COMPRESSION ARTHRODESIS OF THE ANKLE AND SHOULDER

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Success with arthrodesis of the knee by compression (Charnley 1948) has now prompted the writer to describe his experiences with compression arthrodesis in the ankle and shoulder.

The application of compression to arthrodesis of the ankle and shoulder is more difficult than it is in the knee, and the writer does not wish to minimise the fact that the methods to be described perhaps demand a little more mechanical aptitude than is necessary in most orthopaedic procedures; on this account there may be some who will deplore any tendency to complicate operative procedures, in the belief that all the great operations of surgery are essentially simple. But practically all the classical operations of surgery have now been explored and, unless some revolutionary discovery is made which will put the control of osteogenesis in the surgeon's power, no great advance is likely to come from modifications of their detail.

For the same reason the elaboration of techniques which depend on bone grafting would also seem to have a restricted future, with the exception of a few instances, notably that of the Brittain operation in the hip, where the function of the graft seems to be in harmony with some natural trend in the architecture of the skeleton. Experience with the tibial graft during a quarter of a century, following the pioneer work of Albee in the shaping and fixing of this graft, has shown that the fate of cortical bone is unpredictable; these grafts sometimes fail to unite, sometimes fracture after union, sometimes fail to heal when fractured, and at all times are slow to become incorporated. In the same way cancellous bone has not shown any phenomenal ability to bridge the moving zone of a joint line either by itself or when its lack of rigidity has been supplemented by metallic internal fixation.

Until recently the idea has been prevalent that an autogenous bone-graft was "osteogenic"; but further experience has now made it obvious that the osteogenic powers of a bone graft are almost non-existent and that osteogenesis is a property only of the living bone of the host.

In compression arthrodesis direct union is achieved between the living bones forming the joint surfaces without the intervention of an inert graft. One of the effects of compression is to eliminate all shearing strains as well as preventing a gap between the cut bone surfaces. Under these conditions the healing of a compression arthrodesis is more aptly compared to the healing of an accurately coapted skin wound than to the union of a displaced fracture with the production of callus.

Technical researches in compression arthrodesis make it inevitable that operative procedures will become more complicated; but with surgeons specially trained to this at an early part of their career, and with the protection now afforded by antibiotics, elaborate techniques will offer no danger in the hands of the orthopaedic surgeon of the future, provided that sufficient attention is paid to the minutiae of the technique. For this reason the technical procedures have been described here in minute detail to emphasize the fact that the time is coming when no surgeon will embark on a new procedure with only a general knowledge of the principle and in the hope of himself improvising the details.

ARTHRODESIS OF THE ANKLE

In order to gain free access to the upper surface of the talus and the lower surface of the tibia, so as to shape them into plane surfaces which can be exactly coapted under compression, the approach advocated here may, at first sight, seem unnecessarily destructive; but before
it was finally decided that this method provided the best answer to the problem numerous trials were made on cadaveric as well as on living subjects. In this way experiments were made with the following exposures: 1) The anterior midline longitudinal approach. 2) The lateral approach, with resection of the lower end of the fibula. 3) The combined medial and lateral approaches, with resection of both malleoli, in the way described by Anderson (1945) as "concentric arthrodesis." But it was found that none of these approaches lent itself to the compression technique as easily as did a transverse anterior incision. Compression

Fig. 1
The problem of arthrodesis of the ankle in mal-position. By this technique it was possible to restore the alignment of the talus to the tibia. This necessitated the correction of 45 degrees of inversion of the talus.

Fig. 2
Position six months after operation. Early evidence of bone union.
can be applied, though with difficulty, through any of the standard incisions when the ankle is anatomically normal, but it is when the talus lies in malalignment, as after an unreduced Pott’s fracture or an epiphyseal injury disturbing growth, that the advantages of the transverse incision are appreciated (Figs. 1 and 2).

Numerous arguments can be advanced against the idea of a transverse incision, dividing as it does the extensor tendons, the anterior tibial vessels and nerves and the terminal branches of the musculo-cutaneous nerve; but in practice all have proved insignificant. Thus it can be argued: 1) that the suture of the divided tendons at the conclusion of the operation would be an exceedingly tedious and irksome procedure; 2) that division of the anterior tibial artery might be a serious loss to the circulation; 3) that anaesthesia of the toes, of a particularly disagreeable nature, may result: 4) that the emergence of the Steinman nail from the ends of the skin incision is undesirable because it offers a communication between the skin wound and the arthrodesis line. In practice all these fears seem to be without foundation; there is no permanent anaesthesia after the operation, and the circulation in the foot is unimpaired.

Technique

Skin incision—The incision crosses the front of the ankle from the tip of one malleolus to the other. It is important to start and finish exactly over the extreme tips of the malleoli; otherwise the distal compression pin, when the wound is sutured, will not emerge easily from the line of the incision. Instead of passing in a straight line across the ankle by the shortest distance between the two malleoli, it is important to make this incision curve distally at its mid-point, because the direct line between the malleoli is to be the line of section of the tendons and this precaution therefore avoids the tendon sutures lying directly under the skin incision (Fig. 3). The proximal edge of the skin wound is dissected up as a flap until the direct line between the malleoli is reached.

Section of the tendons—The tendons to be divided fall into three groups: 1) tibialis anterior, 2) extensor hallucis longus and 3) all parts of the extensor communis digitorum and the peroneus tertius considered as one unit. The intended line of section is identified and thread sutures of the Bunnell type are passed before the tendons are cut (Fig. 4). The passage of the sutures can be done very quickly because there is no need for any very meticulous approximation of the extensor tendons at this level. The group of common extensor tendons is treated as a single tendon and is transfixied by one suture. It is important to discard the distal part of peroneus tertius as this will obstruct the action of the combined tendon on the toes.

Opening the joint—The incision is deepened in the direct line between the malleoli and after ligation of the divided anterior tibial vessels the capsule of the joint is opened transversely from one malleolus to the other.

Defining the malleoli—The proximal flap of the joint capsule is now elevated from the front of the tibia for about half an inch by sharp dissection. The subperiosteal exposure is carried laterally and medially until both malleoli are exposed and until the posterior edges of both malleoli are within reach. This is the crucial step in the operation; unless the posterior margins of the malleoli are accessible the subsequent steps will be obscured and there will be danger to the soft parts when the saw is used.

Sawing the talus—With a sandbag under the calf and the foot left unsupported posteriorly, the assistant now holds the foot so that it is in the amount of plantar-flexion which it is hoped to perpetuate in the final arthrodesis; this should be enough to allow for a shoe heel. An ordinary amputation saw is now started across the front of the ankle joint just where the talus emerges from below the anterior margin of the tibia (Fig. 5). The malleoli and the talus are sawn through, with the saw held exactly at right angles to the axis of the tibia. It is dangerous to saw completely through the malleoli lest the tendons lying behind them be
Figure 3—Continuous line indicates the skin incision. Dotted line indicates the intended line of tendon section. Figure 4—Bunnell sutures in position before section of the tendons.

Figure 5—Line of first saw cut. To show this the foot has been slightly plantar-flexed but in the correct position the saw cut touches the talus just at its point of emergence below the anterior margin of the tibia. Figure 6—Showing the appearance after removal of the lower end of the tibia. Figure 7—Pins inserted and compression applied. Note the hair-line fit of the opposed surfaces.
damaged, and the saw should therefore be stopped within a quarter of an inch of their posterior surfaces. Because the medial malleolus lies in a more anterior plane than the lateral malleolus care must be taken not to deepen the saw cut as much on the inner side as on the outer. The foot is now forcibly plantar-flexed and the ankle joint will open like a book by the fracturing of the unsawn portions of the malleoli. A flat rectangular cut surface will now be seen on the upper aspect of the talus. 

_Sawing the lower end of the tibia_—In the plantar-flexed position of the foot, the lower end of the tibia is completely exposed and a slice about a quarter of an inch thick, including both malleoli, must now be carefully sawn off. Care must be exercised when the posterior cortex of the tibia is being reached because of the important structures lying behind it. The slice should be cracked off before the posterior cortex is cut and the projecting bone left behind should be nibbled away with bone forceps. The foot is now brought up to a right angle to test the apposition of the cut bone surfaces (Fig. 6). If possible the distal fragments of the malleolus should be preserved as they provide the natural pulleys round which the tibialis posterior and peroneal tendons pass. 

_Insertion of the distal nail_—The distal Steinman nail, through the talus, should be passed first. It is passed through the open wound without any attempt to pierce adjacent skin. It should be passed slightly anterior to the axis of the talus because the compression force will hold the anterior edges of the arthrodesis closed while the pull of the Achilles tendon will keep the posterior edges closed. 

It is important to see that the nail is clear of the subtalar joint, and that it is at right angles to the axis of the tibia as seen in the front view. (Any rotary error is unimportant as it can be corrected later by the range of adjustment provided in the clamps.) 

_Passing the proximal nail_—The compression clamps are now attached to the distal nail so as to guide the second nail in parallel through the lower end of the tibia. It is important to use nails which have drill points, because the simple trocar point will often split a tibia if driven in with a mallet. 

_Closure_—The screw clamps are now tightened until the nails are slightly bent under the compression force and the firmness of the arthrodesis is tested by attempts to move the talus on the tibia (Fig. 7). If any error in rotation is detected at this stage it can be adjusted by releasing the compression, twisting the foot into correct relation with the tibia and then retightening the clamps. The tendons are now approximated by tying the appropriate sutures and the skin is closed in one layer. Dressings are applied, a thick layer of wool to cover everything, and a pressure bandage is applied before the tourniquet is released. A light plaster case is advisable for comfort and permanence of the dressings though it is not necessary for fixation. 

_Post-operative management_—The dressings are left untouched for four weeks; during this time the patient is confined to a bed or couch, and is not allowed to hold the ankle in a dependent position. After four weeks the pins are removed and a walking plaster is applied for another four weeks. At the end of this time, that is, eight weeks after operation, plaster is discarded and the patient allowed to start rehabilitation, and he should be fit for light work three months from the time of the operation. 

_Results_ 

The writer has now performed this operation nineteen times in three years. The results have been most encouraging even though the technique was subject to many changes in the first ten cases. The end-results were excellent in all nineteen cases except one, and in this case mid-tarsal arthritis was later found to have existed before the operation and a subtalar and mid-tarsal fusion had to be carried out later. 

In four cases bony fusion failed to take place. The functional result of these four fibrous unions was, however, practically equivalent to bony fusion; the reason for this seems
to be that the closely applied flat surfaces of this fusion cannot work loose to form a pseudarthrosis. Two of the four failures to get bone fusion occurred in cases where the tibia had been split by the proximal pin and where, therefore, the compression force was inadequate.

In the remaining two cases of fibrous union the talus was not accurately fitted to the tibia and the talus was never quite immobile against the tibia—there being in both cases a tendency for the line of the arthrodesis to gape in front. Thus all four failures to get bony union could be traced to technical errors.
From these experiences with compression arthrodesis in the ankle it would appear that this joint does not possess the same natural potential for bony union as exists in the soft cancellous bone of the knee. The narrow latitude for technical error probably follows from the fact that the cut surface of the talus often shows it to be a remarkably dense and bloodless bone; in this respect it stands in marked contrast to the cut surface of the lower end of the tibia, and though even this is very much harder than is the cancellous bone at the upper end of the tibia, it always shows red marrow and a cancellous structure. In some cases of osteoarthritis of the ankle the cut surface of the talus suggests that it might even be ischaemic.

In the radiological examination of these ankles after operation, it takes at least six months for trabeculation to be seen crossing the line of the fusion. When fibrous union has taken place the line of bone apposition becomes sclerosed and this fact is useful in predicting osseous union because, so long as there is no sclerosis at six months, it can be inferred that osseous union is already present, and that trabecular continuity will eventually follow (Figs. 8 and 9).

**ARTHRODESIS OF THE SHOULDER**

**Principle**—In arthrodesis of the shoulder the discrepancy between the small size of the glenoid fossa and the large size of the humeral head makes stable apposition of the two, under a compression force, a precarious and uncertain feat. In the method to be described it has been found possible to secure stability under compression, if the head of the humerus is compressed against the scapula in a subluxated position.

If the head of the humerus is displaced slightly upwards and forwards, it will take up a position in which it lies snugly between three bony points: the acromion above, the coracoid in front, and the upper part of the glenoid below. These three bony structures form, as it were, a hollow pyramid into which the head of the humerus can be driven and where it will automatically find three points of bone contact and considerable stability. In practice, the contact of bare bone against the head of the humerus is possibly only at the under-surface of the acromion and the upper part of the glenoid, because the coracoid process cannot be easily denuded of the soft tissues covering it. Despite this, the coracoid still offers an important anterior buttress and prevents the head of the humerus from slipping forwards and thereby losing contact with the two areas on the glenoid and acromion.

In the shoulder joint the configuration of the parts does not lend itself to an ideal design for compression arthrodesis—that is, one in which the surfaces of cancellous bone are accurately coapted over an extensive area, as exemplified in the knee and ankle. This handicap can be overcome—and with success, as results have shown—by producing bony union under compression at two separate points, even though these points each possess only a small area of contact. The essential feature seems to be that these two points are at widely separated places on the humeral head and together they thus achieve, in some measure, one of the mechanical effects of contact over a large area, that is, a wide base. The humerus thus becomes adherent to the scapula in a way which is able to resist the strains of adduction and of rotation, without a tendency for the arthrodesis to work loose and form a pseudarthrosis as happens when a single point of contact coincides with the centre of movement. In this operation the only axis of movement which is unstable is that which passes simultaneously through both points of contact; this axis corresponds roughly with the movement of flexion and extension. It is worth emphasizing that in this arthrodesis the movements of abduction-adduction and of rotation are both strongly resisted; this is important because these are the directions in which the shoulder is under the greatest strain when the patient lifts a weight in front of the body with the elbow at right angles and the forearm horizontal.

By a recent and easily performed addition to the compression technique, it has been found possible to strengthen the end-result even further by combining it with the Putti method of arthrodesis. In the Putti arthrodesis the greater tuberosity is split away from the humeral head so as to allow the tip of the acromion to be inserted into the cleft. This ancillary
procedure does not participate in the rapid fusion which is shared by the two other points of bone contact, because it is not under compression, but as it increases the area of contact and as it is so easily combined with the compression technique, there seems every reason for retaining it in the routine (Fig. 10).

**Technique**

*Position* Before operation a plaster jacket is applied so that an arm plaster applied at the end of the operation can be easily converted into a shoulder spica. The patient is operated on in the sitting position in a dental chair (Abbott et al., 1949).

*Skin incision* The "sabre cut" incision is used passing from front to back over the outer edge of the acromion.

*Exposure* The deltoid is detached from the acromion by sharp dissection so as to leave the raw bone of the outer part of the acromion exposed. The capsule of the shoulder joint is incised and extended as far as possible down the anterior and posterior aspects until the head of the humerus can be retracted downwards and outwards to reveal the depths of the glenoid fossa. 

*Preparation of the bony surfaces*—The glenoid fossa is denuded of cartilage with a wide gouge after the glenoid labrum has been dissected away. The cancellous bone is opened up with an osteotome by cross-cuts into the surface. The under-surface of the acromion is exposed by dissecting off the remains of the subacromial bursa and its cancellous substance is exposed with a wide gouge. The head of the humerus is now denuded of articular cartilage and the way in which it will gain apposition against the surfaces to which it is to be fused is now tested. To do this the assistant holds the arm and forearm in the position of arthrodesis while the surgeon explores the points of contact with his finger.

It is at this point that the possibility of increasing the strength of the final fusion by incorporating the Putti fusion can be assessed. If the case is favourable for this added detail, it will be found that, in the arthrodesing position, the summit of the great tuberosity abuts against the outer edge of the acromion and prevents the head of the humerus riding upwards for its denuded surface to make firm contact with the deep surface of the acromion. If this is the case the great tuberosity must be split outwards with an osteotome and on again trying the apposition it will be found that the head now reaches snugly under the acromion and in addition that the acromion is received into the upper end of the cleft between the head of the humerus and the detached tuberosity.
Insertion of the compression nails—The proximal nail is inserted first. Because it is the crux of the operation the details of this manoeuvre must be studied closely. In a thickset patient a ten-inch nail is necessary. The nail is passed through the outer inch of the clavicle and directed backwards, outwards and downwards. It traverses the supraspinous fossa and pierces the thick part of the spinous process of the scapula just where it springs out of the blade of the scapula. It will be seen that it is impossible for this nail to wound any of the important structures in the axilla as it is separated from them by the body of the scapula.
This rather complicated spatial direction of the nail, involving as it does three different planes, is not difficult to estimate if it is checked by its relation to the position of the arm when the latter is held in the arthrodesing position (Figs. 11 to 13). For this purpose it is recommended that the arm should be held: 1) in 45 degrees of abduction; 2) advanced 45 degrees in front of the coronal plane; and 3) with the humerus externally rotated so that the forearm is inclined about 45 degrees above the horizontal when the elbow is held at a right angle. In this position it will be found that the proximal nail must be passed at right angles to the axis of the humerus and roughly parallel to the axis of the forearm.

The second nail is now passed through the upper end of the humerus. To do this the compression clamps are attached to the first nail so that it will automatically guide the second nail in a parallel direction. It is important that this nail should be provided with a drill point because the bone of the shaft of the humerus is very dense and it may split if the mallet has to be used on a nail with only a trocar point. The only direction which must be carefully watched in the insertion of the second nail is its inclination to the horizontal. The nail should enter slightly higher in front than its point of exit behind. It should pass as near to the surgical neck of the humerus as possible so as to diminish as far as possible the remote chance of its wounding the radial nerve, which at this level lies medially, in the neurovascular bundle, though at a safe distance from the nail.
Tightening the clamps—On tightening the clamps the arthrodesing position should be checked. If not quite satisfactory, the degree of abduction and rotation can be altered by releasing the clamps and moving the humerus in the desired direction. The only angle which cannot be reset at this stage is that which controls the amount which the elbow is advanced in front of the coronal plane; this is governed by the sitting of the proximal nail and if it is seriously wrong this nail will have to be reinserted. This proximal nail must always lie transversely to the axis of the humerus when the patient is viewed from above (Fig. 11); if this detail is not observed the clamps will not compress the humeral head in the right direction.

In the four consecutive cases in which this operation has so far been used, the sitting of the nails has offered no difficulty and the rigidity of the fixation when the clamps are screwed up has far exceeded what one might have expected from a superficial examination of the anatomy of the parts.

Fig. 18
Compression arthrodesis of the shoulder for brachial plexus palsy. Eight weeks and two days after operation.

Fig. 19
Radiograph of another patient seven months after operation. Osseous union has not taken place but clinically the shoulder is firmly fused and patient is at work as a fitter. Note the "Putti" modification described in text.

Application of plaster—The forearm and arm are now incorporated in a plaster which is then connected to the previously applied body case, thus making a shoulder spica.

Post-operative management—The plaster is retained for four weeks, the patient being preferably kept in bed while the nails are in position. At the end of four weeks the nails are removed and the shoulder spica is retained for a further four weeks. At the end of this time all external fixation has been abolished and unsupported use of the shoulder has been permitted, but it is probable that in future a considerably longer period in plaster would be wiser.

Results

The rapidity with which the patients have returned to normal activity after this operation has been so striking that the writer feels justified in making this report though it only concerns four cases; but arthrodesis of the shoulder is not a common operation and it is likely that it would take several years before this series could be significantly increased.
Three of the patients were operated on for paralysis of the shoulder following brachial plexus injuries and because of the mobility of the shoulder joint this is a condition in which, in the adult, it is notoriously difficult to obtain successful arthrodesis at the first attempt. The fourth case concerned a tuberculous shoulder and though it appears to have been successful it is probable that in this disease para-articular methods are to be preferred.

In all four cases the patients were able to elevate their arms actively and without hesitation four weeks after the operation when the compression pins were removed. Ten weeks after the operation they were able to sustain a weight of five pounds with the elbow straight and abducted from the side (Figs. 14 to 18). In one of the cases of brachial plexus injury there is a suspicion that bony union has failed to occur but the functional result is so good that this point seems immaterial. This patient returned to his ordinary work as a draughtsman three months after the operation and has now been back at work without interruption over six months. This illustrates the importance of the "wide base" by which the humerus is attached to the scapula and which thereby produces a sort of bone block should bony fusion fail to occur.

The longest post-operative period is now ten months and it is interesting in this case to observe that though there can be no doubt on clinical examination that bony fusion has taken place, the radiological evidence of bony union is still not convincing (Fig. 19). This tardy development of trabecular continuity is perhaps not unexpected in the shoulder joint because the forces which it transmits, unlike the weight-bearing joints of the lower extremity, are less in amount and variable in direction.

REFERENCES