(i) The principles of foot and ankle arthrodesis

Lee Parker
Dishan Singh

Abstract
Successful arthrodesis of a diseased joint for pain relief and stability in the appropriate patient is achieved by thorough pre-operative planning and attention to risk factors for non-union, meticulous surgical technique including respect for soft tissues, adequate joint surface preparation and co-aptation of joint surfaces with stable fixation in the position of most useful function. Here we outline how these principles are applied in the foot and ankle.

Keywords ankle joint; arthrodesis; osteoarthritis; subtalar joint

Introduction
Arthrodesis is the surgical fusion of a diseased joint for the purposes of obtaining pain relief and stability. The bones are fused in a position permitting most useful function but lose their natural motion. Henry Park is said to have performed the first arthrodesis of a tuberculous knee joint with a fixed flexion deformity, in Liverpool in 1781. However, Edward Albert later introduced the term “arthrodesis” in 1882 when he realised its potential in stabilising the foot and ankle of polio sufferers.

Orthopaedic trainees are often exposed to the principles of arthroplasty; the aim of this article is to introduce and reinforce the basic principles of arthrodesis as applied to foot and ankle surgery.

Extra-articular arthrodeses, where the joint surface is not prepared, relies on osteoconduction along a bone graft and is not usually useful in foot and ankle surgery, except possibly for fusion of the subtalar joint in paediatric cases. It is preferable to rely on intra-articular arthrodesis, where all cartilage is denuded and primary bone healing proceeds between two apposed cancellous surfaces. The technique of dowel grafting, where only part of the joint surface is prepared and union is attempted by osteoconduction along an interposed bone graft, generally gives inferior results to full joint preparation in foot and ankle surgery.

Indications
Arthrodesis is a suitable alternative to arthroplasty in the painful, stiff, deformed or unstable joint where loss of motion will not significantly compromise overall function. It is used in the treatment of primary degenerative osteoarthritis and in secondary arthritis due to trauma, inflammation, infection, and avascular necrosis. It is also employed to stabilise joints with ligamentous injury or neurological deformity where gross instability cannot be treated with soft tissue procedures alone.

Pre-operative preparation
The aetiology of a patient’s joint disease is important. Diabetic patients with Charcot’s arthropathy inevitably have microvascular disease, with the potential for compromise of skin and bone healing. Associated, progressive neurological deformity is difficult to control with standard internal fixation techniques due to associated osteoporosis. Patients with avascular necrosis require resection of devitalised bone, which can lead to limb shortening and mal-alignment.

The presence of mal-alignment in the coronal and sagittal planes, areas of maximal tenderness, restricted range of movement, ligament instability, tendonopathy, adjacent joint degeneration, as well as the patient’s skin condition and neurovascular status, should all be considered in the surgical plan.

Investigations
Plain x-rays are the most useful investigation and should be taken weight-bearing to represent the patient’s physiological alignment. Due to the close-packed arrangement of the joints of the foot, pain is often poorly localised by the patient and radiographic changes do not always correlate with the site of reported pain. Fluoroscopic-guided injections of local anaesthetic and contrast (Figure 1), after which a pain diary is kept, are helpful in

Figure 1 Ankle arthrogram under fluoroscopy. Contrast is seen in the ankle joint but does not penetrate the subtalar joint (30% of patients may have a connection between the ankle joint and the subtalar joints in which case the study may not be of diagnostic value). This rheumatoid patient obtained almost complete pain relief after injection alone and a subsequent ankle fusion has improved her mobility.
confirming the source of pain, particularly when adjacent joints are also degenerate. Relief of pain after injection is highly predictive of pain relief after fusion.5 With severe arthritis, or when the anatomy is disordered (for example after previous fracture), or when there is pseudoarthrosis, CT-guided injections allow better joint access and subsequent assessment of the joint disease.5

Adjacent joint degeneration

The joints adjacent to the proposed arthrodesis should never be ignored. A scannogram of the whole lower limb is helpful in determining how a single joint deformity affects overall limb alignment. It is preferable to deal with more proximal joint degeneration and mal-alignment first. For example, meticulous alignment of an ankle fusion can later be upset by a knee replacement that alters coronal lower limb alignment by as little as 2°. A fused joint becomes less able to dissipate the forces placed through it, thereby potentially accelerating adjacent joint degeneration. The incidence of subtalar fusion five years following ankle fusion has been quoted to be 2.8% but retrospective analyses of pre-operative x-rays of patients with ankle arthrodesis report that co-existent hind or midfoot arthritis was present in 95.8% of cases.7

Alternative treatments

All patients should have a trial of conservative management before being offered an arthrodesis. Patients with ankle arthritis benefit from activity modification, weight-loss, analgesics anti-inflammatories and walking aids. Orthoses, such as a moulded Ankle-Foot-Orthosis (AFO), Solid Ankle Cushion Heel insert (SACH) or insoles, work by limiting the motion of the joint that brings about pain and by mechanical unloading. Patients with tarso-metatarsal arthritis may benefit from localised steroid injections, insoles and rigid soled shoes with a rocker.

Patients with MTPJ arthritis of the hallux may benefit from similar footwear adaptation or from a manipulation and steroid injection, particularly for milder grades of arthritis.5 Cheilectomy (excision of dorsal osteophytes and up to a third of the metatarsal articular surface) leads to pain relief and improvement in joint motion,9 thereby delaying the need for an arthrodesis in properly chosen patients.

Similarly, for those patients with anterior ankle impingement pain, arthroscopic debridement can give good long-term pain relief in those with anterior osteophytes and minimal joint space narrowing.10

The role of ankle arthroplasty in the treatment of ankle arthritis is controversial. The early major revision rate for arthroplasty is far higher than for arthrodesis at five years (23% vs. 11%).6 Its use is therefore to be avoided in younger patients, though in the elderly or rheumatoid patient where stiffness of the remainder of the foot is a concern, preservation of ankle motion with arthroplasty may be appropriate.11

Managing co-morbidity, medications and smoking

Co-morbidity

The patient as a host must always be considered in determining whether arthrodesis will be successful. Union of an arthrodesis can be allied with fracture healing in cancellous bone and those factors which influence it should be considered. The literature on fracture healing has previously been extensively reviewed12.

Patients with significant co-morbidity, in particular cardiovascular disease and diabetes with microangiopathy and those rheumatoid patients on long-term immunosuppressive steroids, are at particular risk of infection and non-union. In patients with peripheral vascular disease, local tissue hypoxia can lead to delayed bone union and poor wound healing. Oxygen is required for the hydroxylation of proline residues during collagen formation and iron is essential for cellular electron-transport systems. Studies in iron-deficient, anaemic rats have shown poor rates of union and decreased strength of bony union.13 Tight glycaemic control is also important in diabetics to minimise the risks of delayed and non-union, which are significantly higher in this group of patients.14 Animal studies have demonstrated reduced levels of cellular proliferation, osteoblastic activity and collagen synthesis in diabetics as a result of growth factor inhibition, ultimately leading to a reduction in the tensile strength and stiffness of callus.15 While it is unlikely that patients who are being considered for arthrodesis will be malnourished, it has been shown in animal studies that deficiencies of vitamins B6, C, D, E, calcium and phosphorus all delay the synthesis and maturation of callus.16–18

Medications

Continual use of non-steroidal anti inflammatory agents (NSAID’s) can be regarded as a risk factor for the development of non-union. Even the use of Celecoxib (a selective COX-2 inhibitor) has been shown in the rat model to lead to unfavourable histological and mechanical properties in the healing bone and the effect is more profound the longer the drug is administered.19 It would seem prudent, therefore, to reduce the use of NSAIDs in patients undergoing arthrodesis. In the rheumatoid patient, DMARDS (Disease Modifying Anti-rheumatic Drugs) such as methotrexate, cyclosporine and anti-TNF-α, are often used in low doses. There is no evidence to suggest they adversely affect bony union. The long-term administration of corticosteroids is known to be detrimental to tissue healing and fracture repair. Short term administration seems to have little effect on bone healing20 whereas continual administration leads to high rates of non-union in animal models.21 Bisphosphonates are osteoclast inhibitors and are used in the treatment of post-menopausal osteoporosis, steroid-induced osteoporosis, Paget’s disease and neoplastic conditions associated with bone destruction. There is no evidence that they increase bone union rates in the setting of either fracture or arthrodesis.

Smoking

Smokers have a higher risk of wound healing complications, non-union and poor outcome in ankle fusion.22 The relative risk of non-union of ankle arthrodesis is 3.75 times higher than that of non-smokers and, when confounding factors for non-union such as diabetes, cardiovascular disease and use of NSAIDS are excluded, the relative risk of non-union in smokers is 16 times that of non-smokers.23 When patients give-up smoking for their hindfoot fusion, their rate of non-union reduces from 18.6% to 11.1%, compared with 7.1% in non-smokers.24 Despite the well-known detrimental effects of smoking on foot and ankle fusion,
as few as 23% of foot and ankle surgeons take measures to reduce their patients’ smoking before surgery and only 9% record non-union as a direct complication of smoking on the pre-operative consent form. In our opinion smokers should give up smoking at least 2 weeks prior to surgery and remain off cigarettes until soft tissue healing and bony union have occurred.

Managing infection

Arthrodesis is the treatment of choice for limb-threatening septic arthritis of the ankle and subtalar joint. The surgery is often complicated by limb oedema, scarring from previous surgery, chronic osteomyelitis and poor bone stock. The patient is often unemployed, or becomes unemployed because of prolonged sickness, and compliance with treatment can be poor. A two stage arthrodesis is required in infected cases, with the initial removal of implanted metal-work, radical soft tissue debridement with excision of secretory fistulae and sinuses, removal of osteonecrotic bone and implantation of antibiotic beads and spacers with concomitant administration of parenteral intravenous antibiotics. The second stage depends on the filling of large bone voids with bone graft, obtaining length, alignment and stability, usually with a combination of internal and external fixation. Adequate soft tissue coverage may necessitate a muscle transfer procedure.

Stability is paramount in the eradication of infection. Internal fixation reduces the effective surface area of cancellous bone that is able to take part in fusion and has potential to loosen in the presence of on-going infection. External fixators can achieve interfractionary compression without interfering with the local blood supply and loose wires can always be re-tensioned, however, pin-track infections and irritation of the soft tissues can be a problem. When internal and external fixation are used in combination in the ankle, union rates of 86.6%, 84.2% and 93% have been reported.

The patient’s expectations, and the alternative of below knee amputation, with a shorter period of convalescence and lower potential complications, should be explored before salvage surgery for infection.

Patient education

Managing patient expectations is a priority when considering fusion. Patients should be informed of the risks specific to fusion, which include: infection requiring subsequent surgery or even amputation, neurovascular injury, delayed union and non-union, painful hardware requiring removal and the development of adjacent joint arthritis. They should be told that a small minority of patients require subtle footwear modification to improve gait after foot and ankle fusion.

Patients often wrongly imagine that they will walk with a marked limp after surgery. A patient with a fused ankle has an average of a 75% reduction in total sagittal motion of the foot; however, the successful outcome of ankle fusion is not reliant on compensatory tarsal hypermobility, which only occurs in 27% of cases. What is more likely is that patients undertake subtle modifications to their gait, which are aided by having a normally functioning ankle in the contralateral leg, some normal residual motion in the tarsal joints of the ipsilateral leg (not necessarily hypermobility) and suitable footwear, which might on occasion require a rocker outsole. Patients who undergo a triple arthrodesis only lose inversion and eversion, but patients often wrongly believe that they will also lose plantarflexion/dorsiflexion.

In our institution we have found that our patients’ concerns are best managed in a nurse-practitioner-led “fusion forum”. This is set-up as an informal group meeting between patients considering fusion and the orthotist, plaster technicians and patients who have previously undergone fusion. Such a forum enables the patient to understand the surgery and its potential benefits and risks as well as addressing concerns over gait issues.

Operative preparation

Surgical approaches and arthroscopy

Planning the initial incision is important in order to avoid neurovascular structures and to be able to carry-out meticulous and thorough joint preparation through an adequate exposure. This has to be balanced against the detrimental effect of excessive soft-tissue dissection and periosteal stripping on the healing of the skin and indeed the arthrodesis itself. The Charnley anterior transverse approach to the ankle, with division of the extensor tendons, has now been abandoned in favour of the anterior approach between the tendons of tibialis anterior and extensor hallucis longus. Previous scars and frail skin should be avoided and occasionally the surgical approach has to be modified in order to avoid areas of excessive soft tissue tension, which can be a particular problem with the valgus hindfoot.

The Ollier approach to the subtalar and Chopart joints has largely been abandoned by adult foot and ankle surgeons because of the difficulty exposing and preparing the medial part of the talonavicular joint and the significant risks of nerve damage leading to painful neuromata. It is however still used in paediatric orthopaedics and in polio surgery. The preferred approach is to use the lateral utility incision from the tip of the fibula to the base of the 4th metatarsal to expose the subtalar joint and the calcaneocuboid joint if necessary (Figure 2). If a triple arthrodesis is being performed, a separate medial utility incision is used between the tibialis anterior and tibialis posterior tendons to prepare the boat-shaped talonavicular joint (Figure 3). Arthroscopic fusion of the subtalar and Chopart joints is possible but as yet is not common in practice.

Providing there is only minor mal-alignment and bone loss, and there is no need for bone graft, arthroscopic ankle arthrodesis has proven to yield similar fusion rates to open ankle arthrodesis. Arthroscopic ankle arthrodesis has gained popularity, since it addresses concerns about excessive soft tissue dissection and improves post-operative pain and recovery, yielding high patient satisfaction rates. A skilled arthroscopic surgeon can perform most ankle fusions, thought conversion to an open procedure is occasionally necessary and the patient should be warned of this pre-operatively.

Joint surface preparation

An arthrodesis is essentially a controlled fracture and although there is considerable interest in the development of biomatrices and growth factors to promote union, there is great innate potential for union, which can be optimised by enhancing the natural biology of the fusion site through adequate
decortication. All articular cartilage should first be removed to expose the underlying subchondral bone. The use of a laminar spreader to distract the articular surfaces is invaluable for this purpose. Thorough decortication of the surfaces down to bleeding cancellous bone is then carried out while taking care to maintain congruous surfaces, which can be brought into close coaptation. Maintenance of natural joint shape and congruity has been shown to be more biomechanically stable than flat arthrodesis cuts.

Following decortication, the exposed cancellous surfaces should be “feathered”, “fish-scaled” or “petalised” in two perpendicular directions to create pits and furrows thereby maximising the area of interdigitation between surfaces and exposing pluripotent marrow-derived stem cells (Figure 4). All decortication and petalisation should be carried out with sharp chisels wherever possible: the use of saws and power burrs should, in our opinion, be avoided due to the generation of high localised temperatures which are known to impair bone healing in animal models. Power burrs are acceptable in arthroscopic arthrodesis, where high cold water inflow and outflow control heat exchange. Thorough decortication may not be necessary for certain patients, percutaneous and spontaneous arthrodesis is possible in the joint which has undergone chondrolysis as a result of immobility or in the rheumatoid joint as a result of synovitis. However, thorough joint preparation by meticulous removal of all cartilage and feathering in two perpendicular directions provides a better environment for successful bony healing.

**Filling of cancellous defects — bone void fillers**

Charnley stated that union of an arthrodesis takes place between perfectly co-apted cancellous surfaces with intact circulation, making it comparable to fracture healing in an undisplaced fracture under ideal conditions, with both surfaces participating equally in osteogenesis. He concluded that bone grafts acted as little more than “passengers for three or four months until they secure a blood supply”. Charnley was also of the opinion that bone graft is slow to become incorporated and can occasionally fracture and fail to unite. In hindfoot fusion only local graft from the excised joint surfaces is needed to achieve comparable
union rates. We tend to avoid the use of bone graft in uncomplicated primary fusion procedures, but accept that its use is occasionally necessary when the anatomy of the joint does not lend itself well to internal fixation, when there is significant bone loss from the primary pathology or when revising from an arthroplasty to a fusion.

Bone void fillers include autograft, which can be obtained locally or from the iliac crest, freeze dried or fresh frozen acellular cadaveric allograft and bone substitutes such as DBX (de-mineralized bone matrix). OP-1 or recombinant BMP-7 (bone morphogenetic protein) has been used as a safe alternative to iliac crest bone allograft and bone substitutes such as DBX (de-mineralized bone matrix). OP-1 or recombinant BMP-7 (bone morphogenetic protein) has been used as a safe alternative to iliac crest bone graft in achieving posterolateral spinal fusion, in tibial non-union and has been shown to reduce time to bony union in tibial fractures treated with external fixation; however, it has not come into popular use in foot and ankle surgery.

Obtaining correct position and alignment
The optimum position for ankle arthrodesis is important to note and has been found, through gait analysis, to be approximately 5° of ankle and subtalar valgus, neutral ankle dorsiflexion and 5° of external rotation with slight posterior positioning of the talus under the tibia. The valgus position of the hindfoot maintains the mobility of the midfoot by “unlocking” the transverse tarsal joint; the neutral/slight dorsiflexion and external rotation of the ankle guard against a varus-thrusting gait where the patient leads to bone resorption and separation of the surfaces. Excessive compression, however, leads to high stresses on the medial collateral ligament of the knee.

It may be necessary to perform soft tissue releases to achieve a plantigrade foot prior to fusion; for example, an equinus ankle may require a percutaneous lengthening of the Achilles tendon. Similarly, lengthening of the peroneal tendons may be necessary when performing a triple arthrodesis for correction of planovalgus. When planovalgus is corrected, the medial column of the foot is effectively shortened by the correction manoeuvre, which is internal rotation of the calcaneum on the talus, reduction of subtalar valgus and re-alignment of the talonavicular joint which is fixed first. When the talonavicular joint is aligned, apposed and fixed, the talonavicular joint may not be apposed, in which case a small bone block may be required to achieve lateral column lengthening.

In all forefoot and midfoot fusions, it is important to test the proposed position of fusion by asking the operative assistant to press a flat surface against the sole of the foot to simulate optimal foot position when weight-bearing (Table 1). In first tarsometatarsal fusion there is considerable opportunity to reposition the metatarsal into a more plantarflexed or dorsiflexed position to assist with correction of forefoot pronation or supination respectively and this can be combined with a calcaneal osteotomy or “heel shift”.

Co-aptation, fixation and compression
In his early work on knee arthrodesis, Charnley proposed that optimal cancellous healing occurred across an arthrodesis when the cancellous surfaces were held rigidly in compression, which encourages union by several means: when co-aptation of cut bony surfaces is imperfect, space exists between the cut surfaces in which fibrous union can occur. When compression is applied across an arthrodesis, the pressure is initially concentrated on the proudest parts of the cut surfaces which, as a result, undergo resorption by osteoclasts. This brings the surfaces into closer co-aptation. Under the influence of moderate dynamic compression, osteoblasts are then stimulated to achieve union across the arthrodesis (Figure 5a).

Compression, rigidity and co-aptation are highly interrelated. With imperfect co-aptation between bone ends held with high compression, considerable rigidity can be achieved since compression neutralises shear and bending forces and prevents separation of the surfaces. Excessive compression, however, leads to bone resorption and so the ideal arthrodesis should have moderate compression and near perfect coaptation, which in fact provides conditions for considerable rigidity.

Rigidity of fixation alone is probably less important than compression and co-aptation. The difference between very rigid and less rigid fixation is revealed in the histological characteristics of bone healing prevailing within the respective mechanical

<table>
<thead>
<tr>
<th>The optimum position of foot and ankle fusions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ankle Arthrodesis</strong></td>
</tr>
<tr>
<td>Neutral dors/plantarflexion</td>
</tr>
<tr>
<td>5° hindfoot valgus</td>
</tr>
<tr>
<td>Same external rotation as other side</td>
</tr>
<tr>
<td>Talus posterior</td>
</tr>
<tr>
<td><strong>Subtalar Arthrodesis</strong></td>
</tr>
<tr>
<td>Neutral dors/plantarflexion</td>
</tr>
<tr>
<td>10° heel valgus</td>
</tr>
<tr>
<td><em>Talonavicular Arthrodesis</em></td>
</tr>
<tr>
<td>Neutral dors/plantarflexion</td>
</tr>
<tr>
<td>10° heel valgus</td>
</tr>
<tr>
<td>Neutral forefoot abd/abduction</td>
</tr>
<tr>
<td>Neutral forefoot pro/supination</td>
</tr>
<tr>
<td><strong>Calcaneocuboid Arthrodesis</strong></td>
</tr>
<tr>
<td>Flat surface should be applied to</td>
</tr>
<tr>
<td>sole of foot intra-operatively to determine</td>
</tr>
<tr>
<td>correct dors/plantarflexion</td>
</tr>
<tr>
<td>15° proximal phalanx valgus</td>
</tr>
<tr>
<td>Neutral phalangeal rotation</td>
</tr>
<tr>
<td><strong>First MTPJ Arthrodesis</strong></td>
</tr>
<tr>
<td>Simulated weight-bearing can be performed by</td>
</tr>
<tr>
<td>using the cover of the screw set</td>
</tr>
<tr>
<td>Best assessed by assessing alignment with</td>
</tr>
<tr>
<td>second toe</td>
</tr>
<tr>
<td>Plane of movement of interphalangeal joint</td>
</tr>
<tr>
<td>more important than</td>
</tr>
<tr>
<td>alignment of nail plate</td>
</tr>
</tbody>
</table>

Table 1
environment. Direct or primary bone healing is seen after rigid stabilisation with perfect co-aptation and minimal interfragmentary motion. Osteoid is laid down behind “cutting cones” of osteoblasts which traverse the fracture or arthrodesis line. Small gaps are filled by woven bone that is later remodelled to lamellar bone. External callus is not seen and bone strength is not restored for many months. In contrast, more external callus is seen in less rigidly fixed fractures and in arthrodeses, when mechanical integrity is restored more rapidly to physiological levels as bone is remodelled in accordance with Wolff’s law. Decreased stiffness of fixation and the application of short duration controlled micro-motion are also known to improve the healing characteristics of tibial fractures providing the boundaries of strain magnitude and force of application are not exceeded.47

Various methods are available for the stabilisation of the arthrodesis. Internal fixation can be carried out with screws, plates, intra-medullary nails and k-wires. External fixation can be carried out with mono-axial or circular frames, or even plaster of Paris. A combination of techniques can also be used.

Internal fixation with screws is likely to be the most stable construct for ankle arthrodesis, particularly when the screws are crossed just above the joint line in the tibia37 (Figure 5b). Our preference, however, is to use two parallel partially-threaded cannulated cancellous screws with washers, ensuring both screw threads entirely cross the joint-line to obtain adequate compression of the fusion, (Figures 5c and 6). A retrograde

Figure 5

Figure 6 Lateral radiograph 3 months after ankle fusion in a patient with Charcot Marie Tooth presenting with pes cavus and a painful arthritic ankle with a fixed varus deformity; injection studies into the ankle joint had abolished his pain and the arthritic subtalar joint was therefore not fused. The plantarflexed first ray was corrected by a dorsiflexion osteotomy of the first metatarsal and a tibialis posterior tendon transfer to the peroneus tertius were carried out at the time of the ankle fusion.
This 40 year old patient from the Middle East had developed a hindfoot varus with osteoarthritic ankle and subtalar joints after sustaining a peroneal tendon laceration at the age of 5. A The fixed hindfoot varus led to the patient walking on the lateral border of her foot and caused painful callosities. B Arthritis of the ankle and subtalar joints with a varus hindfoot is seen on the mortise view of the ankle. C Due to the amount of deformity, a takedown and tibio-calcaneal fusion using an intramedullary nail were carried out through a lateral approach; the radiographs at four months demonstrate union of the arthrodesis.

Figure 7
intramedullary nail inserted through the calcaneum across the ankle and subtalar joint is an excellent way of achieving coronal stability when both the ankle and subtalar joint are arthritic and mal-aligned (Figure 7a-c).

The “chisel test” is a useful intra-operative technique used to assess the stability and co-aptation of an arthrodesis after fixation. It is performed by inserting the chisel between the prepared, immobilised surfaces and attempting to separate the arthrodesis by twisting the chisel (Figure 8). If no separation is observed then further augmentation of the fixation with more screws is unnecessary.

Post-operative care

The arthrodesis is splinted until evidence of union occurs clinically and radiographically, with bony trabeculae crossing the fusion line on X rays. There is wide variation in clinical practice concerning postoperative immobilisation. Our own regimen for ankle arthrodesis is to allow protected weight-bearing in a cast after 4 weeks, provided the stability of the internal fixation is deemed acceptable. With arthroscopic ankle arthrodesis, earlier weight-bearing has been shown to be safe with no impact on union rates compared to those patients conventionally managed with longer periods of restricted weight-bearing.

Patients undergoing a subtalar arthrodesis are allowed to fully weight-bear after 2 weeks but are managed in a cast until radiographic union. Patients undergoing a Chopart or tarsometatarsal arthrodesis are managed non-weight-bearing for six weeks and then gradually allowed to increase weight-bearing in a cast until union, at an average of 12 weeks post-operatively. For first MTPJ and TMTJ fusions, patients tend to be managed with 6 to 8 weeks in a wedge shoe, which offloads the forefoot.

Complications

The most significant complication of any arthrodesis procedure is failure of union. Union rates for ankle arthrodesis have improved with modern surgical techniques from 80% at 6 months in Charnley’s era31 to as high as 94% with fusion times of 8.7 weeks using arthroscopic techniques.33

Non-union rates for triple arthrodesis as high as 10% have been reported with most non-union occurring at the talonavicular joint.49 Improvements in surgical techniques have yielded non-union rates as low as 4%40 without the use of supplementary bone graft, although the modern trend may also reflect fewer polio/neuromuscular cases. Table 2 summarises the principles of dealing with non-union of an attempted arthrodesis.

Deep infection rates are low (0.4% acute osteomyelitis) for ankle arthrodesis6 but are serious and require prolonged antibiotics and staged revision procedures often using bone graft and additional or alternative fixation methods. Below knee amputation rates of 0.3% have been reported.6

Mal-alignment producing gait abnormalities and painful metalwork requiring removal are less common complications which can often be remedied with footwear modification and minor surgery.

Conclusions

1 Arthrodesis is surgical fusion of a diseased joint for the purposes of pain relief and stability.
2 Consider the aetiology of joint abnormality, for example, uncorrected muscle imbalance will lead to deforming forces at adjacent joints.
3 Image-guided injections of local anaesthetic and contrast with provision of pain diary are helpful in confirming the

---

Table 2

<table>
<thead>
<tr>
<th>Treatment of non-union</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify biological causes</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Identify mechanical causes</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Identify infection</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Revision principles</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

---

Figure 8 The “Chisel test” is performed by inserting the blade of the chisel between the prepared and fixed joint surfaces and twisting the handle of the chisel. Further fixation with additional screws or plates is carried out if the surfaces can be separated by twisting the chisel handle.
source of pain, particularly when the adjacent joint is also degenerate.
4 Infection must be treated before attempting arthrodesis.
5 Smoking significantly increases the risk of non-union.
6 In the lower limb, deformity of proximal joints must be corrected before attempting fusion of more distal joints.
7 Respect for the soft tissue envelope is important.
8 Meticulous removal of all cartilage and perpendicular feathering of the subchondral bone provide better bone coaptation.
9 The arthrodesed joint must be placed in the optimum position of function.
10 Compression and rigid internal fixation promote bony union.

**REFERENCES**

12 Gaston MS, Simpson AHRW. Inhibition of fracture healing. *JBJS Br* 2007; 89: 1553—60.

19 Simon AM, Manigrasso MB, O’Connor JP. Cyclo-oxygenase 2 function is essential for bone fracture healing. *J Bone Miner Res* 2002; 17: 963—76.
40 Rosenfeld PF, Budgen SA, Saxby TS. Triple arthrodesis: is bone grafting necessary? The results in 100 consecutive cases. *JBJS Br* 2005; 87: 175—8.


