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ORIGINAL PAPER

The use of a new locking 90° blade plate in the treatment of atrophic proximal humerus nonunions

Christian Allende · Bartolome T. Allende

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Abstract This level IV case series study prospectively evaluated patients with atrophic proximal humerus nonunions stabilised with a locking 90° blade plate. All patients were women with an average age of 69 years (range 56–78). Time from trauma to nonunion treatment averaged 23 months. Five patients had had previous surgical treatments. Two patients had a history of infection and one patient with active infection was reconstructed in two stages. Follow-up averaged 22 months (range 18–36); union was achieved in all seven cases after an average of 5.85 months. The DASH score at the last follow-up averaged 25 points and Constant score averaged 72.7 points. No patient required additional procedures. At the last follow-up all patients were free of infection, and there were no cases of avascular necrosis. The results with locked 90° blade plates in atrophic nonunions of the proximal humerus in adults were favourable in this series.

Résumé L'objectif de cette étude est de réaliser une évaluation prospective des pseudarthroses arthrophiques de l'extrémité supérieure de l'humérus stabilisées par une lame plaque verrouillée à 90°. tous les patients étaient des sujets féminins avec un âge moyen de 69 ans (56 à 78). La période entre le traumatisme et la pseudarthrose était en moyenne de 23 mois. 5 patients n'avaient pas eu de traitement avant la survenue de la pseudarthrose. Deux patients avaient une histoire d'infection et 1 patient une infection évolutive avec une reconstruction en deux temps. le suivi moyen a été de 22 mois (18 à 36). Une consolidation a été obtenue dans tous les cas après 5,85 mois en moyenne. Le score DASH au dernier suivi était de 25 points et le score de Constant de 72,7 points. Aucun patient n'a nécessité un geste chirurgical additionnel. Au dernier suivi aucun patient ne présentait d'infections, il n'y avait pas de nécrose vasculaire. le résultat du traitement d'une pseudarthrose arthrophique de l'extrémité proximale de l'humérus avec une lame plaque de 90° chez l'adulte est extrêmement favorable.

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C. Allende (✉) · B. T. Allende
Department of Upper Extremity and Reconstructive Surgery,
Sanatorio Allende, Hospital Nacional de Clínicas,
Universidad Nacional de Córdoba,
Hipolito Yrigoyen 384,
Cordoba 5000, Argentina
e-mail: Christian_allende@hotmail.com

Introduction

Indications for open reduction and internal fixation of proximal humerus fractures in patients older than sixty years require continued analysis [2, 19]. Nonunions of the proximal and distal humerus remain difficult to treat, mainly because achieving stable fixation to maintain the intraoperative reduction is unpredictable [1]. Bony union and restoration of shoulder function are the ultimate goals when treating proximal humerus nonunion. Previous operations, quality of bone stock, a small proximal fragment, infection, rotator cuff dysfunction, degenerative changes, and joint stiffness may be associated, implying significant challenges for the treating surgeon. The surgical goal in these cases is to create a biological environment that will foster union, ensure good alignment of bony fragments, and achieve adequate stability as to allow prompt motion. Numerous fixation systems have been described to augment stabilisation in osteoporotic fractures and nonunions in which one of the fragments to be stabilised is small, including extra or intramedullary fixation techniques, compound osteosynthesis, and hemiarthroplasty.

Recent publications have shown that locked plates allow union to occur in a wide range of complex fractures and nonunion, with a low rate of complications related to the implant; but these complications have been more frequent in the humerus [23, 24]. The use of locked plates has been found to be biomechanically superior to intramedullary nails [4] and blade plates [25] in stabilising fractures of the surgical neck of the humerus; but, despite recent advances of locked-plate technology, humeral head necrosis, osseous malalignment, nonunion, deep infection, hardware cut-through, and loss of reduction after open reduction and internal fixation of proximal humerus fractures remain a problem [17, 19, 26]. In order to decrease these complications and increase the stability in complex metaphyseal nonunions of the proximal humerus associated with bone loss, a small proximal fragment, osteoporosis, and multiple previous operations, we designed a locked 90° blade plate implant, which combines the advantages of the blade plate with those of locking plates. This allows placement of the proximal locked screws in a divergent orientation into the humeral head to increase medial metaphyseal support, preventing of varus collapse of the proximal segment, and aiding the maintenance of fracture reduction [8].

The purpose of this study was to evaluate the radiographic and functional results achieved with the use of locked 90° blade plates in adult patients with atrophic nonunion of the proximal third of the humerus.

Materials and methods

We prospectively evaluated seven patients treated between 2004 and 2006 presenting a nonunion of the proximal third of the humerus and stabilised with locked 90° blade plates (Table 1). All patients were women and referred pain, severe functional loss, and instability at the site of nonunion. Patient's ages averaged 69 years (range 56–78). The right dominant arm was affected in two cases, and the left non-dominant arm in five cases. Time from trauma to definitive surgery averaged 23 months (range 9–51). Five patients had had previous surgical treatments (average 2.4), and five patients smoked one or more packs of cigarettes per day. One patient, initially treated with a brace, developed a reflex sympathetic dystrophy with severe hand and finger stiffness. The initial fracture was secondary to a fall from a standing height in two cases, and a motor-vehicle accident in five cases. All nonunions were unstable, had no signs of healing, and were considered atrophic according to the criteria of Weber and Cech [27].

Locked 90° blade plates were designed by the authors of this paper, based in cadaveric bone, with AutoCad/3DMax Microsoft Corporation, Macromedia Inc., copyright Dainippon Ink and Chemicals, Inc., USA). The locked blade plate was

Table 1 Patient characteristics

Case	Age (years)	Gender	Previous surgeries	Time from trauma to definitive surgery (months)	Bone graft
1	69	F	4 (plate x 2, IM nail, debridement)	28	Allograft
2	77	F	3 (plate x 3)	26	Allograft
3	78	F	None (brace)	9	Autologous
4	56	F	None (brace)	11	Autologous
5	62	F	2 (plate x 2)	51	Autologous
6	72	F	1 (endomedullary nail)	17	Autologous
7	69	F	2 (IM nail, plate)	20	Allograft
Case	Associated observations	Constant preop	Dash preop	Pain preop[a]	Plate length[b]
1	Active infection, loose IM nail, osteoporosis, bone loss, obese	20	78	9	14
2	Three packs cigarettes per day, broken plate, osteoporosis, bone erosion, necrosis	19	91	7	12
3	Osteoporosis, finger stiffness, one pack of cigarettes per day	28	86	6	11
4	One pack of cigarettes per day, depression	32	84	9	12
5	History of infection, two packs of cigarettes per day	44	67	6	13
6	Osteoporosis	34	81	9	12
7	Obese, bone loss, history of infection, two packs of cigarettes per day	14	94	9	14

[a] Visual analog pain score
[b] In number of holes

Fig. 1 Anteroposterior (**a**) and lateral (**b**) views of cadaveric bone with locked 90° blade plate showing divergent locked screw orientation into the humeral head

manufactured by Implant Cirugia Argentina SRL. They have a low profile, a hole in the top of the blade to allow the insertion of a guiding Kirschner wire, three proximal locked screws with divergent orientation into the humeral head aiming to increase screw pullout resistance, and medial metaphyseal support (Fig. 1). Two holes at the level of the 90° angle allow passage of wires or sutures. The blade acts as a broad and stable point of fixation, is not dependent on thread-bone purchase, and gains a more predictable hold in osteopenic metaphyseal bone. The distal holes are combination holes, which allow compression or locking according to the surgeon's decision. Three different blade lengths have been developed (3, 4.5, and 6 cm). Different implants are used for the left and right humerus as the proximal screws have specific orientation.

Patients were operated upon in the beach chair position under interscalene brachial plexus block. An extended deltopectoral approach was used in the five cases in which implant removal and thorough debridement was required, and the plates were placed using a less invasive technique in two cases with no previous surgical treatment (Fig. 2). In five cases the radial nerve was identified before plate fixation was performed. Prior to performing blade plate osteosynthesis, reduction and alignment of the bony segments was obtained, achieving good bone contact and restoring medial buttress in the metaphyseal area. A K-wire was preliminarily placed in the middle of the proximal half of the humeral head, as an orientation aid, 7–10 mm below the top of the greater tubercle, lateral to the bicipital groove, perpendicular to the long axis of the humerus. The seating chisel was placed perpendicular to the axis of the humeral shaft using an osteotome guided by the orientation K-wire placed in the humeral head for application of the blade. Proximal placement of the implant may lead to subacromial impingement. The blade plate placement is guided by the orientation K-wire. During the application of the blade, the plate must remain parallel to the humeral shaft, and plate positioning must be checked with an image intensifier before the screws are applied. Obtaining good reduction and bone contact are the main surgical goals, even when some humeral length has to be sacrificed.

In one case with active infection and in two with history of infection (all with *Staphylococcus epidermidis*), postoperative treatment with ciprofloxacin and clindamicin for three weeks was indicated by the microbiology department of our institution. In the patient with active infection, a two stage reconstruction was performed—in the first stage a loose intramedullary nail was removed and a cement spacer with antibiotics was placed within the intramedullary canal for twelve weeks, then definitive fixation with a locked blade plate was performed (Fig. 3). Thorough debridement of avascular, infected, and necrotic tissues was performed in the five cases with previous surgical treatment to create a well vascularised

Fig. 2 Less invasive approach, with radial nerve identified distally

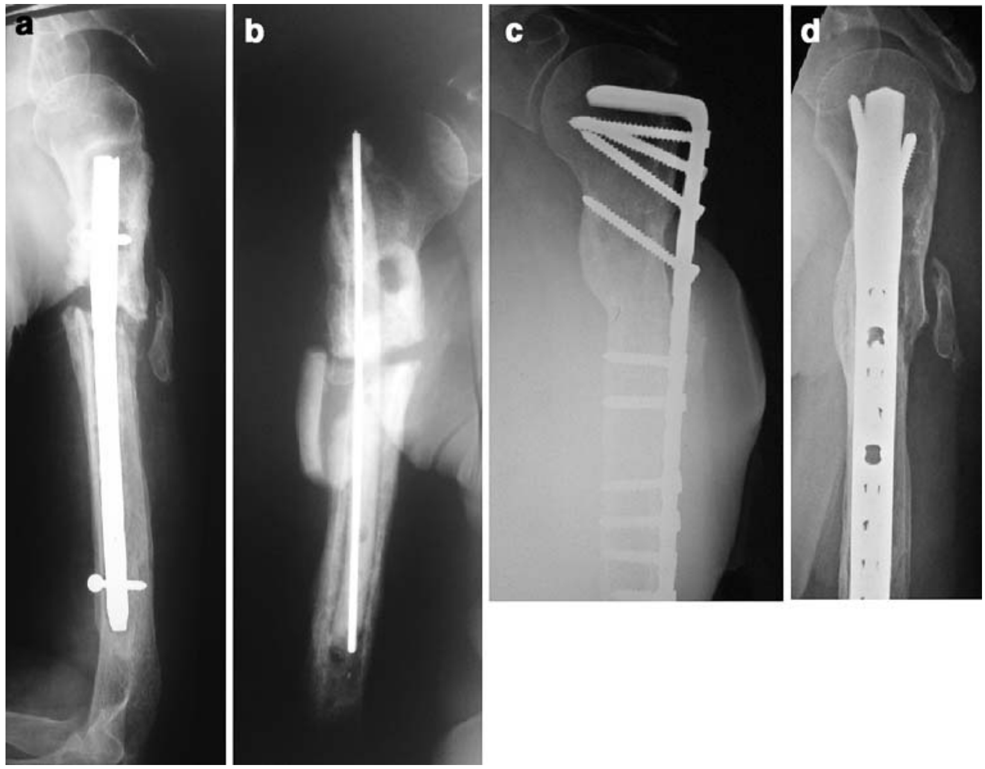

Fig. 3 **a** Preoperative X-ray, loose intramedullary nail, bone loss, periosteal reaction, active infection. **b** Intramedullary nail removal and placement of a cement spacer with gentamicin and vancomycin powder for 12 weeks. **c** Anteroposterior view at last follow-up showing bony union and remodelling after placement of a locked 90° blade plate and morcellized bone allograph

bed before stabilisation with the 90° locked blade plate and placement of the bone graft. Decortication around the area affected by the nonunion was found in the five cases which had an extensile exposure, and when the bone ends were sclerotic the medullary canal of each fragment was opened with the use of a square point device. Three patients, who had had autogenous iliac crest grafting in their previous operations, did not accept another procedure for autogenous graft extraction and in those three cases morcellized allograft with two grams of vancomycin powder was used to fill the bony defects and erosions induced by previous implants. In the remaining four cases autologous iliac crest bone graft was used.

An antirotatory sling was used until radiological evidence of union was obtained. Prophylactic intravenous antibiotics were administered for 48 hours. Patients started early passive ROM exercises immediately postoperatively, and active range of motion was started once there was evidence of fracture healing. Radiological imaging consisted of the standard shoulder trauma series: anteroposterior, scapular Y, and axillary views. Preoperative objective and subjective evaluations performed were Constant and Murley score [3] (average 27.3 points), disabilities of the arm, shoulder and hand questionnaire [12] (average 83 points), and a visual analog scale for pain (0 being no pain, and 10 severe pain) (average 7.85 points) (Table 1). These same evaluation systems were used for follow-up in all cases (Table 2).

Table 2 Results

Case	Time to union (months)	Constant score	Dash	Pain
1	6	76	28	0
2	8	67	20	1
3	4	78	36	0
4	5	76	18	1
5	5	72	14	0
6	6	75	31	2.5
7	7	65	28	1

Results

Follow-up averaged 22 months (range 18–36). Clinical and radiographic union was achieved in all seven cases without loss of reduction or fixation stability, after an average of 5.85 months (range 4–8). No patient required additional procedures, nor was there any infection or avascular necrosis. All patients had complete elbow range of motion. DASH score at last follow-up averaged 25 points (range 14–36). Constant score at last follow-up averaged 72.7 points (range 65–78). The analog scale of pain averaged 0.78 points (range 0–2.5).

One patient has radiological evidence of impingement between the angle of the plate and the acromion during shoulder abduction, but with no pain or functional impairment. All four patients that smoked preoperatively quit for at least the first three months after surgery; and the patient with finger stiffness recovered complete hand function after four months of intensive hand therapy.

Discussion

Surgical treatment of atrophic nonunion of the proximal humerus remains a challenge due to its frequent association to a small proximal fragment, poor bone quality, infection, bone loss, joint stiffness, and multiple previous operations. Reduction and fixation must be stable enough to allow for early shoulder motion to maximise the chances to restore a good functional outcome. Recent developments in open reduction and internal fixation have been based in better knowledge of bone biology, fracture fixation biomechanics, new surgical techniques, and the analysis of previous failures. The use of locked plates and blade plates might not be the ideal solution for fractures of the proximal humerus in elderly patients [5, 10, 17, 19]. The benefits of locked 90° blade plates are that they increase sagittal plane rotational stability, blades in metaphyseal bone are stronger than screws, they still allow multidirectional locking screws with ease of insertion of locking or non-locking screws into the shaft, and they do not remove much bone. The results we report are encouraging, considering the complexity of the lesions treated. There are several limitations to this study. First, no biomechanical testing in comparison with other already available implants has been performed, but it combines two stabilisation systems that have already been extensively tested. Second, there was no control group. Third, it is a small group of patients. But the low incidence of this pathology and the good preliminary results achieved justify the report of these results.

Numerous techniques have been described and continue to evolve to increase the stability achieved in osteoporotic bone and in fractures or nonunion with small bone fragments. These include the use of double plating, combination of a plate and a nail, placement of the screws in divergent distribution, addition of cement to increase screw purchase [13], augmentation with onlay bone plate allograft [11], replacement of cortical 4.5 mm screws by 6.5 mm cancellous screws, placement of an intramedullary plate [6], use of blade plates [14], and stabiliaation with screws locked to the plate, whether by the addition of Schuhli nuts to standard plates or by the use of locked compression plates [20–23]. Although the use of hybrid fixation was initially not recommended and even though it is not yet established which is the biomechanically ideal construction for each particular case, recent publications recommend the use of combined or hybrid fixation [15], because the combination of screws in the hybrid configuration do not alter the mechanical properties of the construction [7]. Locked 90° blade plates are essentially a hybrid stabilisation method with plates that combine the mechanism of stabilisation of the blade plate and that of the locked compression plates. This allows simultaneous divergent screw placement in the proximal fragment, which is usually small, and combination of compression and locking in the remaining screw holes. The use of blade plates requires a precise surgical technique for correct placement of the blade.

Locked compression plates are complex systems that require deep knowledge of biomechanical principles, meticulous preoperative planning, and a precise surgical technique to avoid failures and complications [24]. The surgical technique for placement of a locked 90° blade plate is even more demanding, because an inadequate placement of the blade in the head of the humerus could make the locked screws miss the humerus or could produce an impingement between the plate and the acromion. In metaphyseal and diaphyseal humerus fractures, locked plates allow, but generally do not require, a precise reduction and do not need to be bent as to match with the anatomy of the bone because they provide axial and angular stability, reducing the risk of primary loss of reduction. Locked 90° blade plates have the advantage of combining two different, but well known, methods of fracture fixation in the same implant, increasing the mechanical properties of the two fixation technologies.

In this series of patients, time to union took significantly longer in cases in which allograft was used (average seven months) than when autologous bone graft was used (average five months). But this cannot be considered relevant, as the number of patients was low and morcellized allograft was used in the three cases with multiple previous interventions and more significant bone loss.

Implant selection is one of the multiple elements to be evaluated in the treatment of these complex lesions. Locked 90° blade plates were designed to aid the surgeon in achieving adequate fixation in complex osteoporotic metaphyseal fractures and nonunion of the proximal humerus, to bridge segmentary comminuted metaphyseal and pathological fractures, and for revision of implant failures with bone loss, necrosis, and erosion in the proximal metaphysis of the humerus. Proper operative planning and technique, with near anatomical reconstruction and good intraoperative imaging, are important to avoid complications when using this device. When using blade plate fixation more precise positioning of the implant is needed than in locked or conventional plates. Careful consideration must also be made in selecting an appropriately sized implant and screw placement in the humeral shaft. A relatively short plate with a decreased working leverage results in increased screw load stress, increasing the probability of implant failure [5]. The latest data suggests that the integrity and attained stability of the medial column is the key factor for predicting loss of fixation [8]. The use of an intramedullary fibular allograph has been proposed as a possible solution to this problem. But it too has major drawbacks associated with its use, being cadaver cortical allografts, with all the implications that this represents:

limited supply, high cost, infection risk, and the need of a wider approach for application [9].

Lever et al. performed biomechanical testing of conventional plates and blade plates for proximal humerus fractures and found that low contact 4.5 mm dynamic compression plates contoured into a blade shape, with a "triangulation "screw, and two additional screws into the humeral head were significantly stiffer than other non-locked constructs [15]. Blade-plate fixation, in combination with autogenous iliac-crest bone grafting, has yielded good results when used for management of proximal humerus nonunions [14, 18, 22]. Biomechanical studies have shown that, compared to other types of available implants, the locking plate is comparatively flexible and maximises fracture stabilisation by minimising the peak stresses at the bone implant interface [16]. Although not formally tested, locked 90° blade plates allow the combination of both technologies (that of the blade plate and the locked plate), to more effectively support and transfer forces from the loads applied and to increase the resistance to deformation. Screw pullout resistance is theoretically also increased by their divergent orientation, "triangulation" effect, and the fact that they are locked to the plate.

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