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Neil G. Burke
Royal College of Surgeons in Ireland

Jim Kennedy
Royal College of Surgeons in Ireland

Grainne Cousins
Royal College of Surgeons in Ireland, gcousins@rcsi.ie

David Fitzpatrick
University College Dublin

Hannan Mullett
Royal College of Surgeons in Ireland

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Locking plate fixation with and without inferomedial screws for proximal humeral fractures: a biomechanical study

Neil G Burke,[1,2] Jim Kennedy,[1,2] Grainne Cousins,[3] David Fitzpatrick,[4] Hannan Mullett[1,2]
[1] Department of Orthopaedic Research, Royal College of Surgeons, Dublin, Ireland
[2] Department of Orthopaedic Surgery, Cappagh National Orthopaedic Hospital, Dublin, Ireland
[3] HRB Centre for Primary Care Research, Royal College of Surgeons in Ireland
[4] School of Electrical and Mechanical Engineering, University College Dublin, Ireland

ABSTRACT

Purpose. To compare the efficacy of locking plate fixation with and without inferomedial screws in maintaining the reduction of a proximal humeral fracture.
Methods. 22 synthetic humerus models were used. A standardised 3-part proximal humeral fracture with a 4-mm wedge segment was created and fixed with a locking plate and screws with (n=11) and without (n=11) inferomedial screws. The intrafragmentary motion of the construct at 250, 500, 750, and 1000 cycles of 532 N loading, and the load to failure of the 2 groups were compared.
Results. Locking plate fixation with inferomedial screws reduced the mean intrafragmentary motion in all cycles ($p<0.01$) and increased the load to failure (1452 N vs. 1159 N, $p<0.001$), compared to fixation without inferomedial screws.
Conclusion. Additional inferomedial screws provide medial column support for fracture healing. This may reduce intrafragmentary motion and thus implant complications resulting from varus malalignment such as screw perforation or loss of reduction.

Key words: *bone plates; bone screws; shoulder fracture*

INTRODUCTION

Approximately 20% of proximal humeral fractures require surgical intervention; most are 3- or 4-part fractures.[1,2] The treatment goals are to achieve minimal soft-tissue dissection and anatomic reduction with sufficient stability to enable early shoulder mobilisation. Surgical options include the use of percutaneous Kirschner wires, T-plates, angled plates, cloverleaf plates, locking plates, intramedullary nails, tension band wires, and primary prosthesis.[3]

Locking plate fixation is widely used, especially in patients with poor bone stock, but it is associated with high complication rates.[4–7] One such complication is screw penetration into the humeral head secondary to varus deformation (Fig. 1). To prevent such complication, support of the medial column is advocated.[7–10] Mechanical support to the inferomedial

Address correspondence and reprint requests to: Mr Neil Burke, Department of Orthopaedic Surgery, Cappagh National Orthopaedic Hospital, Dublin, Ireland. Email: nei1burke@yahoo.co.uk

region of the proximal humerus prevents subsequent loss of reduction.[9] Medial column support can be achieved by anatomic or slightly impacted stable reduction, and placement of a superiorly directed oblique locking screw into the inferomedial region of the proximal humeral fragment. This screw is referred as the inferomedial or kickstand screw. This study aimed to compare the efficacy of locking plate fixation with and without inferomedial screws in maintaining the reduction of a proximal humeral fracture.

MATERIALS AND METHODS

Based on a radiological study using loss of humeral head height as an indicator for loss of reduction following locking plate fixation of a proximal humeral fracture, the group with inadequate mechanical medial support (i.e. without an inferomedial screw or with non-anatomic humeral head reduction) had an significantly greater loss of humeral head height (5.8 vs. 1.2 mm, p<0.001).[9] A sample size of 11 in each group was calculated to provide a 95% power (standard deviation, 1.4).

Fourth-generation composite humerus models (Sawbones, model 3404; Pacific Research Laboratories, Washington, US) were used. A standardised 3-part proximal humeral fracture was created in each sawbone using an oscillating saw. Osteotomies were performed at the surgical neck level, and then perpendicular to the surgical neck at the greater tuberosity level. The centre of the bicipital groove and the posterior aspect of the outlined articular cartilage were used as anatomic landmarks. A 4-mm wedge segment was removed to create medial comminution. The humeral shaft was cut transversely at 20 cm from

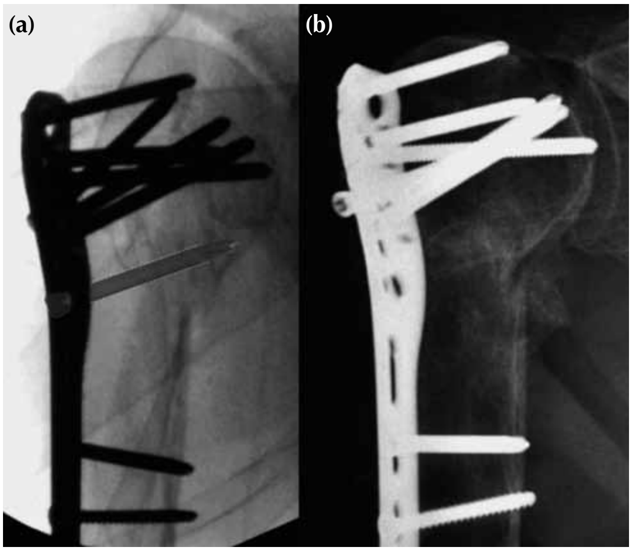

Figure 1 Radiographs showing **(a)** malreduction of the medial cortex and non-insertion of the inferomedial (kickstand) screw (in grey colour). **(b)** After 2 months, the humeral head becomes varus with screw backing out and penetrating the articular surface. (Reproduced with permission: Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. J Orthop Trauma 2007;21:185–91.)

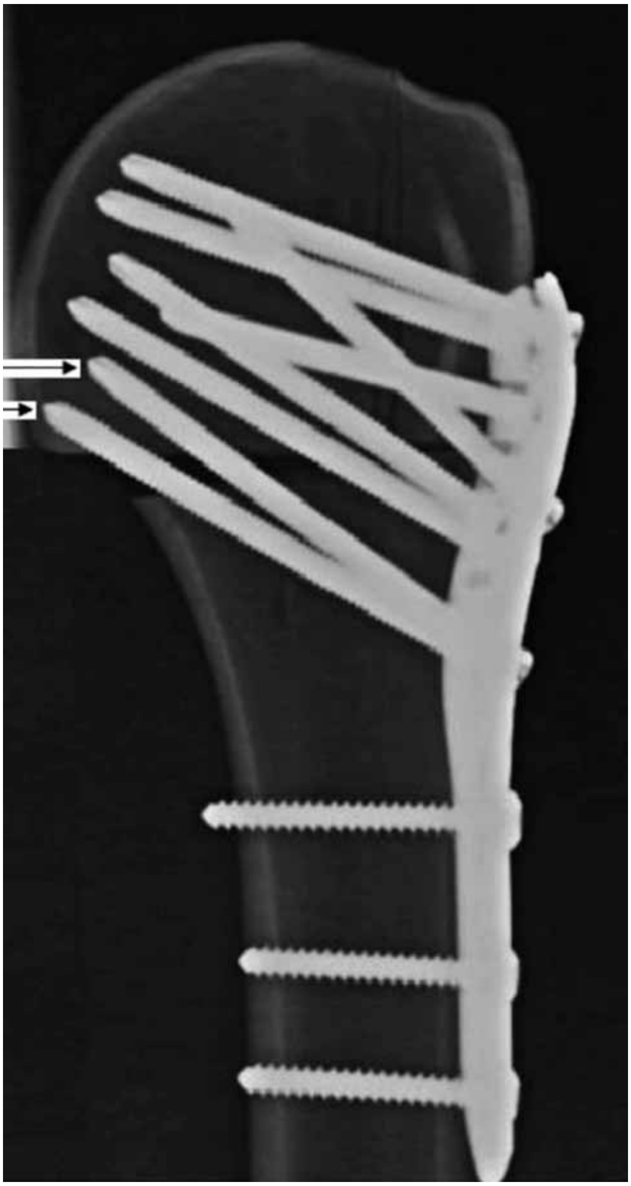

Figure 2 Radiograph showing a 3-part proximal humeral fracture fixed with a locking plate and screws, including the inferomedial screws (arrows)

the greater tuberosity and mounted vertically in the jig using the Simplex rapid dental cement. A protocol was used to ensure accurate and reproducible vertical alignment.

The 3-part fracture was fixed with a proximal humerus internal locking system (PHILOS) plate (Synthes, Oberdorf, Switzerland) using the standard technique. The subchondral bone was drilled with care, without penetrating the articular surface. Locking screws of uniform length were inserted into all screw holes using a torque-limiting screwdriver (Fig. 2). The distal of the plate was fixed with 3 bicortical compression screws. In controls, the inferomedial (kickstand) locking screws were not inserted (Fig. 1).

The intrafragmentary motion was measured using an optoelectronic camera system (Optotrak 3020; Northern Digital, Waterloo, Ontario, Canada). It continuously tracked the 3-dimensional motion of the sensors at a frequency of 20 Hz. The sensors were mounted on the greater tuberosity, articular surface, and humeral diaphysis (Fig. 3). The relative linear and rotational motions (in mm) of each fracture fragment relative to the humeral shaft were plotted against time to determine the stability of the construct under simulated physiological loading.

A model re-creating the normal forces at the glenohumeral joint was used.[11–13] The maximum reaction force in the human shoulder is equal to 89% of body weight at 90º of isometric abduction in the scapular plane, and thus an average man weighing 72 kg has a reaction force of 532.6 N.[12] A load of 532.6 N was applied vertically using a biaxial servo hydraulic testing machine (model 8205; Instron, Canton, Massachusetts) with a teflon glenoid. 1000 compressive cycles at a frequency of 1 Hz were applied, as the highest load reduction and loss of fracture stabilisation usually occur within 1000 cycles.[14] Subsequently, the load was increased progressively until failure.

The Mann-Whitney *U* test was used to compare the 2 groups in terms of intrafragmentary motion at 250, 500, 750, and 1000 cycles, and the load to failure. The Wilcoxon rank-sum test was used to determine whether the intrafragmentary motion varied within each group across different cycles (0–250, 251–500, 501–750, and 751–1000). A p value of <0.05 was considered statistically significant.

Figure 3 The bio-mechanical testing model with the Optotrak sensors.

RESULTS

Locking plate fixation with inferomedial screws reduced the mean intrafragmentary motion after 250 (0.365 vs. 0.524 mm, p<0.01), 500 (0.373 vs. 0.605 mm,

Table
Intrafragmentary motion in locking plate fixation with and with inferomedial screws

No. of cycles	Mean±SD intrafragmentary motion (mm)		p Value
	Locking plate fixation with inferomedial screw (n=11)	Locking plate fixation without inferomedial screw (n=11)	
250	0.365±0.117	0.524±0.067	<0.01
500	0.373±0.125	0.605±0.004	<0.01
750	0.402±0.118	0.755±0.082	<0.001
1000	0.459±0.127	0.853±0.072	<0.001

p<0.01), 750 (0.402 vs. 0.755 mm, p<0.001), and 1000 (0.459 vs. 0.853 mm, p<0.001) cycles, and increased the mean load to failure (1452 N vs. 1159 N, p<0.001), compared with fixation without inferomedial screws (Table). The mean intrafragmentary motion increased significantly from 250 to 1000 cycles within each group (all p<0.01).

DISCUSSION

Fixed angled locking plates for treatment of proximal humeral fractures are widely used,[4,8,9,15,16] but the complication rate associated with hardware failure is high. In a systematic review, the complication rate is 7.9% for avascular necrosis, 11.6% for screw cut-out, and 13.7% for re-operation.[7] Screw penetration is commonly due to varus deformation of the fracture fragments. 30% of fractures with deficient medial support result in screw perforations, compared with 6% for fractures with an intact medial support.[9] This highlights the importance of medial column support in fixation with fixed angled plates.[7–10] Inferomedial screws are important in providing medial column support. In our study, fixation with inferomedial screws decreased intrafragmentary motion and better maintained reduction in the presence of medial comminution. The intrafragmentary motion is greater in patients with poor bone stock resulting in an increased likelihood of varus malalignment.

Bone quality and quantity are highest in the inferior and dorsal regions of the proximal humerus.[17] The inferomedial screws connect this trabecular network and decrease implant complications (such as screw penetration of the articular surface or plate breakage), and are of particular benefit in osteoporotic bone.

When the PHILOS plate is used, the fixed angled screws act as struts to prevent varus displacement of the humeral head, and therefore maintain the reduction and enable early mobilisation. Good functional outcomes have been reported for complex proximal humeral fractures.[4–6,18,19] The PHILOS plate enables placement of 2 screws into the inferomedial proximal humerus to provide medial column support.

Supplementing internal fixation with calcium cement or synthetic bone grafts also reduces intrafragmentary motion.[20,21] Intramedullary fibular grafts provide further construct stability, especially in fractures with medial comminution, significant voids, and low bone stock.[22,23]

In our study, the maximum lever arm of the upper extremity was re-created, and soft-tissue attachment to the proximal humerus was accounted for in the biomechanical testing, which was partly based on the isometric study of the glenohumeral joint,[12] which assumes that the force in a muscle is proportional to its area times the electromyographical signal. The testing simulated the maximum joint reaction forces in the human shoulder and reflected the activity of the supraspinatus, anterior middle and posterior portions of the deltoid and subscapularis.

Synthetic humerus models resemble the flexural rigidity of human humeri.[24] This enables uniform testing and eliminates variation between specimens which may occur in cadaveric humeri. Nonetheless, osteoporotic bone is not reflected, which is increasingly encountered clinically. The 3-part fracture pattern may not replicate in clinical practice. The intrafragmentary motion may be greater if cortical bone loss occurs. The inferomedial screw may not be useable in clinical situations such as comminuted fractures and minimally invasive osteosynthesis.

CONCLUSION

Additional inferomedial screws provide medial column support for fracture healing. This may reduce intrafragmentary motion and thus implant complications resulting from varus malalignment such as screw perforation or loss of reduction.

DISCLOSURE

No conflicts of interest were declared by the authors.

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