Atrophic ununited diaphyseal fractures of the humerus with a bony defect

TREATMENT BY WAVE-PLATE OSTEOSYNTHESIS

D. Ring, J. B. Jupiter, J. Quintero, R. A. Sanders, R. K. Marti

From Massachusetts General Hospital, Boston and the Alabama Sports Medicine Centre, Birmingham, Alabama, USA, The Hospital Clinical San Rafael, Bogota, South America and the Academisch Medisch Centrum, Amsterdam, The Netherlands

We treated 15 patients with atrophic nonunion of a diaphyseal fracture of the humerus with an associated bony defect using an autogenous cancellous bone graft and a plate to bridge the defect. There were nine men and six women with a mean age of 48 years. The mean length of the bony defect was 3 cm.

At a mean follow-up of 30 months only one fracture failed to unite. This suggests that, in the presence of a well-vascularised envelope of muscle, the application of an autogenous cancellous bone graft in conjunction with a bridging plate represents a good alternative to more demanding surgical techniques.

Received 15 April 1999; Accepted after revision 17 February 2000

The challenge of inducing healing in an atrophic nonunion is increased when there is a bony defect between the fragments. Defects can result from open or infected fractures, synovial nonunion producing a false joint, or loose internal fixation. In addition to the absolute loss of bone at the site of the fracture, there may be a relative deficiency which extends several centimetres into each fragment.

While a number of methods of managing atrophic ununited fractures with bony defects have been suggested, each has its drawbacks. Grafts of cortical bone revascularise slowly and incompletely. There is a substantial risk of infection, delayed union and nonunion, and fractures through the graft are common.\textsuperscript{1-6} Vascularised bone grafting requires surgical experience and equipment not readily available in every hospital. The technique is demanding of time and resources, and vascular thrombosis may compromise the result.\textsuperscript{7-11} Bone transport, using distraction histogenesis in the treatment of complex post-traumatic problems, has a certain appeal, but enthusiasm for the Ilizarov technique has been tempered by its complexity and technical difficulty, the commitment of time and resources required for a good result and the potential for numerous complications.\textsuperscript{12,13}

The application of a plate and screws to stabilise the fracture fragments and span, or bridge, the bony defect was used by Nicoll among others.\textsuperscript{14} He achieved healing with a non-structural autogenous cancellous bone graft. Studies in which external fixation was used to bridge large bony defects in the tibia, have demonstrated that skeletal defects as large as 15 cm in length will heal with the application of autogenous cancellous bone grafts, provided that they are surrounded by well-vascularised soft tissues.\textsuperscript{15-17} Weber and Brunner\textsuperscript{18} used bridge plating in the treatment of complex nonunions associated with loss of bone, suggesting that the vascular envelope provided by the surrounding muscle should be completed by contouring the plate so that a gap of 0.5 to 1 cm is left between the bone and the plate at the site of the nonunion.

The method of bridge plating and applying autogenous cancellous bone graft offers a number of potential advantages: the operative technique is relatively straightforward and efficient, cancellous grafts incorporate more rapidly than cortical grafts and the plate fixation provides sufficient stability for mobility in the limb to be restored while the grafts are healing. We present our results using a contoured bridging plate and autogenous bone graft according to the technique of Weber and Brunner,\textsuperscript{18} the so-called ‘wave-plate osteosynthesis’, for the treatment of atrophic non-united diaphyseal fractures of the humerus with bony defects. This is the consecutive experience of four surgeons at four different medical centres, reviewed retrospectively.

Patients and Methods

The indication for wave-plate osteosynthesis was a diaphyseal fracture of the humerus which had remained ununited for at least four months and was associated with a bony

\begin{flushleft}
D. Ring, MD, Director of Research
J. B. Jupiter, MD, Chief, Hand Surgery Service
Harvard Medical School, Massachusetts General Hospital ACC 527, 15 Parkman Street, Boston, Massachusetts 02114, USA.
J. Quintero, MD, Assistant Professor of Orthopaedics and Traumatology
Hospital Clinica San Rafael, Centro Médico Almirante Colon, Carrera 16 no 84A-09 (310), CO-Bogota, Colombia, South America.
R. A. Sanders, MD
Alabama Sports Medicine and Orthopaedic Centre, 1201 11th Avenue South, Suite 200, Birmingham, Alabama 35205, USA.
R. K. Marti, MD, Director of Orthopaedics
Academisch Medisch Centrum, Meibergdreef 9, NL-1105 AZ Amsterdam, The Netherlands.

Correspondence should be sent to Dr D. Ring at 11 Hancock Street, Unit 4, Boston, Massachusetts 02114, USA.
©2000 British Editorial Society of Bone and Joint Surgery 0301-620X/00/610124 $2.00
\end{flushleft}
defect at the time of operative debridement. Patients with an excessively scarred, indurated soft-tissue envelope or with a poor blood supply, were excluded and treated by a vascularised fibular transfer. Because of the rarity and complexity of this specific problem it was not possible to include a control group.

There were 15 patients (9 men, 6 women) with a mean age of 48 years (22 to 80). The right upper limb was involved in five (two dominant) and the left in ten (one dominant). The fracture was the result of a motor-vehicle accident in five patients, a fall from a height in two, a fall from a standing position in six, and a bicycle accident and a gunshot wound in one each. One patient had a periprosthetic fracture at the distal limit of an upper humeral prosthesis. Six fractures were associated with an open wound rated according to the classification of Gustilo and Anderson and Gustilo, Mendoza and Williams as type II in three patients and type IIIA in three. Four patients already had palsy of the radial nerve; three required tendon transfers at the wrist.

In 14 patients the initial treatment of the fracture had been operative; the remaining patient had been treated initially by a hanging cast. The six open fractures were treated by debridement of contaminated or devitalised tissue, followed by irrigation of the wound. Stabilisation of these open fractures was provided by Rush pins or Ender nails in three, an external fixator in two and skeletal traction in one. Of the nine patients with closed fractures, six were treated by plate and screw fixation, one by Ender nails, and the patient with a periprosthetic fracture had revision from a short to a long-stemmed, cemented shoulder prosthesis. Seven patients had had between one and five additional operations, with a mean of two, before presentation to us. Ten patients presented with loose or broken implants including intramedullary nails in six and plates and screws in four. One patient had a segmental nonunion after an additional fracture, which occurred below a plate, failed to heal.

Infection occurred in four patients including the one with the shoulder arthroplasty. The infection was quiescent in three and active in one; Staphylococcus aureus was cultured from two of these patients and Staphylococcus epidermidis from two. The patient with an active infection was treated with serial debridements and parenteral antibiotics before the planned procedure for nonunion.

The mean interval from the initial injury to the wave-plate osteosynthesis was 30 months (7 to 192). After removal of loose metal implants and debridement of necrotic or infected bone and synovial nonunion, the mean length of the bony defect was 3 cm (2 to 6).

Operative technique. Under general anaesthesia autogenous cancellous bone graft was obtained from the iliac crest. Exposure of the humerus was dictated by previous operations and the site of the nonunion. An anterolateral exposure was used in 10 patients, a posterior approach in four, and a medial in one. Metal implants were removed in all except one patient in whom two Ender nails could not be extracted and were left in place.

During the dissection care was taken to avoid devitalising the bone and soft tissues. Muscle was elevated only in a narrow area for application of the plate and the periosteum was left in place. Avascular bone and fibrous, inflammatory and synovial tissues were debrided from the site of nonunion until bleeding bone was seen. A skeletal distractor was used in some cases to facilitate debridement and reduction and to provide temporary stabilisation of the fragments while the plate was contoured and applied. We avoided the use of circumferential bone clamps.

A 4.5 mm dynamic compression plate (Synthes, Paoli, Pennsylvania) was used; broad plates (two with limited contact design) were used in nine patients and narrow plates (five with limited contact design) in six. The mean size of plate used was one of 11 holes (9 to 14). In three patients fixation of an osteopenic proximal fragment was enhanced by bending the proximal portion of a narrow 4.5 mm plate through approximately 90° and impacting this portion into the proximal humerus as a blade. Other measures to improve fixation in the presence of extreme osteopenia included the use of Schuhli nuts (Synthes) in one patient, and the application of an ancillary intramedullary plate (10-hole 4.5 mm broad dynamic compression plate) in two others.

A gentle curve was made at two places on the plate so that its mid-portion stood between 0.5 and 1.0 cm away from the bone for a distance extending from one screw hole proximal, to one screw hole distal, to the limits of the bone defect. The length of the plate was chosen so that it could be secured by three or four bicortical screws, proximal and distal to the site of the fracture. Autogenous cancellous bone was obtained from the iliac crest and placed beneath the contoured portion of the plate, between plate and bone and into the bony defect.

At the final follow-up, the patients were examined by the treating surgeon. Radiographs of the humerus in two orthogonal planes were examined for the presence of bridging bony trabeculae, indicating union, as well as for evidence of loosening or breakage of the implants. Symptoms of pain, instability or dysfunction were recorded, and the movement of adjacent joints was measured.

Results

The patients were followed for a mean of 31 months (24 to 48). Healing was observed, both clinically and radiologically, within 12 weeks in all, except one. The patient with a persistent nonunion is a 76-year-old woman whose ununited fracture had been present for 192 months and operated on many times before coming under our care. After removal of a loose intramedullary rod and debridement of the site of nonunion, there was a bony defect of 6 cm. Lucency around some of the screws was noted at the six-month follow-up, but has not progressed and neither
the plate nor the screws have broken 48 months after the wave-plating. Although substantial incorporation of the cancellous bone graft occurred, a fracture line remains visible. She has poor function, in part due to anxiety about the potential for reinjury, as well as shoulder pain and stiffness related to injury of the rotator cuff during the placement and removal of the original intramedullary rod.

None of the patients with healed fractures complains of persistent pain or instability at the site of nonunion. A good range of forward elevation and external rotation of the shoulder within 20° of the opposite side was achieved in 11 of the 14 patients. Three patients have restricted shoulder movement with forward elevation measuring 60°, 80° and 120°, and external rotation 20°, 30° and 40°, respectively.

Complications included postoperative blood transfusion in one patient who required removal of graft from both posterior iliac crests, and one case of *Clostridium difficile* enterocolitis. One patient developed a draining fistula three months after the operation after the fracture had healed because of deep infection with *Staphylococcus aureus*. Removal of the implants and debridement, carried out nine months after the initial procedure, led to resolution of the fistula (Fig. 1).

Discussion

Wave-plate osteosynthesis is an operative approach to the treatment of ununited fractures with bony defects and incorporates a number of principles widely recognised as important in the healing of fractures and incorporation of bone graft. These include the importance of preserving the blood supply to the bone, by both limited operative dissection and limited contact by the plate, the potential for rapid revascularisation and incorporation of autogenous cancellous bone grafts placed in a well-vascularised bed, and the role of a non-rigid or flexible bridging plate transfixing the defect and allowing healing by callus.

In contrast to the use of a plate to compress fragments of
the fracture, the wave plate acts as a bridge across a bony gap. It provides sufficient stability for immediate functional movement of the upper limb, and healing occurs by formation of callus rather than by direct primary bone healing.23

The use of plates designed to have limited contact with bone has become a well-established means of preserving its vascular supply.23,29 Wave-plate osteosynthesis represents the ultimate limited contact plate, having no contact at the critical site of pathology. It has been described as an ‘internal external fixator’.29 It has also been suggested that the contour of the wave plate has mechanical advantages, including the distribution of cyclic bending forces over a greater length, thus diminishing the risk of failure of the plate, and the translation of a bending moment laterally so that only the lateral cortex needs to be restored to establish a tension-band function for the implant.18,26,28

The emphasis on limited separation of muscle from the bone and preservation of the periosteum characteristic of so-called indirect reduction techniques, forms an essential part of the procedure.22,23 Whereas early AO/ASIF teaching emphasised the provision of maximal mechanical stability and described stripping of the periosteum over a large area of bone, together with rigid, anatomical fixation of all fragments of the fracture, experience has shown that the biological determinants of fracture healing are at least as important as the mechanical and must be respected.22,23,26,29 One example of this is the study by Kinast et al,30 who demonstrated that comminuted subtrochanteric fractures of the femur, treated by extensive operative dissection in an attempt at rigid fixation, were less likely to heal than similar fractures treated by a bridging plate used to maintain length and alignment and applied with limited operative dissection. Devitalisation of bone and soft tissue is restricted by the use of alternative means of achieving alignment, and the avoidance of extensive subperiosteal dissection and the use of circumferential clamps. A distractor or temporary external fixator is most useful in this endeavour.21,22 The use of plate-tensioning devices and a variety of other techniques, many of them documented by Mast et al,23 is occasionally useful.

In some cases, healing occurred through a bridge of bone lying immediately beneath the contoured portion of the plate, while a bony defect persisted opposite the plate. Although this pattern of healing often appears imperfect on radiographs, the formation of bone in this area is expected when using the wave plate, since bone graft is placed directly beneath the contoured portion of the plate where a rich blood supply is available. The contour of the plate changes the mechanics so that a column of bone on the same side as the plate receives forces of compression, since the moment arm is shifted outwards towards the plate. In the presence of a bony defect any bridge of bone will help to protect the plate and may be expected to hypertrophy gradually over a period of years in response to the forces placed upon it during normal daily use. We have observed hypertrophy of the graft in several patients, but have no quantitative proof that this always occurs.

Our series of patients demonstrates the ability to achieve union across atrophic diaphyseal defects as large as 6 cm using autogenous bone graft alone. The use of a bridging plate with a wave contour allows functional mobilisation of the limb while the cancellous graft receives optimal circulation from the soft-tissue envelope.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

THE JOURNAL OF BONE AND JOINT SURGERY


