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A hybrid approach to mid-shaft clavicle fixation

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ABSTRACT

Background: The purpose of this study was to demonstrate the strength characteristics of a hybrid uni-cortical construct for clavicle fixation. The technique reported aims to combine benefits of uni-cortical fixation with stability comparable to traditional bi-cortical fixation. The approach utilises long, oblique uni-cortical screws at the distal ends of the plate acting as surrogate bi-cortical screws. Locked uni-cortical screws positioned centrally provide bending and torsion strength to the construct. This alternative hybrid uni-cortical technique does not require far cortex screw or drill penetration required in bi-cortical fixation techniques, thus avoiding potentially catastrophic vascular and or neurologic injury. The purpose of this study was to compare the mechanical behaviour of the hybrid uni-cortical construct to standard bi-cortical fixations under both torsion and bending loads.

Method: Thirty osteotomized human cadaveric clavicles were randomly allocated to three surgical fixation techniques: bi-cortical locked screw fixation, bi-cortical non-locked screw fixation and hybrid uni-cortical screw fixation. Each clavicle construct was tested non-destructively under torsional loading, and then under cantilever bending to failure. Construct bending and torsional stiffness, as well as ultimate failure strength, were measured.

Results: There were no significant differences between uni-cortical or bi-cortical fixation constructs in either bending stiffness or ultimate bending moment ($p > 0.05$); however, there was a trend towards greater bending stiffness in the hybrid construct. The uni-cortical hybrid fixation technique displayed a significantly lower mean torsional stiffness value when compared with the bi-cortical locked screw fixation (mean difference: 134.4 Nmm/degrees, 95% confidence interval [32.3, 236.4], $p = 0.007$).

Conclusion: A hybrid uni-cortical approach to clavicle plate fixation that may improve screw purchase and reduce risk of intra-operative vascular damage demonstrates comparable bending strength to current bi-cortical approaches.

Introduction

Fractures of the clavicle represent approximately 2–5% of all fractures in the body and 45% of fractures to the shoulder girdle [1,2]. The majority of displaced mid-shaft clavicle fractures occur in young males under the age of thirty [3], typically due to excessive torsional and bending forces or from direct impact to the clavicle in sporting or road traffic injuries. In displaced mid-shaft clavicle fractures, the decision to use a surgical approach to repair the clavicle is supported by evidence suggesting a shorter time to union, reduced risk of non-union and increased patient satisfaction compared with non-operative approaches [4–6]. Whilst there remains a lack of consensus as to the optimal method of stabilization, bi-cortical locking plate fixation is one of the most commonly employed techniques [7–9].

Serious perioperative complications associated with plate fixation are rare; however, when encountered, they can be catastrophic and potentially life threatening. Iatrogenic damage to adjacent neurovascular structures can become apparent acutely [10–13] or present after a time delay, sometimes many years after surgery [14–16]. Published reports describe pseudoaneurysm [14–17], subclavian arteriovenous fistula [11], brachial plexus compression [13] and fatal air embolus following subclavian vein drill penetration and laceration [10] (Clitherow and Bain [18]). In one Canadian retrospective study of 1350 patients, damage to subclavian vessels and the brachial plexus during or following surgery were observed in five patients [19]. Despite low incidence, over-drilling with far cortex plunging or excessive bi-cortical

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screw penetration, often associated with surgical inexperience, increases the likelihood of neurovascular complication associated with clavicle fracture plate fixation.

Studies have emphasised the proximity of the subclavian vessels during plate fixation for mid-shaft clavicle fracture [20–22]. From a postero-superior position medially, these vessels run inferiorly and laterally passing under the clavicle at a point medial to the midpoint approximately 32–45% along the clavicle length [20,21]. The variable anatomical position of these vessels between patients increases the likelihood of possible intraoperative vessel damage, particularly during bi-cortical fixation. An antero-inferior approach to clavicle fixation is clinically attractive because it directs screws away from the subclavian vessels [23,24]. This approach accounts for any complications that may occur inferior to the midpoint of the clavicle; however, potential for bi-cortical screw tip contact with subclavian vessels in medial screw holes remains a concern [25].

The most reliable way to prevent neurovascular complications with clavicle plate fixation would be to avoid far cortex penetration by drill or screw. This would require the use of uni-cortical locking and non-locking screws. The uni-cortical construct would ideally have similar mechanical strength to the bi-cortical fixation constructs currently in use. However, while some biomechanical studies have demonstrated adequate strength of uni-cortical locking screw fixations [26], other studies suggest limited resistance of these constructs to both bending and torsional loads [27,28].

The aim of this study was twofold. Firstly, to develop a mid-shaft clavicle fracture plate fixation technique using long oblique uni-cortical screws at the ends of the plate as surrogate bi-cortical screws, combined with uni-cortical locking screws, and to biomechanically evaluate this construct and compare the findings with those of bi-cortical locking and non-locking screw constructs.

Materials and methods

Specimen preparation

Thirty clavicles (13 left, 17 right; mean age: 82.4 yrs, range 48 to 97 yrs) were dissected from twenty adult formalin fixed cadavers. Clavicles were removed of all soft tissue by sharp dissection and were visually screened for macroscopic abnormalities.

Surgical repair

Clavicles were randomly assigned to three fixation groups of ten clavicles (Fig. 1): bi-cortical fixation with locking screws, bi-cortical fixation with non-locking screws, and a uni-cortical hybrid fixation, which included uni-cortical locking screws placed in the central holes and two uni-cortical non-locking screws orientated obliquely at the most medial and lateral screw holes. Each clavicle was surgically fixed using six-hole, decreased curvature clavicle plates (VariAx, Stryker, Michigan, USA) placed on the superior surface of the clavicle. Screws used were 3.5 mm in diameter and varied in length between 10 and 24 mm.

After fixation, a mid-length vertical osteotomy was created on each clavicle with a bone saw. A pilot study showed that creating the osteotomy after surgical fixation of the plate generated a reproducible fracture pattern that reduced inter-specimen variation in fracture gap size. The simulated fracture technique is similar to that used by others [29].

Torsional loading

All repaired clavicle specimens were first tested non-destructively in torsion. Both sternal and acromial ends of the clavicle were potted in custom-built fixtures using dental plaster, and then attached to an Instron Materials Testing Machine (Instron, Model 3521, Parker Hydraulics) (Fig. 2). The sternal end of the clavicle was fixed to the lower crosshead of the Instron, while the acromial end was fixed to the upper crosshead. The mechanical axis of the clavicle was aligned parallel with the vertical axis of the Instron.

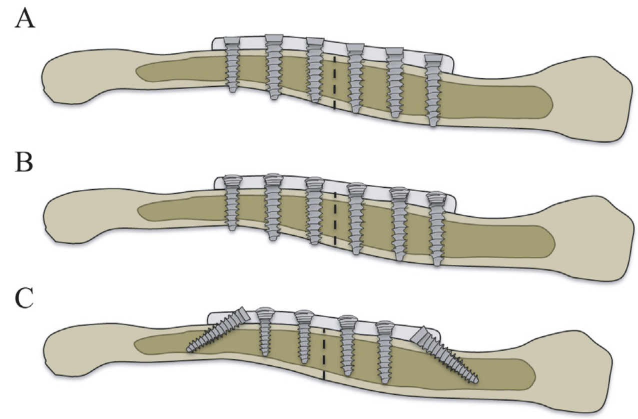

Fig. 1. Screw configurations used for clavicle fixations in this study, including bi-cortical fixation using non-locking screws (A), bi-cortical fixation using locking screws (B) and hybrid fixation (C).

With the sternal end of the clavicle rigidly fixed, the acromial end of the clavicle was twisted by applying angular motion at a constant rate of 0.5 deg/s [30,31] until a pre-defined upper torque limit of 9 Nm was reached. This limit was defined as 60% of the total torque required to fracture an intact clavicle, and was chosen in a pilot study to produce a sufficient linear torque vs. displacement relation for calculation of stiffness. The test was aborted if a rotational displacement of 12 degrees was produced before the torque limit was reached. A pilot study showed that rotation beyond this limit results in substantial fracture instability. During testing, applied torque and angular displacement (rotation)

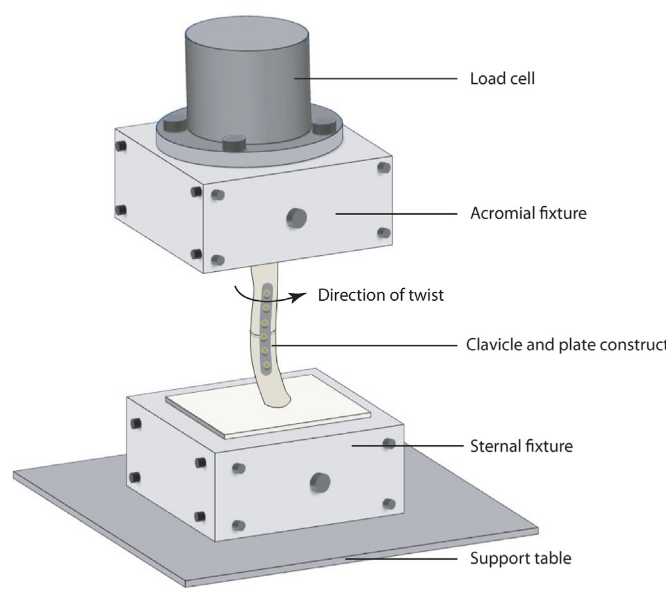

Fig. 2. Schematic diagram of clavicle fracture fixation testing in torsion. The clavicle and plate construct was mounted vertically by embedding the sternal and acromial ends of the clavicle in custom-designed potting fixtures. The sternal fixture was attached to a support table, while the acromial fixture was mounted to a load cell that was bolted to the upper cross-head of an Instron materials test system. Torsion was applied to the construct by applying twisting motion to the upper crosshead at a constant rate.