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ORIGINAL STUDY

Distal femur non-union after interlocked intramedullary nailing. Successful augmentation with wave plate and strut graft

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Eleven patients with aseptic non-union of a distal metaphyseo-diaphyseal femoral fracture after intramedullary interlocked nailing were treated by wave plate fixation and an interposed tricortical iliac strut graft with the nail *in situ*. Complete clinical and radiological union occurred in all cases in a mean period of 7.5 months (range : 7-10).

Augmentative wave plate fixation with a tricortical iliac strut graft is a biological and simple solution for non-union of the distal diaphyseo-metaphyseal femoral shaft fracture following an intramedullary locked nail fixation. No special instrumentation is required. In spite of early weight bearing, it led to bony union in a reasonable delay in all the patients reported.

Keywords : interlocking nail ; distal femur non-union ; wave plate ; graft augmentation.

INTRODUCTION

Interlocked nailing is the method of choice in the treatment of most acute femoral shaft fractures in adults. The reported rate of union is as high as 99%. There is no clear consensus regarding the treatment of non-union after interlocking nail fixation (*16,21, 26,27,36,38,42*). Exchange nailing and nail dynamisation are the widely practiced methods (*2,12,15, 22,26,34,41*) to address this problem. Results of exchange nailing were found to be confusing in the literature with a wide range of success rates between 53 and 96% (*2,15,26,41*). Dynamisation when carried out alone reportedly gave a union rate as low as 50% and an increased incidence of shortening (*42*). Conversion of failed IMN to plating has been also described (*32*). Since the introduction of the concept of wave plate osteosynthesis, it has been widely used for treating non-union of long bone diaphyseal fractures (*1,4,14,18,28-31,33,40,44*). Augmentative plate fixation with or without autogenous bone graft on top of intramedullary nail fixation was found to be a useful method in treating non-union of the femoral shaft (*16,28,38,39*). The aim of this study is to assess the results of using a wave plate with an interlocked autogenous tricortical strut graft for distal third femoral non-union without removing the interlocking nail.

PATIENTS AND METHODS

Eleven patients with femoral non-union after having intramedullary interlocking nail for treatment of a traumatic fracture of the femur were included in this study (9 antegrade nails and 2 retrograde nails) (Table I). All

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Table I. — Patients demography

No.	Age (y)	Sex	First surgery	No. of previous interferences	Duration since injury (m)	Time to union (m)	Follow-up (m)
1	21	m	Interlocking nail femur	1	4	4	36
2	42	m	Retrograde femoral nail	1	6	8	12
3	39	f	Interlocking nail femur	3	12	6	24
4	51	m	Interlocking nail femur	2	8	7	30
5	49	m	Interlocking nail femur	1	4	10	34
6	27	m	Interlocking nail femur	1	5	9	14
7	32	m	Interlocking nail femur	1	10	6	18
8	34	m	Interlocking nail femur	2	10	8	22
9	35	m	Retrograde femoral nail	1	7	8	18
10	40	m	Interlocking nail femur	1	6	6	26
11	57	m	Interlocking nail femur	1	7	9	32

were treated by augmentative wave plate fixation and iliac bone graft with the nail *in situ* at Damanhur National Medical Institute in the period between January 2008 and December 2010. The inclusion criteria were : (a) distal metaphyseo-diaphyseal fracture ; (b) aseptic non-union confirmed clinically and by laboratory investigation (complete blood picture, erythrocyte sedimentation rate, and C-reactive protein). The mean age for the patients was 40 years (range : 21-57). Ten were males and only one was female. All the patients had previous intramedullary nailing. They had a mean of 1.36 (range : 1-3) previous interferences. Three patients had repeat surgery after the intramedullary nailing. One patient had 2 sessions : dynamisation after 6 months and exchange nailing after 9 months. One patient had dynamisation after 4 months and the last one had grafting after 6 months. The main duration from the initial surgery was 7.1 months (range : 4-12).

Established non-union of the femur was defined as a failure of the fracture to demonstrate complete healing within 6 months or a lack of progression toward healing within a 3-month period on serial radiographs. There was evidence of chronic fracture site pain, motion at the fracture site felt by the patient or elicited by the examining doctor, and decreased ability to ambulate. Radiographically, there was increased fracture edge sclerosis, absence of bone crossing the fracture site, and persistent fracture lines.

Operative technique

Under spinal anaesthesia, the patient was positioned in lateral decubitus. A lateral approach was used with minimal soft tissue dissection. After confirmation of absence of infection, the fracture ends were thoroughly debrided and refreshed. Multiple drill holes and decortication of multiple small areas of the cortices near the fracture were carried out to increase raw bone surfaces. A tricortical strut 2 × 5 cm autograft together with additional cortico-cancellous bone chips were then taken from the ipsilateral ilium wing. An AO/ASIF 4.5 mm broad dynamic compression plate 12-14 holes was contoured using a plate-bending device to provide a gentle sloping wave in the middle of the plate to lift its mid-portion 0.5 to 1.0 cm away from the bone in the region of the non-union. The length of the plate was chosen so that 3-4 screws could be placed both proximally and distally to the fracture either in front or behind the nail depending on nail position, anatomy of the femur, and direction needed to displace the fracture end either anterior or posterior in order to improve the reduction. If distraction was present at the non-union site, removing interlocking bolts at one end of the IMN was needed to achieve compression (Fig. 1). The tricortical iliac strut graft was then fastened firmly between the concavity of the wave portion of the plate and the lateral cortex of the femur bridging the fracture site. It was snuggly pressed to the lateral bone at the end of screw tightening. There was no difficulty in insertion of bicortical screws as the canal was wide enough at this area. The fracture site was circumferentially packed with corticocancellous bone graft chips. Lastly, closure under Portovac suction was carried out.

Patients were immediately advised for full weight bearing on the affected extremity with continuous knee and hip exercises. Clinical follow-up was conducted at

Fig. 1. — (a) Non-union of the distal metaphyseo-diaphyseal right femur 7 months after retrograde nailing in a 35-year-old male. Augmentative wave plate-strut graft fixation with the nail *in situ*. The proximal locking screws were removed to achieve compression. Union was achieved after 8 months. (b) End follow-up after 18 months : radiological union with fully integrated strut graft.

2 weeks, 6 weeks, and then monthly until union was achieved. Union was defined clinically by absence of pain at the non-union site and radiologically by the appearance of satisfactory bridging callus.

RESULTS

The average delay of complete clinical and radiological union was 7.5 (range, 7-10) months after final revision surgery (Fig. 1). There were no complications during the procedures. We had no postoperative infections. The mean follow-up period was 24.2 (range, 12-36) months. All patients were ambulatory without pain at the fracture site during weight bearing at the final follow-up. There were no donor site morbidities following resection of the iliac graft. None of our patient had any restriction of motion in hip and knee joints at the time of final follow up.

DISCUSSION

The non-union rate after contemporary nailing techniques appears to be 6-12% (*26,27,36*). Boyd *et al*, Finkemeier *et al*, Crowley *et al*, and Wu described that "the key factors" for effective treatment of non-union and appropriate healing were osteogenesis stimulation, good bone contact, compression, and solid fixation (*5,9,11,43*). In the face of the reported unsatisfactory results of exchange nailing and dynamisation of an interlocking nail, the need for different modalities of treatment was aroused to address this difficult problem of non-united fractures of the femur. Exchange nailing remained in many regards the treatment of choice. It provides rigid fixation and offers osteogenic potential that allows early ambulation. Conflicting reports on its success have been recently documented (*11,12,15,26*). Several authors reported union rates of 96% with a relatively low morbidity (*12,15,37*). Weresh *et al* reported a union rate after exchange of 53% and have demonstrated that the effectiveness of exchanging an IMN is not as uniform as once believed (*41*). Banaszkiewicz *et al* concluded that although fracture healing was eventually achieved in 95% of their cases, complications following exchange nailing occurred in 11 out of 19 fractures

(58%), and additional surgery was required to achieve union or to deal with complications (*2*). Four cases needed repeat exchange nailing, two had an Ilizarov frame application and five had nail removal for pain and irritation. They recommended that the role of reamed exchange nailing in the treatment of femoral non-union should be re-evaluated (*2*). On reviewing the literature, it was found that while exchange nailing is worth considering, especially in cases of femoral non-union of the isthmus region, it may not be ideal in several situations as in diaphyseo-metaphyseal fractures, in atrophic or oligotrophic non-unions, that necessitate debridement and bone graft, and finally, in cases where exchange IM nailing may risk excess morbidity as in buried nails, in obese patients, or in cases of a retrograde IMN requiring knee arthrotomy (Fig. 1) (*16*). Many authors did not postulate exchange nailing for distal femoral non-union and recommended augmentation plating with the nail *in situ* (*6,19,37*).

Dynamisation on the other hand was not found to be beneficial to achieve union, particularly in comminuted fractures. It produced a significant instability at the non-union site and femoral shortening (*19*). Conversion of failed IMN to plating has the disadvantage of a long incision to fix the plate, prolongation of the operative time to remove the nail in addition to loss of the stabilizing effect of the nail. Surface fixation provided by the plate is mechanically weaker than medullary fixation and does not allow weight bearing until the fracture unites (*32*).

Augmentative plate fixation with an *in situ* intramedullary nail was described by Ueng *et al* in 1997 (*38*). Since then, many authors have reported on the same technique with 100% rate of union using either traditional or locked plates (*3,7,13,16, 19,32,38,39*). The general shortcoming of these publications was the small number of cases (Table II). The concept of wave plate osteosynthesis was described by Weber *et al* in 1982 (*40*). The novel idea in this study was the combination of an augmentation 4.5 AO broad DCP wave plate and an interlocked iliac strut graft to fix a femoral non-union with the interlocking nail *in situ*.

Park *et al* found a 2.6-fold increase in bending stiffness and a 3.3-fold increase in torsional stiffness in plate augmentation leaving a nail *in situ* compared to interlocking nailing only in the distal third fracture of the femur (*25*). The absolute fixation power at the fracture site by an interlocking intramedullary nail, especially against rotational force, is limited : a rotational movement of 10-15° at the fracture site fixed with an interlocking intramedullary nail did not need much force. In distal shaft or comminuted fractures of the femur the canal-filling is missing, which reduces stability in both bending and rotation. These cases may require more stability than is afforded by interlocking intramedullary nailing alone and augmentative plating is indicated in such cases (*6,7,19,37*).

It was found that while the retained nail acts as a load-sharing device, neutralizing shear forces on the non-union site and maintaining alignment of the fracture, the plate augments the fixation and prevents rotary instability. The screws will assist in improving the reduction and fixation of fractures at the metaphyseal-diaphyseal junction and will function against the retained nail like blocking screws, when there is a strong tendency for axial displacement. The screws of the plate will press the nail against the wall of the widened medullary canal and consequently will increase bone-to-nail contact along the bone shaft and so will decrease the working length of the nail. The end result is a rigid femoral combination fixation that allows early postoperative weight bearing and physiotherapy (*10,13, 17,35*).

Traditional and locked plates are weakest in bending and torsion and during cyclical loading. In the presence of medial or segmental bony defects they are subjected to an excessive local concentration of bending forces and possible failure (*4,26,29*). Locking plates do not allow choosing screw direction and application of the plate in the presence of an intramedullary nail can be difficult (*13*). Many mechanical advantages have been described for the wave plate. Firstly, contouring of a plate into a wave form enhances its mechanical role by distributing this bending force over a wide area rather than focusing it at a local fulcrum with the consequent decreased incidence of plate failure (*4,23,29,31*). Secondly, although the wave bends in the plate will translate the axial load laterally with the subsequent

Table II. — Review of literature

Authors	Source	Year	Title	No. of cases	Time elapsed from initial IMN (months)	Mean time for union (months)	Success rate	Remarks
Ueng SW *et al* (*38*)	J Trauma	1997	Augmentative Plate Fixation for the Management of Femoral Nonunion after Intramedullary Nailing	17	15 (range 6-32)	7 (range, 6-10)	100%	- Used AO DCP bicortical fixation - Cancellous bone grafting was used in only 7 cases.
Ueng SW and Shih CH. (*39*)	J Trauma	1998	Augmentative Plate Fixation for the Management of Femoral Nonunion with Broken Interlocking Nail	5	9 (range, 7-13)	5.4 (range, 4-7)	100%	- Used AO DCP bicortical fixation - Cancellous bone grafting was used in 3 cases.
Choi YS and Kim KS. (*7*)	Int Orthop	2005	Plate augmentation leaving the nail in situ and bone grafting for non-union of femoral shaft fractures	15	10	7.2	100%	- Used AO DCP bicortical fixation - Cancellous bone grafting was used in all cases.
Jung HG *et al* (*19*)	J Korean Orthop Assoc	2007	Treatment of the Femoral Shaft Nonunion Occurred after Intramedullary Nailing	14	-	-	100%	- Uses AO DCP unicortical fixation- The IMN was changed to a dynamic mode before plating. - Cancellous bone grafting was used in all cases.
Birjandinejad A *et al* (*3*)	Orthopedics	2009	Augmentation Plate Fixation for the Treatment of Femoral and Tibial Nonunion After Intramedullary Nailing	25	-	4.78	100%	- 4.5-mm broad DCP Or Condylar plate with bicortical fixation. - Cancellous bone grafting was used in all cases.
Hakeos WM *et al* (*16*)	J Orthop Trauma	2011	Plate Fixation of Femoral Nonunions Over an Intramedullary Nail With Autogenous Bone Grafting	7	8.8	5	100%	- Long broad 4.5-mm LC-DCP bicortical fixation. - Cancellous bone grafting was used in all cases.
Gao KD *et al* (*13*)	Orthopaedic Surgery	2011	Management of femoral diaphyseal nonunion after nailing with augmentative locked plating and bone graft	13	-	7.5 (range, 6-12)	100%	- Locked plating unicortical fixation. - bone graft for all cases. - Included only non isthmic and oligotrophic/atrophic nonunion.
Said GZ *et al* (*32*)	Int Orthop	2011	Failed intramedullary nailing of femur : open reduction and plate augmentation with the nail in situ	14	7-9	4.3	100%	- 4.5-mm broad DCP bicortical fixation. - Cancellous bone grafting was used in all cases.

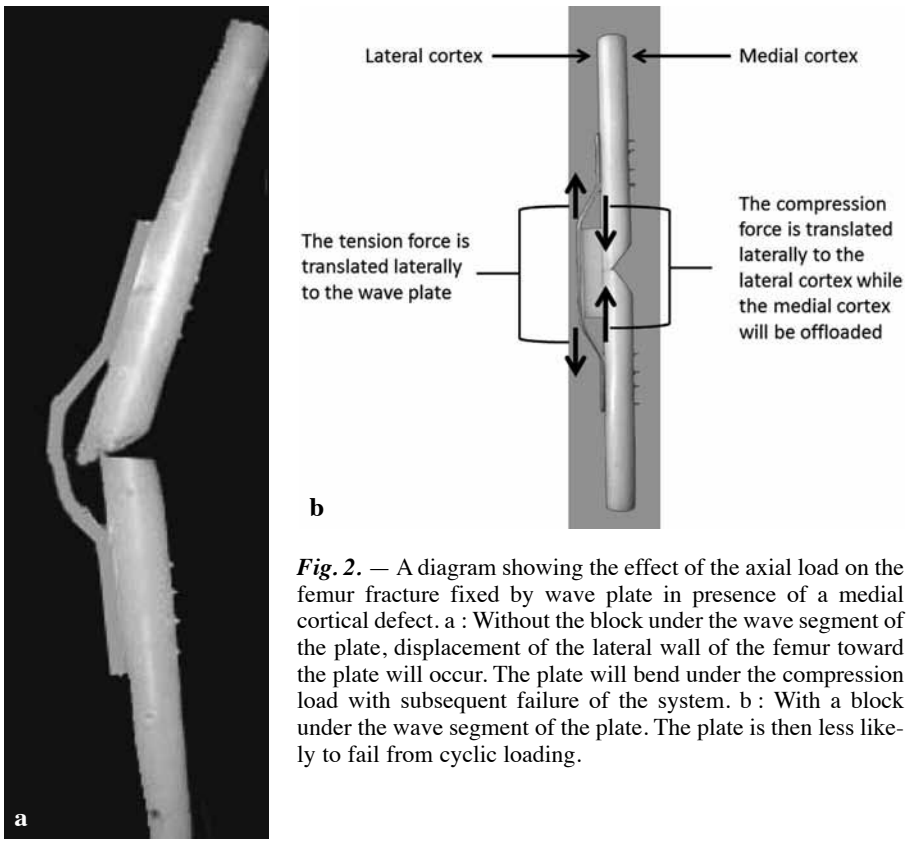

Fig. 2. — A diagram showing the effect of the axial load on the femur fracture fixed by wave plate in presence of a medial cortical defect. a : Without the block under the wave segment of the plate, displacement of the lateral wall of the femur toward the plate will occur. The plate will bend under the compression load with subsequent failure of the system. b : With a block under the wave segment of the plate. The plate is then less likely to fail from cyclic loading.

increase in the bending moment arm on cyclical loading, this is beneficial in cases with medial cortical defect where the intact or reconstituted lateral cortex in these cases will support the compressive forces on the femur and allow the plate to function as a lateral tension band (*9,20,29,30,40*). Lastly, the use of the tricortical iliac strut graft locked in under the wave segment of the plate will add a great mechanical advantage as this block will not allow the femur to deform toward the wave. Through the interlocked graft there will be a contact of the wave with the lateral cortex that will act like a fulcrum distant from the plate. The medial cortex will be offloaded (*23*) : on axial loading, the compression force which is normally loaded on the medial cortex will be translated laterally to the lateral cortex while the tension force normally exerted on the lateral cortex will be also translated laterally to the wave plate. So, the forces on the wave plate become primarily tensile rather than bending. The plate is then less likely to fail under cyclic loading (Fig. 2). Kojima *et al* proved in their *in vitro* study that using this strut enables using a long wave bent section without decreasing the mechanical stability of the bone plate construct (*23*). The tricortical iliac crest graft adds good structural properties until healing, while the cancellous grafts add osteogenic and osteoconductive potential.

Biologically, the combined wave plate, interlocked graft and cancellous bone have many advantages. We limit operative dissection to preserve blood supply to bone. The wave plate has no contact at the critical site of pathology. The strut is placed in a well-vascularised bed and keeps the ability for good incorporation and rapid revascularisation (*30*). Lastly, it maintains fracture alignment without absolute rigidity and permits axial micromotion promoting union with a good secondary callus formation (*20*). There was some concern that plate augmentation after intramedullary nailing might cause a disastrous event in the vascular supply of the femur but this did not occur. Although Cole

examined the vascular supply of the femur after intramedullary nailing and showed the whole vascular supply of the femur had been restored as early as 2 weeks after nailing, in recent studies most authors unanimously agreed that the intramedullary arterial system appears to be restored by three months (*8,24*).

We conclude that augmentative wave plate fixation with tricortical iliac strut graft is a biological solution for non-union of the distal diaphyseometaphyseal femoral shaft fracture following an intramedullary locked nail fixation. The technique is simple and does not require any special instrumentation. It facilitates early weight bearing and gives a recovery from non-union within a reasonable delay.

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