POSITIVE PRESSURE IN ARTHRODESIS OF THE KNEE JOINT

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Albert Key (1932) described a method of arthrodesis of the tuberculous knee joint in which the cut bone surfaces were compressed against each other after excision of the joint. He had previously been impressed with the difficulty of securing bone union in this condition, but in five cases treated with compression he reported that union was achieved "in an unusually short period of time." His claims were restrained, and in 1937 he described another technique, using a tibial graft as a central bone peg without compression force. In England the technique of positive compression is almost unknown, nor is it widely practised in the United States. In a recent personal communication Key still shows guarded enthusiasm; he goes no further than to state that the method is good. From experience of the use of compression I believe that this method is superior to any other; moreover, it has revealed side-issues which may have an important bearing on osseous union.

TECHNIQUE OF POSITIVE PRESSURE ARTHRODESIS

Under a tourniquet the skin is incised in the midline, and the patella is excised. The knee is flexed and the bone ends are sawn in such a way as to give flat surfaces of cancellous bone which, when opposed, leave the limb almost but not quite straight. The bone surfaces are held together by an assistant and the edges of the skin wound are temporarily approximated by one or two volsella. This enables two parallel Steinmann nails to be passed, one through the upper end of the tibia and one through the lower end of the femur, without tension in the skin surrounding the nails when the wound is finally sutured (Fig. 1). The nails are four millimetres in diameter and nine or ten inches long. The projecting ends are connected by special screw-clamps and the wing-nuts are tightened until the nails bow under the compression force (Fig. 2).

Some points concerning the screw-clamp are worthy of note. The first Steinmann nail is passed carefully through the head of the tibia exactly at right angles to the long axis of the bone, taking care to avoid the external popliteal nerve. The passage of the second nail, parallel to the first, is secured automatically by using as a guide the screw-clamp attached to the first nail (Fig. 1). The design of this clamp allows for the correction of rotation deformity. When the clamps have been tightened, rotation of the foot in relation to the axis of the femur can be corrected by slackening the wing-nuts. Since the metal blocks can rotate, the new position of rotation is held when the wing-nuts are tightened once more.

As a rule the knee is fairly rigid under this compression, and the fit of the cut surfaces is "hair-line" (Fig. 3). Although quite rigid to forces causing lateral angulation, the mechanical system is potentially unstable to flexion and extension forces. For this reason external fixation is required after the final compression bandage has been applied. The best external splint is a Thomas' splint and here I differ from Key, who incorporates the pins in a plaster cast. I believe that plaster provides less protection than a Thomas' splint. Moreover the patient derives greater comfort if a Thomas' splint is used in this manner: a ring is chosen which is a neat fit for the groin; to get it past the projecting Steinmann nails the ring is cut just in front of the outer side bar with a hacksaw (Fig. 4); the Steinmann nails rest on the side bars of the Thomas splint, provided that the knee is arthrodesed in no more than 5 degrees of flexion; with the nails resting on the splint all pressure is removed from the popliteal fossa and the patient is surprisingly comfortable; slings are applied under the leg and ankle and a foot piece is provided to support the foot. Radiographs of a typical case are shown in Fig. 5.
The joint has been excised and the surfaces are opposed. The first nail is at right-angles to the tibia. The second is being guided parallel to the first by the aid of the clamp. Note the stockinette and mastisol, and the temporary closure of the wound while the nails are being inserted.

Fig. 2 illustrates the arrangement of nails and clamps on the femur and tibia. Note the co-aptation.
Fig. 3 shows the "hair-line" fit of the joint surfaces seen at operation.

A mechanical defect which has happened on three occasions has been spontaneous fracture of the four-millimetre Steinmann nails, due to slight erosion when the stainless steel is not of the highest quality. This annoying accident can be avoided by softening the nails by heating to red heat, cooling slowly, and repolishing—a procedure which can be done in any hospital engineering shop.
The ring is split at A to allow the Steinmann nails to pass. The nails rest on the side bars thus avoiding compression of the under-surface of the knee.

Fig. 4

Radiographs after operation showing the close fit of the cut surfaces.

EXPERIENCE WITH THE METHOD

Fifteen consecutive arthrodeses have now been performed with completely satisfactory results; six were for old tuberculous disease of the knee joint with fibrous ankylosis in bad position, and nine for osteoarthritis. In the first three cases compression was maintained for six weeks before the joint was tested for union: all three showed firm clinical union. In one case the observation was made, though it did not arouse special interest at the time, that one of the Steinmann nails had fractured in two places despite the fact that there was solid union. Since it is unlikely that a nail would fracture after union had occurred, the bones were probably united some time before the end of six weeks. The fourth case was the one which revealed by accident that osseous union was taking place with unusual rapidity. On the ninth post-operative day, the patient had sudden pain in the knee and thought that something had broken." Radiographs showed that one of the Steinmann nails had snapped. It
Case 4. The bone ends were united clinically when tested under anaesthesia on the twelfth post-operative day.

Case 4. Bone trabeculation crossing the line of arthrodesis after six months.

was decided to substitute a new nail at the next convenient operating session three days later. On the twelfth post-operative day the patient was anaesthetised and the dressings were taken down; to the astonishment of everyone in the theatre the knee was clinically firm (Fig. 6). Compression was therefore discarded and plaster was applied; bony union took place and in eight weeks the patient was walking without plaster and without discomfort.

After this surprising experience, I brought to the theatre two other patients who had been operated on fourteen days and twenty-one days before; in both, the arthrodesis was found to be clinically firm. The nails were extracted, plaster casts were applied, and weight-bearing was begun at once. The next case to be operated on (Case 7) was deliberately examined.
fourteen days after operation; clinical union was again present; the nails were extracted and a plaster cast was applied. All these cases progressed uneventfully to sound bone union as shown in radiographs six months later (Fig. 7). Although there could be no doubt from clinical tests that union by bone was present at twelve weeks, the radiographs naturally did not show evidence of it at so early a stage.

It seemed important next to establish the optimal duration for compression. Although it was apparent that clinical union could be present as early as twelve or fourteen days, this could in fact be nothing more than union by osteoid tissue, and no good purpose could be served by adopting so short a period of compression in every case. It was decided therefore that the routine should be four weeks’ compression on a Thomas splint, four weeks’ ambulation in a plaster cast, and four weeks’ rehabilitation without splintage. With this sequence reliable union was present in eight weeks and the patient was fit for full employment twelve weeks after operation.

DISCUSSION

Comparison with other methods of arthrodesis—The feature of this technique, which is in most clear contrast with other methods, is the accuracy of timing which is possible. It is known precisely when bone union will occur. With other methods the time of union seems to be quite indefinite; after various changes of plaster, slight movement at the excised joint slowly becomes less and less, thus giving the impression that union takes place after preliminary fibrous ankylosis. In fact one cannot help suspecting that the final state is sometimes no more than a firm fibrous ankylosis. Although this result may eventually be satisfactory, it means that full painless function is delayed for many weeks. In my experience arthrodesis of the knee joint by other methods takes an average time of six months and there is an appreciable incidence of failure. On the other hand, when compression is used in the manner described it may be predicted with certainty that the clamps can be removed after four weeks with the knee showing clinical union, that union by bone will be present by eight weeks as indicated by the absence of pain on straining the ankylosis, and that the patient will be fit for re-employment by the end of the third month. These claims may sound excessive, but unless they are stated in this manner the full significance of the method may not be appreciated and it might again be overlooked, as it was when first introduced some sixteen years ago.

Rationale of the method—In arthrodesis by compression, union takes place between two perfectly co-apted surfaces of cancellous bone with intact circulation. Union of the arthrodesis is thus comparable to that of a fracture without displacement under ideal conditions. Both the cut bone surfaces share actively in osteogenesis. By contrast, methods of arthrodesis which depend upon a bone graft seem illogical. Though it is customary to state that a bone graft can be used to combine the functions of internal fixation and osteogenic stimulation, in actual fact a graft provides very imperfect fixation, and cortical bone has less power of osteogenesis than the bones which it joins together. When bone grafts are used, whether from the tibia, the tibial tubercle, or the patella, they probably act as no more than “passengers” for three or four months until they have secured a blood supply. It is unlikely therefore that grafts are capable of mechanical function in less than four or five months.

These adverse criticisms of the bone graft in intra-articular arthrodesis might be used in planning the ideal arthrodesis. The principle of using living bone to secure early union is of course applicable only where the bones forming the joint lend themselves to this purpose. When anatomical conditions make it impossible to hold the living bone-ends firmly together, a bone graft may be the only choice; but it should be regarded as a necessity rather than as a method of election. This axiom applies only to intra-articular arthrodesis; it conflicts in
no way with the use of bone grafts in extra-articular arthrodesis because here the method is chosen to avoid disturbing local pathology inside the joint.

In its particular application to the knee joint, compression arthrodesis offers two points of detail which are worthy of remark. In the first place it is quite unnecessary to use a hip spica after operation; a Thomas' splint is enough to support the system in its weakest direction, namely the plane of flexion and extension. Secondly, it is free from the danger of fracture at the donor site of a tibial graft. This is a real hazard, because there is undue strain on the tibia when the natural shock absorber of a mobile knee joint has been removed.

The influence of compression on bone union—Few observations have been recorded on the effects of bone compression on fracture union, though the general impression exists that firm bone contact is beneficial. This impression may perhaps be derived more from the known ill-effects of distraction than from direct observation on the effects of compression. Against the value of compression is the common knowledge that heavy pressure may stimulate osteolysis rather than osteogenesis. Moreover, many fractures, with complete lack of contact of the fragments, unite by profuse periosteal callus. In this method of compression-arthrodesis, three physical factors are simultaneously in action: (a) apposition of bone surfaces; (b) fixation of the fragments; (c) compression.

Apposition of bone surfaces—The less accurate the apposition of cut bone surfaces the more space there is in which fibrous tissue can develop as an interposing membrane. In compression-arthrodesis, exactness of co-aptoation can be very perfect indeed; this in itself could be regarded as an important factor in facilitating union, even in the absence of compression force. On the other hand the most instructive case in the series (Case 4) was that in which spontaneous fracture of a nail demonstrated accidentally that clinical union was present as early as the twelfth day; and this case had the least perfect co-aptoation of any (Fig. 8). At the end of the operation on this patient the knee was found to be flexed nearly 20 degrees, and instead of removing a further bone wedge I decided to let the arthrodesis gape posteriorly. The knee was forced straight by another 10 degrees and fixed in the Thomas' splint by appropriate slings. This manoeuvre was possible because the nails hold the knee with only moderate rigidity against angulation in the sagittal plane. The effect was to increase pressure between the anterior parts of the bone ends and to put an increased strain on the apparatus; this may have contributed to the fracture of one of the nails. This experience suggests that perfect co-aptoation of the bone surfaces, though an obvious mechanical advantage, is not the main influence in producing very early clinical union.

Fixation of the fragments—The isolated effect of fixation on the healing of fractures is another fundamental matter on which there have been few direct observations. Many feel that absolute fixation inhibits the production of periosteal callus, as may often be seen after the treatment of fractures by Lane's plates; and conversely that slight movement, as in the treatment of fractures of the femoral shaft, increases the development of periosteal callus. In compression-arthrodesis, for technical reasons, the degree of fixation varies slightly from case to case. Fixation is of a high order if the pins are accurately centred and the clamp is
well designed. At other times a distinct range of movement may be possible, particularly if improvised compression apparatus such as a cord, bandage, or rubber tube, is used instead of special clamps. Close scrutiny reveals perceptible flexion movement, even in the firmer of cases, if strain is applied.

In assessing the contribution made by fixation to early clinical union it is impossible to eliminate the two other factors, namely "fit" and compression, because a poor "fit" with heavy compression gives considerable rigidity, as does a good "fit" with moderate compression. My observations convince me that absolute fixation is rare and that it cannot be the main reason for such early clinical union.

**Hypothesis**—A theoretical point of interest now emerges. If one considers an arthrodesis fixed by any method other than compression, slight movement progressively loosens the fixation, be it internal or external, until a certain excursion is present. If we visualise this movement between opposing trabeculae, we see that it affects all trabeculae at all parts of the cut bone surfaces, and that the movement can be of any type varying from longitudinal separation to lateral shear. In general, unless a continuous force is present tending to push the cut surfaces towards each other, movement tends to separate them until fibrous tissue grows between. Under these conditions the opposing fringes of osteoid tissue, thrown out by the cut trabeculae, cannot blend. There is also histological evidence that excessive movement predisposes to the formation of cartilage at a fractured line instead of woven bone.

Contrast this with what must happen in compression-arthrodesis. Angulating strains cause the line of excision to gape, but as soon as the strains are removed the fracture line closes. Such angular movement can be repeated continuously but **under the force of compression the trabeculae which are in contact at the hinge are relatively fixed** (Fig. 9). At the fixed point of the hinge the osteoid fringes can blend; some distance away, the movement may be too great and this may be impossible. It is reasonable to expect that the pre-osseous substance or osteoid tissue has the flexibility of connective tissue such as cartilage. Thus bending movement may be possible without loss of continuity. Once a continuous bridge of osteoid is established in the absence of shearing movements it may ossify rapidly even though continuously subject to slight bending movements. The process of ossification can then extend laterally even if exact co-aptation of the cut bone surfaces is not present.

Further consideration of Case 4 suggests another interesting possibility bearing on the nature of ossification. It is held by most histologists that the ultimate conversion of osteoid to bone takes place by the deposition of bone salts, and that it is largely a chemical reaction. Theories advanced from time to time suggest that this chemical phase is related to physical phenomena such as a changing pH value in tissue fluids at the fracture site. In Case 4 the nail fractured on the ninth day, causing sudden pain which necessitated a sedative. It may be presumed from the
sudden pain that the fracture was still capable of slight movement. Between the ninth and twelfth post-operative days, however, clinical union took place and fusion became firm. After fracture of the nail, the compression force did not disappear entirely because one-half remained in the bone and was still held by the clamps; but the compression force must have been diminished. I am tempted to suggest that an "osteoid bridgehead" had become established by the ninth day under the influence of compression, and that when the nail fractured, the "bridgehead" remained intact by virtue of its elasticity, and ossified during the next three days.

The action of compression—The most obvious effect of compression is the simple impaction of cancellous surfaces until trabeculae almost interdigitate. The force actually used has been measured by a simple device in which the clamps are screwed against a grip dynamometer until the nails show a curvature equivalent to that seen in the radiograph. No less than sixty to eighty pounds of pressure were registered by this method (Fig. 11). Whether such pressure has special virtue in producing early union must remain a subject for speculation; we know only that it assists mechanical fixation and thus aids union. I feel, however, that there is probably some real virtue in high compression force and suggest two possible mechanisms.

In the first place, high compression forces act only on the "high spots" between opposed bone surfaces. At these points of very high pressure osteoclasis may be stimulated, with consequent absorption of the "high spots," thus allowing the rest of the bone surfaces to come into intimate contact. Pari passu with the local removal of bone by osteoclasis the bone substance thus made available may be redeposited by osteoblasts a few millimetres away at points where there is no pressure (Fig. 12). This suggestion of local transference of bone substance by cellular activity seems more acceptable than many of the chemical theories of ossification which, in the past, were accepted widely.

In the second place, compression-arthrodesis gives rise to dynamic forces which stimulate cellular activity. If the process of union after plating a fracture is visualised, one cannot imagine any stimulus for union if there is absolute fixation, and if the plate transmits all strains. By contrast, in compression-arthrodesis the compression force may evoke in sensitive osteoblasts a response to the stimulus of function. Under the influence of compression the dynamic process of union contrasts markedly with the slow progress which is observed when bones lie passively splinted during early weeks.
SUMMARY

1. The technique of compression-arthrodesis of the knee joint is described.

2. Fifteen consecutive cases are reported in which clinical union was detected at the first inspection from twelve days to six weeks after operation. By this method the total period of disability is reduced to three months.

3. Three mechanical factors which might be responsible for this very early clinical union are examined: compression is believed to be the main factor, although fixation is also important.

4. A fallacy is exposed in the use of bone grafts for arthrodesis of the knee; the graft is less osteogenic than the substance of the bones which form the joint, and it provides inefficient internal fixation.

5. A theory is suggested that compression, even in the presence of slight movement, acts by producing a fixed 'hinge' without shearing movement; at this point a bridgehead of flexible osteoid tissue is established in which ossification inevitably takes place despite slight bending movement.

6. A second theory is suggested that high compression forces stimulate early union by liberating bone salts at points of maximum pressure through the action of osteoclasts, and that the local excess of bone salts is redeposited under cellular activity within a range of a few millimetres where there is no pressure.

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REFERENCES