean steady-state construct stiffness for cephalad bending was 0.889±0.064 Nm/deg for group one and 0.880±0.044 Nm/deg for group two; the difference was not significant (p=0.807). The mean steady-state construct stiffness for caudal bending was 2.523±0.29 Nm/deg for group one and 2.774±0.25 Nm/deg for group two; the difference was not significant (p=0.182).

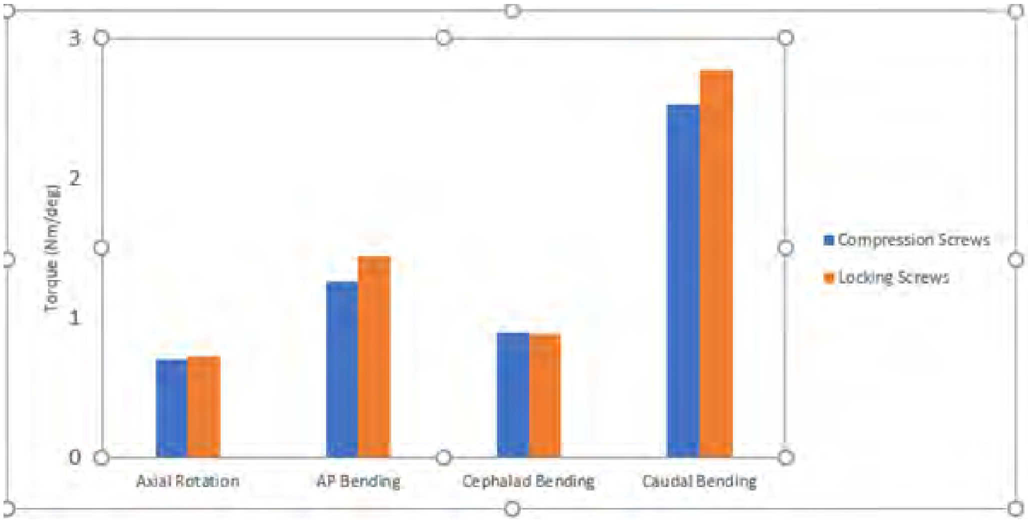


Figure 1. Mean steady-state construct stiffness for axial rotation, anterior-posterior bending, cephalad bending, and caudal bending between group 1 (bicortical compression screws) and group 2 (unicortical locking screws).

5. Discussion

Following the Canadian Orthopaedic Society's findings that operative fixation of displaced adult mid-shaft fractures resulted in improved functional outcomes with reduced nonunion and malunion (when compared with non-operative treatment), one assumes clavicle fixation rates increase [5]. Yet, clavicle fixation is not without risk [8]. Vascular injury in surgery or even post-operatively can be limb threatening [6,7]. As plates and screws are familiar to orthopaedic surgeons and provide excellent clavicu-lar shaft rotational control, constructs that do not violate the inferior clavicle cortex may allow treatment while reducing vascular injury risk. Therefore, the purpose of this study was to perform a biomechanical comparison of mid-shaft clavicle fracture fixa-tion constructs with unicortical locked screws and standard bicortical compression screws. Previously, Collinge, et. al. described anterior plate fixation to improve fixation and decrease risk of vascular injury [9]. This technique requires some deltoid detach-ment laterally and may not allow vascular protection in all. Robertson, et. al. suggested anterior-inferior reconstruction plates might be subjected to loads that could cause early mechanical failure [10]. Moreover, Iannotti, et. al. found superior plating of mid-shaft clavicle osteotomies was biomechanically advantageous to anterior plating [11]. Furthermore, they found 3.5 mm LCDC plates were better than 2.7 mm DC plates or 3.5 mm reconstruction plates. But it is unclear if improved stability afforded by LCDC plate is clinically important. Also of note, The Canadian group found hardware removal incidence declined with contoured plates [5]. Our study is not without limitations. We did not create a gap at the fracture site to simulate comminution. Yet, the dynamic healing process changes the overall local en-vironment in vivo such that the loss of stability due to comminution changes continu-ally. Second, we only tested a transverse fracture model. However, oblique fracture lines frequently allow the utilization of an interfragmentary screw that can dramati-cally stabilize the construct. We felt the utilization of a transverse fracture line would more closely approximate an in vivo environment. Third, we utilized 4th generation composite fracture models. It is possible that cadaver specimens may have changed our results. However, we wished to eliminate bone density variability as one (variable) that could significantly alter results, so we used consistent specimens. These limita-tions do not affect our ability to adequately evaluate the biomechanical differences between unicortical locked screw fixation constructs versus standard bicortical screw fixation constructs in a transverse osteotomy mid-shaft clavicle fracture model in 4th generation composite specimens.

5.1. Clinical Relevance: Improved outcomes following displaced mid-shaft clavicle fractures have been demonstrated with plate/screw constructs [4,5,9]. Catastrophic injury risk mitigation with fixation may influence mid-shaft clavicle fracture treat-ment algorithms.

6. Conclusions

In a transverse mid-shaft clavicle osteotomy model, superiorly placed bicortical fixation with 3.5 mm pelvic reconstruction plates did not provide greater rigidity than similarly placed unicortical locking 3.5 mm pelvic reconstruction plate constructs. Unicortical locking fixation provided greater rigidity in AP bending.

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