CASE REPORT

A modified operative technique for enhanced compression of medial malleolar non-union

T. Madhu*, R. Morgan-Jones

Department of Trauma and Orthopaedics, University Hospital of Wales, Heath Park, 63 Castle Road, Cottingham, HU16 5JQ, UK

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Introduction

Primary anatomical reduction and stable internal fixation as advised by the AO group are the underlying management principles for all displaced fractures. Non-union is a rare but disabling complication in the treatment of bimalleolar ankle fractures. Factors favouring union are fracture reduction, adequate stabilisation and a sufficient nutritional supply. An atrophic non-union by its nature is avascular and may require cancellous bone grafting to stimulate osteogenesis. Other methods include electrical stimulation, pulsed electromagnetic field and ultrasound.

An atrophic non-union requires anatomical reduction, stable internal fixation with cancellous bone grafting. Adequate compression across the non-union is essential to maintain stable anatomical reduction. We reviewed the literature concerning medial malleolar non-union, cancellous screws, advantages of bicortical screw purchase, effect of motion and tapping in cancellous bone, advantages of noncannulated over cannulated screws and lastly reinforcement in osteoporotic bones. The literature favours self-tapping bicortical screw purchase over the unicortical screw purchase to provide adequate compression in the atrophic cancellous bone. The senior author (R.M.J.) modified the operative technique to obtain bicortical purchase to fix the non-union of the medial malleolus in three patients. We review the technique and results in these patients.

Patients and methods

Three cases of established bimalleolar non-union referred to the Problem Fracture Clinic at the University Hospital of Wales, Cardiff, were included in the study. Two male and one female patient with mean age of 46 years (35–65 years). Two patients were initially treated by primary open reduction and internal fixation and one patient by closed reduction and plaster immobilisation. A diagnosis of atrophic non-union was made in all three cases, when no signs of radiological bony union was apparent after a mean follow-up of 1 year (Fig. 1). Inadequate primary reduction was thought to be the cause of non-union in all cases. The presenting symptom in all cases was pain.

All patients underwent revision operative fixation of both malleoli. The medial malleolus was reduced and secured using the modified operative technique and the lateral malleolus reduced and secured with a standard neutralisation plate. Post-operatively, all patients were mobilised non-weight bearing on the...
involved leg for 6 weeks, then partial weight bearing for another 6 weeks followed by full weight bearing.

Modified operative technique

Through the previous incisions, the medial malleolus was exposed and the non-union adequately debrided. Cancellous bone graft was obtained from a tibial window proximal to the non-union (Fig. 2) and used to bridge the defect of non-union. The medial malleolus was realigned and fixed with two parallel long 4.5 mm partially threaded cancellous screws obtaining good purchase of the lateral cortex of tibia.

Results

Satisfactory radiological signs of bony union were seen in all cases after a mean follow up of 4 months (Fig. 3). There were no infections and all wounds healed primarily. At a mean follow-up of 1 year all patients were pain free although all had lost the last few degrees of dorsi- and plantar-flexion.

Discussion and literature review

Non-union of medial malleolus

Mendelsohn\textsuperscript{21} reviewed 253 patients over a 10-year period with ankle fractures. The incidence of solitary fractures of the medial malleolus was 22.7\% (57 patients), lateral malleolus 41\% (104 patients) and posterior malleolus 0.4\% (2 patients). He noted non-union in 12 patients, 10 patients (6.8\%) of the medial malleolus and 2 patients (1.1\%) of the lateral malleolus. Mendelsohn emphasised the importance of tibiotalar alignment compared to perfect anatomical reduction. Seven of the 10 patients having non-union of the medial malleolus in his study were characterised by persistent or recurrent talar displacement.

Magnusson\textsuperscript{20} emphasised the importance of anterior tibial tubercle and the relationship of the distal tibiofibular joint. He noted that the medial malleolus has a tendency to slide laterally even in a well-moulded plaster cast and that the more distal the fracture is, the greater the effect of lateral displacement on the healing process.

Muller\textsuperscript{22} noted that the chief factor against anatomical reduction of the medial malleolus is the indrawing of the posterior-fascial covering of the malleolus into the gap between the fragments in a tense curtain-like fold. Walheim\textsuperscript{34} noted soft tissue interposition in 26 of 36 operated cases, including periostem, aponeurotic tissue and musculature. Lee and Horan\textsuperscript{19} also stated that the soft tissue interposition
is a problem in fractures of the medial malleolus that may result in fibrous union.

Watson-Jones\textsuperscript{35} attributed the non-union of medial malleolus to the three following factors: (1) feeble osteogenic activity, (2) obliteration of the fracture haematoma by collapse of the surrounding soft tissues, and (3) interposition of a flap of periosteum and other soft tissues. He further noted that too short a period of immobilisation might produce development of non-union and recommended 8–12 weeks of immobilisation.

Banks\textsuperscript{2} stated that not all non-union of the medial malleolus require treatment. A strong fibrous union in good position may be compatible with full function of the extremity and could produce no symptoms. Mendlesohn\textsuperscript{21} noted that a stable fibrous non-union of the medial malleolus is consistent with an acceptable functional result, if the normal tibiotaral alignment has been restored.

### Cancellous screws

Surgical screws are the most commonly used orthopaedic implants. A screw is a machine that is designed to convert torque to compressive force between the two objects that it engages. Biomechanically, human bone is classified as cancellous if it has apparent density in the range of 0.09–1.26 g/cm\(^3\), or porosity between 30 and 90%.\textsuperscript{14}

Perren\textsuperscript{25} stated that cancellous screws are designed to have greater thread depth and decreased thread cross-sectional thickness in comparison to cortical bone screws, to provide more holding power in porous material such as cancellous bone. Other factors which have been found experimentally to increase the holding power of cancellous bone screws include: increasing the major diameter of the screw,\textsuperscript{24} increasing the length of engaged screw thread,\textsuperscript{12} inserting the screw in cancellous bone of greater apparent density and shear strength\textsuperscript{6} and decreasing the thread pitch.\textsuperscript{13}

The holding power of a screw in bone is a function of both the design of the screw and the properties of the bone into which it is inserted.\textsuperscript{1,32} Surgical screws are designed to generate a compressive force when a torsional moment is applied to the screw head. The maximum uniaxial tensile force needed to produce failure in the bone has been defined as the pullout force.\textsuperscript{5} When a screw is used for orthopaedic applications, the limiting factor that determines the holding power is usually the strength of the surrounding bone.\textsuperscript{11} The loss of screw holding power in cancellous bone is a commonly observed clinical consequence of osteopenia as observed in the metaphyseal area adjacent to a non-union.\textsuperscript{3,19}

### Bicortical versus unicortical screws

Harnroongroj\textsuperscript{15} demonstrated that the metaphyseal cancellous bone plays no role in generating screw-holding power. Only a well-inserted cancellous screw into both cortices can achieve good screw holding power at the metaphysis. In his experimental study, he demonstrated no significant statistical difference in the stiffness and the distance of screw withdrawal at the maximal screw holding power of group I (metaphyseal area of femur without cancellous bone inside) and group II (metaphyseal area of femur with cancellous bone inside). He concluded that the screw holding power at the metaphysis depends on both cortices; the metaphyseal cancellous bone plays no significant role in the cancellous screw holding power. Therefore, good engagement of cancellous screw at both cortices is necessary to provide good screw holding power. Ansell and Scales\textsuperscript{1} demonstrated that the mean holding power of the self-tapping screws increased by approximately 56% for bicortical screw purchase compared to unicortical purchase.

### Effect of motion

Schatzker\textsuperscript{30} concluded histologically that whenever motion takes place between a screw and bone, the histological response is one of marked connective tissue proliferation and bone resorption. Unlike the screw at rest, which becomes enveloped by bone, the screw in motion becomes enveloped by fibrous tissue without any appreciable holding power. He noted that where internal fixation is inadequate and micro-movement results at the screw bone interface, the tissue which develops in response to the screw insertion, differentiates into islands of fibrocartilage, into synovial like lining cells and into a mass of mature fibrous tissue stroma which envelopes the screw threads. Radiographically, this process of loosening appears as an increasing ‘halo’ surrounding the screw threads. He also noted that a screw at rest if inserted into a hole larger than self becomes enveloped and fixed by bone. This implies that a screw stripped at the time of insertion should be left in its hole, for in time its holding power will increase, provided no movement occurs.

### Effect of tapping on cancellous bone

The AO/ASIF technique manual\textsuperscript{29} recommends not tapping in cancellous bone because it is thought that inserting a screw without tapping compresses the trabeculae and gives better holding power. The
process of tapping threads requires that the tap be inserted to cut the threads, then removed and the screws placed into the prepared hole. Some of the material cut by the tap is removed in the process rather than being compressed into the threads. This is confirmed in the experimental study by Chapman et al., that the average cross-sectional area of the holes prepared for 6.5 mm diameter bone screw with tapped threads was $15.4 \pm 0.2 \text{ mm}^2$ versus $12.2 \pm 0.2 \text{ mm}^2$ for non-tapped threads, an increase of 27% in porous material, therefore self-tapping screws are beneficial in the metaphyseal cancellous bone. The average reduction in pullout force due to tapping in cancellous bone was $73 \pm 41 \text{ N}$, a percentage reduction of $8 \pm 4\%$, which is statistically significant.10 Experiments with human bone using self-tapping and non-self-tapping screws have shown that less torque is developed during the insertion of self-tapping screws.

Cannulated or non-cannulated cancellous screws

Hearn et al.16 reported a comparison between cannulated and noncannulated cancellous screws, which did not show any statistically significant difference. Chapman et al.10 demonstrated that the pullout force of 4.0-mm diameter cannulated screw was 20% below that of non-cannulated screws of equivalent diameter, length and thread pitch. This was statistically significant reduction in strength. To compare, both screws had 4.0 mm major diameter, 14 mm length and 1.75 mm pitch. The noncannulated screw has a thread depth of 1.05 mm and a resultant thread shape factor (TSF-ratio of thread depth to pitch) of 0.85. The cannulated screw has a thread depth of 0.63 mm and TSF of 0.71, a 16% reduction. This decrease in TSF accounts for most of the decreased pullout force of the cannulated screws. Screw purchase can be enhanced by increasing the TSF, which result in decrease in pitch or an increase in thread depth.10 However, this study does not address the biologic effects of living tissue such as apposition of bone around the screw threads, which is known to enhance pullout strength with time.

Effect of compression in bone

Wagner33 demonstrated that the cancellous bone under continuous compression by screw threads does not result in resorption, but hypertrophies and re-aligns its trabeculae in line with the force on the side exposed to pressure. Schatzker31 in his study on the reaction of cortical bone to compression demonstrated histologically that all lacunae at the edge of cortex adjacent to the screw threads under compression were empty indicating bone death. No granulation tissue or any new bone formation appeared at the interface under compression. However, there was great activity seen in the form of new bone formation along the opposite cortex and screw junction, which was not under compression. He further noted that where compressive forces exist at the screw bone interface, the metal remains in intimate contact with the dead bone. The non-pressure screw/bone interface in contradiction is an area of great biological activity. Any space present is rapidly filled by granulation tissue, which then matures into bone.32 The dead cortex is replaced by creeping substitution and by invasion of new haversian vessels. This activity proceeds towards the area under compression. Once all the dead bone is replaced by new bone, the compression at the interface falls to zero.

Sperren26 stated that interfragmentary compression prevents relative motion at the fracture site and permits primary bone healing. Schatzker31 further stated that the lag screws during the interfragmentary compression are loaded in tension with resultant compression at the screw bone interface, but there is no mechanism to maintain this tension or generate further tension in the face of continuing bone remodelling.

Screw loosening

The application and maintenance of compression between screw threads and bone are the most important factors in attaining rigid internal fixation by means of screws and plates. If the compression between the screw thread and bone decays rapidly, rigidity is lost and movement, non-union and failure of fixation may be the outcome.30 Radiologically, we recognise either mechanical or biological failure of fixation. In the first, there is either simple screw pull out due to mechanical overload, or there is metal fatigue in which plates fracture or screws shear off. In the second, a radiolucent halo is the classical radiological manifestation of screw loosening.

Reinforcement of cancellous bone

The metaphyseal cancellous bone at the site of non-union is osteopenic secondary to disuse. Kleeman18 evaluated the use of biodegradable material, polymethylmethacrylate (PMMA) and polypropylene fumerate (PPF), for the reinforcement of surgical
screws in fractures involving severely osteoporotic bones. The study compared the pullout force and stripping load of cancellous screws before and after reinforcement with PMMA or PPF composite. The study showed equivalent mean pullout force after reinforcement with PMMA and PPF composite.

Summary of experimental studies

1. Harnroongroj15 and Ansell1 concluded that bicortical screw purchase of self-tapping cancellous screws is superior by almost 56% compared to unicortical screw purchase in the metaphyseal cancellous bone.

2. Schatzker30 concluded that movement causes the screw to become enveloped by fibrous tissue in response to necrosis and resorption of the adjacent bone. This results in a radiologically discernible radiolucent halo about the screw, a certain sign of screw loosening.

3. Chapman et al.10 concluded that increasing the thread shape factor (ratio of thread depth to pitch), and by decreasing the pitch (i.e. creating a finer thread), increase screw purchase strength in porous material.

4. Cannulated screws have lower pullout strengths than noncannulated screws of equivalent diameter in porous material.

5. Tapping in cancellous bone decreases the screw pullout strength in porous material. However, their study was performed on porous material, which is biomechanically equivalent to cancellous bone, but lacked the biological effects of living tissue such as apposition of bone around the screw threads, which is known to enhance pullout strength with time.

6. Ansell and Scales1 advised a torque-limiting screwdriver, as the bending or breaking of a screw on insertion is usually caused by the application of a torque greater than the particular screw can withstand.

Conclusion

The incidence of non-union of the fractures of medial malleolus is approximately five times higher than lateral or posterior malleolus. Non-union of the medial malleolus does not necessarily require treatment if the tibiotalar alignment is maintained. Anatomical reduction, stable internal fixation and cancellous bone grafting is accepted treatment for atrophic type of non-union. A review of literature for experimental studies favoured self-tapping cancellous screws, bicortical purchase and stable fixation.

The modified operative technique described in this paper when used for the fixation of medial malleolar non-union utilises the proposed principles and satisfactory results were achieved in all three cases treated.

References

1. Ansell RH, Scales JT. A study of some factors which affect the strength of screws and their insertion and holding power in bone. J Biomech 1968;1:279–302.

2. Banks SW. The treatment of non-union of fractures of the malleolus. J Bone Joint Surg 1949;31-A:658.

3. Bartucci EJ, Ganzalez MH, Cooperman DR. The effect of adjunctive methylmethacrylate on failures of fixation and function in patients with intertrochanteric fractures and osteoporosis. J Bone Joint Surg 1985;67-A:1094.

4. Bassett CAL, Mitchell SN, Schink MM. The treatment of therapeutically resistant non-union with bone grafts and pulsing electromagnetic fields. J Bone Joint Surg 1982;64-A:1214–20.

5. Bechtol CO, Lepper H. Fundamental studies in the design of metal screws for internal fixation of bone. J Bone Joint Surg 1956;38-A:1385.

6. Benterud JG, Husby T, Graadahl O, Alho A. Implant holding power of the femoral head. A cadaver study of femoral screws. Acta Orthop Scand 1992;63(1):47–9.

7. Brighton CT, Black J, Friendenberg ZB, Esterhai JL, Day LJ, Connolly JF. A multicenter study of the treatment of non-union with constant direct current. J Bone Joint Surg 1981;63-A:2–13.

8. Burchardt H. The biology of bone graft repair. Clin Orthop 1981;174:28–40.

9. Cameron HU, Jacob R, Macnab I, Pilliar RM. Use of polymethylmethacrylate to enhance screw fixation in bone. J Bone Joint Surg 1975;57-A:655.

10. Chapman JR, Harrington RM, Lee KM, Anderson PA, Tencer AF, Kowalski D. Factors affecting the pullout strength of cancellous bone screws. J Biomech Eng 1996;118(3):391–8.

11. Crowell RR, Edwards WT, Hayes WC. Pullout strength of fixation devices in trabecular bone of the femoral head 31st. ORS 1985;10:189.

12. Daum WJ, Tencer AF, Cartwright TJ, Simmons DJ, et al. Pullout strengths of bone screws at various sites about the pelvis—a preliminary study. J Ortho Trauma 1982;2(3):229–33.

13. Evans M, Spencer M, Wang Q, White SH, Cunningham JL. Design and testing of external fixator bone screws. J Biomed Eng 1990;12:457–62.

14. Gibson L, Ashby M. Cancellous bone, cellular solids: structure and properties. New York: Pergamon Press; 1988. p. 316–31.

15. Harnroongroj T, Tchataweewan A. Determination of the role of the cancellous bone in generation of screw holding power at metaphysis. Clin Biomech (Bristol Avon) 1999;14(5):364–6.

16. Hearn TC, Surowaik JF, Schatzker J, Szalai JP. Extraction strength of cannulated cancellous bone screws. J Orthop Trauma 1993;7(2):138–41.

17. Karlstrom G, Olerud S. Fractures of the tibial shaft: a critical evaluation of treatment alternatives. Clin Orthop 1974;105:82–115.

18. Kleeman BC, Takeuchi T, Gerhart TN, Hayes WC. Holding power and reinforcement of cancellous screws in human bone. Clin Orthop 1992;284:260–6.

19. Lee HF, Horan TB. Internal fixation in injuries of the ankle. Surg Gynec Obstet 1943;76:593.
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20. Magnusson R. On late results in non-operated cases of malleolar fractures: clinical-roentgenological-statistical study: fractures by external rotation. Acta Chir Scand 1944;90(Suppl. 84):1136.
21. Mendelsohn HA. Non-union of malleolar fractures of the ankle. Clin Orthop 1965;42:103–18.
22. Muller GM. Fractures of the internal malleolus. BMJ 1945;2:320.
23. Müller ME, Allgöwer M, Schneider R, Wellenegger H. Manual of internal fixation techniques recommended by the AO group, 2nd ed., Berlin, Heidelberg, New York: Springer-Verlag; 1979.
24. Nunamaker DM, Perren SM. Force measurement in screw fixation. J Biomech 1976;9:669–75.
25. Perren SM, Cordey J, Baumgart F, Rahn BA, Schartzker J. Technical and biomechanical aspects of screws used for bone surgery. Int J Ortho Trauma 1992;2(1):31–8.
26. Perren SM. Cortical bone healing. Acta Orthop Scand Suppl 125, 1969.
27. Pilla AA, Mont MA, Nasser PR, Khan SA, Figueiredo M, Kaufman JJ, et al. Non-invasive low-intensity pulsed ultrasound accelerates bone healing in the rabbit. J Orthop Trauma 1990;4:246–53.
28. Reckling FW, Waters III CH. Treatment of non-unions of fractures of the tibial diaphysis by posterolateral cortical cancellous bone-grafting. J Bone Joint Surg 1980;62A:936–41.
29. Schatzker J, Alho A, Sheehan J. In: Muller ME, et al., editors. Screws and plates and their application. manual of internal fixation. New York: Springer-Verlag. p. 184.
30. Schatzker J, Horne JG, Sumner-Smith G. The effect of movement on the holding power of screws in bone. Clin Orthop 1975;111:257–62.
31. Schatzker J, Horne JG, Sumner-Smith G. The reaction of cortical bone to compression by screw threads. Clin Orthop 1975;111:263–5.
32. Schatzker J, Sanderson R, Murnaghan JP. The holding power of orthopaedic screws in vivo. Clin Orthop 1975;108:115.
33. Wagner H. Neue osteosyntheseschrauben und ihre gewebserträglichkeit. Vehr Dtsch Orthop Ges 49 Kohgr; 1962. p. 418.
34. Walheim T. Intraarticular malleolar fractures. A survey. Acta Chir Scand 1936–1937;79:166.
35. Watson-Jones SR. 4 ed., Fractures and joint injuries, vol. 2, 4 ed. Baltimore: William and Wilkins; 1957.