Nonunions. Surgery and low-intensity ultrasound treatment
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Operative treatment of post-traumatic mid-shaft clavicular nonunion
a comparison between wave-plate osteosynthesis
and standard ao/asif osteosynthesis


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Abstract

Background Decortication, debridement, bone graft and AO plate osteosynthesis can all be used in treatment of clavicular nonunion with excellent results. The high incidence of postoperative brachialgia, caused by abundant callus and scar tissue formation in the proximity of the neurovascular bundle, has led to the development of the wave-plate osteosynthesis technique for the treatment of clavicular nonunion.

Methods Between 1974 and 1999, 28 patients with a symptomatic mid-shaft clavicular nonunion were treated operatively using a bone graft and AO plate osteosynthesis. In nine of these patients wave-plate osteosynthesis was carried out. All the patients were documented at the AO Documentation Centre and a final check took place after a mean follow-up of ten years (range 2 to 25 years).

Results All but one nonunion (96%) showed full bony consolidation. Results of operative treatment of a painful clavicular nonunion with standard AO plate osteosynthesis were predictably good with regard to consolidation. There was a high incidence of pre- and postoperative brachialgia, which can be defined as any sensomotory disturbance of the arm. None of the patients treated by wave-plate osteosynthesis suffered from post-operative brachialgia. Those patients with a clavicular nonunion treated by wave-plate osteosynthesis had a higher Constant score than those patients treated using standard AO/ASIF techniques.

Conclusions Wave-plate osteosynthesis as a treatment of clavicular nonunion is a save procedure. Although it is technically more demanding and caused a higher incidence of wound problems early on in the study, this technique is advocated in cases of clavicular nonunion with brachialgia and also to prevent brachialgia post-operatively.
Introduction

Mid-shaft clavicular nonunion is a rare and often disabling complication of clavicle fracture. Etiological factors that predispose to the development of a nonunion include; open fracture; associated polytraumatic lesions; refracture; gross displacement of the fragments; insufficient initial operative treatment and an inadequate period of immobilization. The incidence of a clavicular nonunion is reported to be 0.1 - 0.8% following conservative treatment of a clavicle fracture and 3.7 - 4.6% following its operative treatment. The indications for operative treatment are pain, instability and the consequent limited motion of the shoulder, and brachialgia. Several operative techniques, including intramedullary, internal and external fixation, have been described for the treatment of these nonunions. AO/ASIF techniques using plate and screws have excellent overall results. However, in 30% of these patients brachialgia presents as a serious problem. Brachialgia is defined as any numbness or paresthesia in the arm, with or without muscle weakness, particularly on the medial aspect of the arm. Symptoms occur predominantly in the ulnar nerve dermatome. Excessive callus and scar tissue formation are important factors in the occurrence of this complication. Other etiological factors that may cause brachialgia include; cervical spine and disc problems; scalenus anticus syndrome and thoracic outlet syndrome. A previous, unpublished, study of our data showed that although bony consolidation was achieved, residual brachialgia did occur. We classified any sensory problems of the affected arm as brachialgia.

The wave-plate technique may not only reduce undesirable callus formation in the wrong area, but also contribute to better bone healing and consequently lessen the risk of refracture following hardware removal. Wave-plate osteosynthesis involves bending the plate at its midportion. Due to plate shape at the site of the nonunion, the local blood supply is not disturbed. It allows ingrowth of vessels into the cancellous bone onlay graft and reduces the risk of fatigue fracture of the plate. An autogenous bone graft can be situated under the plate to share the tensile forces. The wave-plate technique has previously been described. Its use in clavicular nonunions was introduced by the senior author [RM]. This review reports on the indication for, the technique used and the results of the operative treatment of clavicular nonunions by wave-plate osteosynthesis as compared to the standard AO technique.

Patients and Methods

In the period between 1974 and 1999, twenty-eight consecutive patients were operated on for a mid-shaft clavicular nonunion at our hospital. There were 15 women and 13 men. The average age at operative reconstruction was 35 years (range 15-51...
There were 20 right sided and 8 left sided cases. In 17 cases the clavicle on the dominant side was injured. In 15 cases fracture was caused by traffic accidents, in 8 cases by sports-related accidents, in 3 cases by a fall, and there were 2 cases of iatrogenic lesion (following partial clavicular resection for thoracic outlet syndrome and subclavian aneurysm). There was one open fracture. Initial treatment was operative in 2 cases and closed (“figure of eight” bandage, sling or cast) in 24 cases. In 2 cases no initial treatment had been given, because the fracture went unrecognised. In 8 cases secondary operative treatments had been performed elsewhere. The time between fracture and our operative treatment was on average, 48 months (range, 4 months – 34 years). By definition of a nonunion of at least 6 months between fracture and operative treatment, one patient with a time span of 4 months should not be included. However, we did include this patient with a painful delayed union of a clavicular fracture because there was no callus formation and immediate surgical repair was considered necessary. There were 10 atrophic, 6 oligotrophic, and 12 hypertrophic nonunions. Indications for operative treatment of these nonunions were: pain at the nonunion site in all but one patient, painful limitation of shoulder movement in 17 cases, loss of power and instability in 11 cases, and brachialgia in 12 cases. Cosmetic problems were present in 14 patients. Nineteen patients were unable to work or play sport.

Standard operative technique
The patient is positioned on the operating table in a semi-recumbent, so-called "beach-chair" position, with a folded towel under the affected shoulder. The entire extremity is prepared and draped so that the arm is freely movable. The donor site (preferably the ipsilateral iliac crest) for the bone graft is also prepared and draped. A lower paraclavicular approach or a pre-existent incision is used. The pseudarthrotic tissue is freed using an osteotome (decortication); the sclerotic bone ends are freshened with a rongeur, until bleeding bone is exposed. The medullary canal is opened on both sides using a power burr. In the case of a hypertrophic nonunion excessive callus tissue is first decorticated and than trimmed to suit the plate. If necessary, a cancellous bone graft is used and if the clavicle is shortened an intercalary bone graft is used. A 3.5 dynamic compression plate (DCP) or occasionally a 3.5-reconstruction plate, is used for fixation. The size of the plate should allow the placement of three screws on either side of the nonunion.

Wave-plate osteosynthesis technique
The same operative technique is employed, but the 3.5 DCP plate is bent in the middle. The plate is positioned so that its midportion is bent away from the clavicle. The intercalary and cancellous bone graft is placed underneath the midportion of the plate. One screw can be
positioned through the plate into the intercalary graft.
The wave-plate technique was used on 9 of the 28 patients.

Postoperative regime
Postoperatively a sling is applied for one to two weeks (for patient comfort). Passive and active mobilization exercises of the shoulder are started directly postoperatively. In 22 cases hardware removal was performed at an average of 21 months (range 6 months – 4 years). Postoperative results were documented prospectively at four months, one year and at two years using the facility of the AO Documentation Centre in Switzerland and retrospectively in 1990 and 1999. The mean follow-up time was 10 years (range, 2 years – 25 years).

Regular postoperative outpatient examination was done in all cases. Two patients had died by the time of the most recent follow-up. For various reasons in 6 patients follow-up in 1999 was not possible. However, results from their earlier follow-up examinations were included but without a Constant score. In 20 cases, Constant scores were only determined at most recent follow-up (1999). This reproducible score\(^2\) estimates shoulder function using the variables; pain, activities of daily living, range of motion and power. A hand-held dynamometer was used to assess the isometric power of the shoulder.\(^2\) A visual analogue scale (VAS) score evaluation for rating subjective result: 0 (no pain) up to 10 (severe pain) was performed in each patient.

Results
Data from all patients included in the study were available for analysis. The results were gathered prospectively up to, two years postoperatively. Union of the clavicle occurred after a mean of 4 months (range 3 – 7 months) in 27 of the 28 patients (96%) with a clavicular nonunion. In one case a bony clavicle defect persisted, although symptoms were diminished. All patients experienced an improvement in function and less pain (no pain or slight pain on palpation). Brachialgia was present preoperatively in 12 cases. Of the patients with preoperative brachialgia, 6 were treated using a standard osteosynthesis technique and 6 patients by wave-plate osteosynthesis. Post-operatively all patients treated by a wave-plate and 2 patients treated by standard osteosynthesis improved (Table 1). However 4 of the patients treated by standard osteosynthesis techniques developed brachialgia postoperatively. In 6 cases electromyography revealed symptoms of dysfunction of the ulnar nerve. Four of the 8 patients with post-operative brachialgia needed operative treatment (first rib resection) for costoclavicular compression syndrome or
Table 1 Postoperative Results: Consolidation, Brachialgy and Constant score

<table>
<thead>
<tr>
<th>Case</th>
<th>Sex</th>
<th>Age</th>
<th>Side</th>
<th>Operative Technique</th>
<th>Outcome Nonunion</th>
<th>Brachialgy (pre/post)</th>
<th>Constant score Right</th>
<th>Constant score Left</th>
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<td>+ / -</td>
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Age = Age at follow-up
Avg = Average age related score
Brachialgy (pre/post) = Presence of brachialgy pre- and postoperatively
N.A. = Not Available

brachialgia. The other four patients were able to cope with their symptoms and refused further treatment.

One of the complications that occurred in the perioperative period was a slight delay in wound healing in two cases (Table 2). These patients had both undergone wave-plate osteosynthesis. A wound infection, treated by operative irrigation and drainage, occurred in three cases. Two had undergone wave-plate osteosynthesis. One of them developed a persistent nonunion. In two other patients, wound healing problems were successfully resolved and scar formation was normal. These wound problems all occurred early in the
Table 2 Postoperative results: Complications

<table>
<thead>
<tr>
<th>Complication</th>
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<th>Wave-plate (N=9)</th>
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<td>Clavicle infection, operative drainage</td>
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<td>2</td>
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<tr>
<td>Crista iliaca infection, operative drainage</td>
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<tr>
<td>Bone defect clavicle</td>
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<td>Refracture</td>
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</tr>
<tr>
<td>Brachialgy</td>
<td>4</td>
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</table>

series. Since we changed the position of the skin incision to beneath the clavicle thus allowing adequate coverage of the plate, no more wound problems have occurred.

In one case, a refracture occurred after healing of the nonunion, possibly because the hardware may have been removed too early. A serious trauma caused the refracture and no bone pathology was present at the time of fracture. No correlation with the operative technique could be established. Healing was achieved within three months of re-osseosynthesis.

The only patient with a persistent nonunion or bone defect had undergone multiple procedures for infected nonunion of the clavicle. A bony bridge, which had developed between the distal clavicle and the coracoid process, may explain the good clinical result.

Constant score

The overall Constant score at follow-up in 1999 was 85 on the affected side, compared with 93 on the sound side (Table 1). Comparing the Constant score of patients with a wave plate osteosynthesis and those with a standard osteosynthesis resulted in an overall score of 93 (96 unaffected side) versus 80 (92 unaffected side). A low Constant score (less than the age corrected Constant score) was determined in 7 cases. The combination of items of the Constant score varied in these patients. The low score was caused by brachialgia in four of these patients. In the other cases concomitant diseases, such as larynx carcinoma, or a poor general condition determined the below average score.

The overall VAS score was 1.4 (range 0 - 5). VAS scores of 3 - 5 were all due to symptoms of brachialgia.

The eight patients from whom no Constant score could be determined were generally satisfied with the end result. Two of them were treated by wave-plate osteosynthesis, the remaining six by a standard osteosynthesis technique. The two patients treated with wave-plate osteosynthesis had an excellent result with no pain or brachialgia, regained normal function and could work and play sport as well as before the accident. Three of six patients with a standard osteosynthesis were satisfied although two experienced slight pain with
activity and one had brachialgia.

The radiographs of the clavicles were not absolutely comparable so no absolute amount of callus was detectable. Our impression is that there is less subclavicular callus formation in the wave-plate treatment group. The radiological length of the affected clavicle compared to the unaffected clavicle was determined in 15 cases. If there was any difference in these cases, it was always less than 10 millimetres.

A forty-nine year old male patient sustained a clavicular fracture after a fall from his bicycle.

Figure 1 Radiograph of the clavicle with a mid-shaft nonunion showing a bony spike near the brachial plexus.

Figure 2 Radiograph of the clavicle after nonunion treatment with a wave-plate osteosynthesis. A nice restoration of length of the clavicle and no abundant callus is shown.
Figure 3 Radiograph of the clavicle after plate removal showing bone healing and a nearly normal configuration of the clavicle.

He was treated with a sling. Clavicular nonunion developed (Figure 1). He had neurologically confirmed symptoms of brachialgia as well as pain and loss of movement in the shoulder. One year post-fracture, wave-plate osteosynthesis was performed (Figure 2). Two years post-operatively all symptoms were resolved. Clavicular length was restored and sound bone healing achieved with no excessive callus formation (Figure 3).

Discussion

Although non-operative treatment of a clavicular nonunion in a series of 47 patients with longstanding nonunion produced satisfactory results in 23 patients, it is generally accepted that an uncomfortable nonunion needs to be treated surgically. Literature describes various operative techniques including the use of onlay bone grafting and screws, wire loops and bone grafting, and bone grafting only, but with unpredictable results. Resection of the nonunion site or total clavectomy might appear to be a solution in the short term, however in the long term it is viewed negatively. It should be considered only as a salvage procedure.

Several studies have reported excellent results from treatment of mid-shaft clavicular nonunions with AO plate osteosynthesis and bone grafting with bony consolidation in 89% to 100% of cases. In our series 96% (27/28) of the midshaft clavicular nonunions healed successfully. All operations were performed by three senior orthopaedic surgeons, familiar with the operative technique, which, apart from the inclusion of the wave-plate technique, has not changed over the years. The typical deformity, with the lateral fragment depressed and pulled posteriorly and the medial fragment elevated, is counteracted...
by a cranial plate. This plate functions as a tension band. An antero-inferior placement of the plate has shown good results in a small series' however more extensive devascularisation of the clavicle is to be expected. Short semitubular plates should not be used for fixation, because of a high risk of failure. The LC-DC plate offers some advantages. It causes minimal damage to the underlying bone, has a low profile and its rigidity gives good stability. External fixation constitutes a solution in cases of serious infection. It can produce satisfying results in open fractures and non-infected nonunion; although wound problems can be expected. The AO plate used as an external fixator provides good stability, so bone healing can be achieved in cases of infected nonunion. This technique has no serious drawbacks for the patients.

A report on the treatment of clavicular nonunion comparing DC plating to treatment using direct current or capacitive coupling electricity, both invasive and non-invasive, has shown plating to give superior union rates (65% vs. 100%).

Intramedullary nailing for nonunion of the clavicle has been reported to give good results in a few small series of patients, although the initial results of this technique are disappointing. We have no experience of this technique, but several disadvantages can be distinguished however. Rotational instability is likely. Displacements of the pins, especially medial can be catastrophic. In a retrospective study, Wu compared intramedullary nailing and plate osteosynthesis techniques in the treatment of aseptic clavicular nonunion. In this study, intramedullary nailing had a slightly lower complication rate and was not considered inferior to plate osteosynthesis in normal bone conditions.

Some authors mention that brachial plexus lesion, subclavian vein compression or even a thoracic outlet syndrome may accompany clavicular nonunion preoperatively. These conditions are associated with hypertrophic midshaft clavicular nonunions and mostly affect the lower trunk of the brachial plexus, thereby causing ulnar nerve symptoms. These symptoms do not always disappear after operative treatment, despite employing meticulous techniques to avoid abundant callus formation. In most clinical reports on treatment of clavicular nonunion the problem of brachialgia is underestimated. In our series, preoperative brachialgia was a serious problem in 43% (12/28) of cases. In 4 cases brachialgia developed postoperatively. To prevent this complication, the wave-plate osteosynthesis was introduced. Brachialgia either did not develop or did not persist in the 9 cases treated by wave-plate osteosynthesis. The use of a wave-plate osteosynthesis has several advantages. First, a form of ‘biological plating’ is established. It preserves the residual blood supply to the bone and soft tissues. Secondly, a mechanically stronger construction is achieved. Thirdly, bone healing is enhanced beneath the mid-portion of the plate, where controlled callus formation is needed. In complex ununited femoral shaft fractures, the wave-plate osteosynthesis technique has achieved very good results.
use of a wave-plate together with a cancellous bone graft in cases of atrophic diaphysial humerus nonunion, produced united fractures in fourteen out of fifteen patients.\textsuperscript{18} The use of the wave-plate osteosynthesis in clavicular nonunion is likely to cause callus formation in the space beneath the plate and away from the neurovascular bundle. Initially the only disadvantage of wave-plate osteosynthesis in clavicular nonunions seemed to be that we saw more wound healing problems in the first four of the nine patients treated. However, after bone healing and plate removal there was no difference in the cosmetic appearance of the scars. This complication can be avoided by making a curved incision $\frac{1}{2}$ cm. below the clavicle thereby forming a well vascularized flap to cover the plate.

Shortening of the clavicle following fracture can cause shoulder girdle dysfunction\textsuperscript{32,55,56} In some cases a corrective osteotomy of a malunited clavicular fracture is necessary to achieve a better shoulder function.\textsuperscript{55,56} In our series, the clavicular length was approximately restored after treatment.

Although consolidation of the nonunion, decrease in pain and improvement of shoulder movement are considered the most important factors in patient outcome, the Constant score is considered to be the gold standard when evaluating shoulder girdle problems.\textsuperscript{35,38} The Constant score is able to discriminate between slight and serious impairment of shoulder function. In this study, the Constant score was determined in 20 cases. In the remaining 8 patients postoperative results were known, but for various reasons the patients could not be examined at the outpatient department for latest follow-up. The patients treated by wave-plate osteosynthesis had markedly higher Constant scores than the patients treated by standard osteosynthesis.

This study was prospective only where the AO documentation was concerned and could not be randomised. It is our opinion that it clearly demonstrates the overall excellent results of wave-plate osteosynthesis in the treatment of clavicular nonunion. The established cases of brachialgia improved and it did not occur at all following wave-plate osteosynthesis.

Acknowledgements

We would like to thank A. B. Stibbe, M.D., Orthopedic Surgeon, for his work on the treatment of clavicular nonunion, and also the AO Documentation Centre.
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