CHAPTER TWO

THE MECHANICS OF CONSERVATIVE TREATMENT

DESCRIPTIONS of operative technique are to be found in most modern textbooks of fracture treatment, and often in great detail; by comparison the details of manipulative technique are usually indicated in only the vaguest of general outlines. This is not surprising if manipulative treatment is regarded as an art rather than as a science, because an art is essentially something which defies description and is therefore to be learned only by practice and apprenticeship.

In this chapter an attempt is made to reveal the scientific basis of manipulative methods. Unless the teacher of manipulative technique is able to create a *mental picture* of a manipulation, the student may waste months of experience and much valuable material before he eventually discovers what others may long have known but have failed to communicate. These mental pictures should not be decried by an experienced operator if the interpretations here offered seem to him open to question; the student must adapt these pictures to suit impressions gained from his own practical experience and they will thus form a useful basis on which to build.

The Soft Tissues associated with a Fracture

When the student inspects the radiograph of a badly displaced fracture, such as that of a Pott's fracture of the ankle, he may well despair at the thought of manipulative reduction. Manual reduction of a case such as that illustrated in Fig. 38 would appear not unlike the assembling of a jig-saw puzzle in the dark. The solution of the difficulty emerges, and the precision of reduction is realised, only when the supreme importance of the soft tissues is appreciated. The importance of the soft tissues is often forgotten because these are not seen in an X-ray. Bone fragments are to be regarded as of secondary importance to the damaged and undamaged soft parts; *the mere fracture of a bone does not determine the displacement of its fragments.* When displacement is present certain soft parts have been ruptured and conversely certain other soft parts usually remain intact; it is the latter which give the clue to the reduction. If the undamaged soft parts are brought into normal relationship, the bone fragments will return to their normal positions. The action of soft tissues in guiding displaced fragments back to their normal position is demonstrated in the fractured femur illustrated in Fig. 39.

FIG. 38

Anatomical reduction by closed manipulation. Without knowledge of the role of the intact soft tissues, the reduction of this injury might appear a forlorn hope.

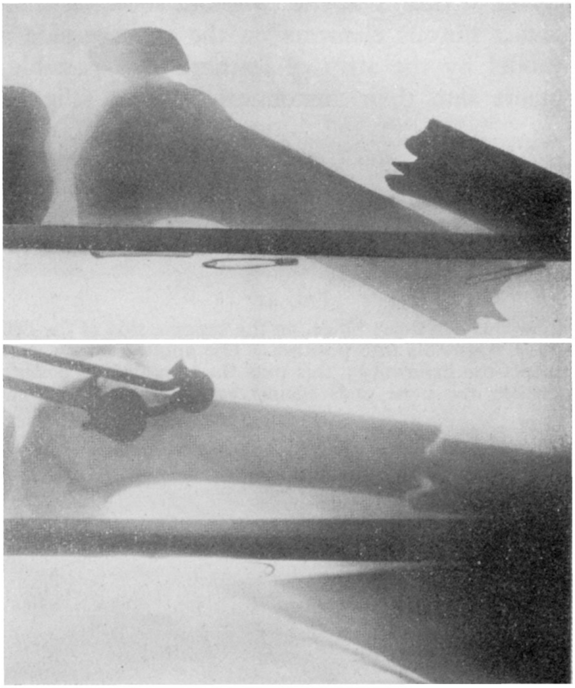


FIG. 39

Reduction of overriding fracture of the femur produced by a single movement of traction under general anæsthesia. This alignment is produced through the mediation of the intact soft parts.

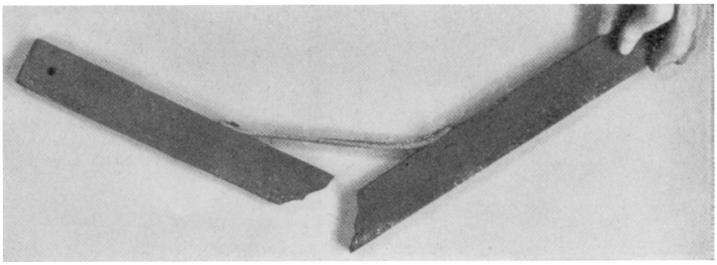


FIG. 40

Model, consisting of two pieces of wood connected by a strip of leather, represents the fragments of a fractured long bone which are connected on the concave side of the deformity by intact periosteum and fibrous structures. If the existence of this soft-tissue hinge is forgotten, because it is radio-translucent, the apposing of the fragments by blind manipulation would be a matter of pure chance.

In the model illustrated in Fig. 40 it might be thought impossible to expect an anatomical reduction of this ' fracture ' without some assistance from the eye; but by using the intact fibrous elements on the concave side of the ' fracture ' (indicated in the model by the strip of leather) it is possible, even blindfold, to guide the fragments into their anatomical position (Fig. 41). This model represents **the mechanism of the soft tissue ' hinge ' common to the majority of fractures.** A similar model illustrating the reduction of fractures such as the Colles', Pott's, and supracondylar fractures of humerus, is illustrated

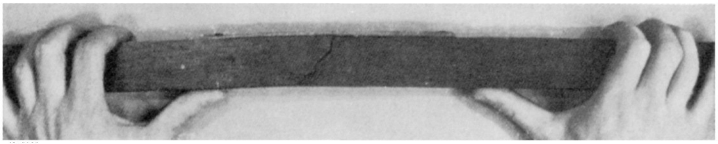
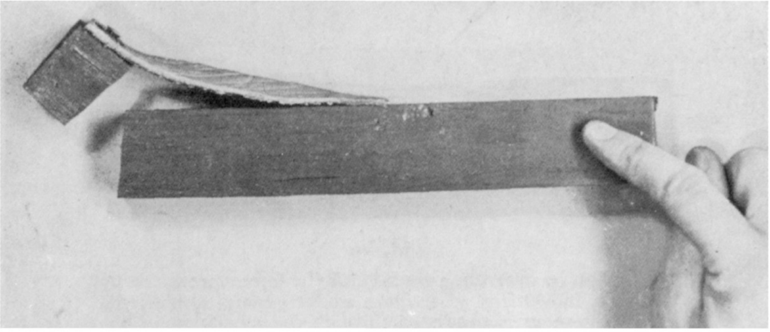
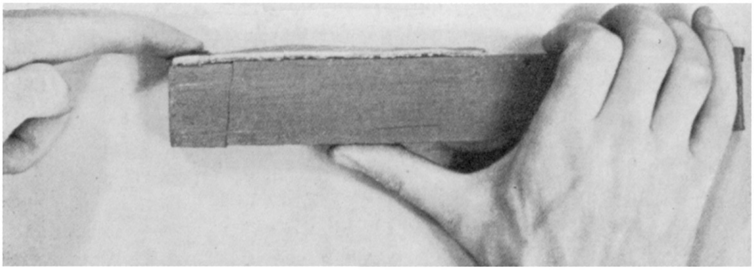


FIG. 41

Showing how the soft-tissue hinge, on the concave side of the deformity, can guide the fragments into position. The applied forces are tending to over-correct the deformity; this puts the tissue hinge under tension and compresses the bone ends against each other. The three-point system.



A



B

FIG. 42

Model illustrating the soft-tissue hinge in fractures at the extremities of long bones, *e.g.*, Colles', Pott's, and supracondylar fractures of the humerus.

in Fig. 42, A and B. These models show why it is almost impossible to over-reduce these fractures; because *the intact fibrous tissues on the concave side of the original deformity prevent over-reduction unless the force used is so great that it ruptures them* (Fig. 43).

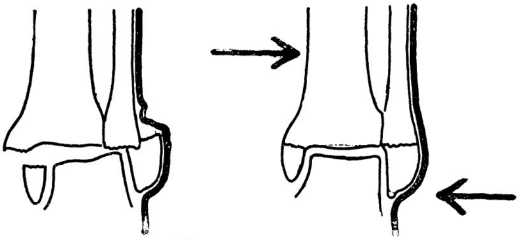


FIG. 43

Showing how it is usually impossible to over-reduce fractures such as the Colles' or the Pott's. The tension in the intact structures on the concave side prevents over-correction. Faulty reduction of the Pott's fracture may sometimes be traced to a fear of over-displacement.

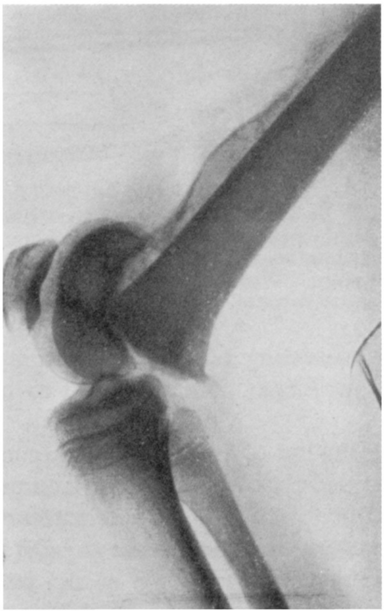


FIG. 44

Five-weeks-old displacement of the lower femoral epiphysis; ossification in the periosteum visibly demonstrating the soft-tissue hinge. The soft tissues are to be regarded as a tube from which the shaft of the femur has escaped into the popliteal space through a posterior tear. (*Mr Palin's case.*)

Visual evidence of the existence of the soft-tissue 'hinge' is demonstrated in the slipped lower femoral epiphysis in Fig. 44 where the periosteum on the concave side of the deformity has become ossified in the relaxed position.

Traction

The value of traction has long been known in the reduction of many fractures. Traction produces a reduction through the surrounding soft parts which align the fragments by their tension. Continuous traction, generated by weights and pulleys, in addition to causing reduction of a deformity, will also produce a *relative fixation* of the fragments by the rigidity conferred on the surrounding soft structures when under tension. This *splinting action* of traction can be illustrated by observing a length of chain in tension; in tension a chain behaves like a solid bar, the individual links possessing no relative motion, but without tension the movement of one link is no longer communicated to its neighbour and so each link is relatively mobile.

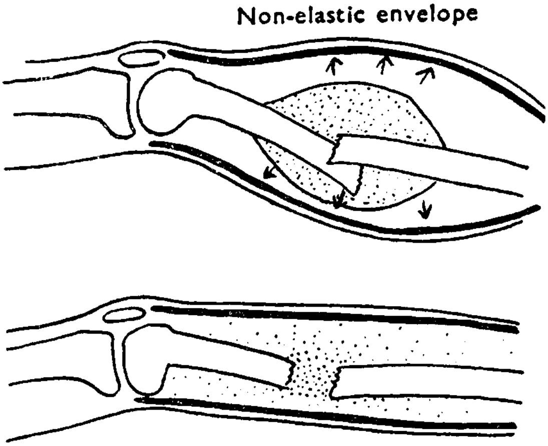


FIG. 45
Illustrating hydraulic obstruction to traction when a limb is grossly swollen. If the inelastic fibrous capsule tends to assume a spherical shape the length of the limb must decrease. When the effusion absorbs and the muscles waste, over-distraction occurs.

Were it not for the stretching of soft parts (with consequent separation of the bone ends), it could be argued that the use of continuous traction would instantly solve **the fundamental problem of closed fracture treatment: how to secure fixation of the fracture and yet preserve joint function.** By continuous traction, alignment can be maintained while at the same time it is possible to devise apparatus permitting joint movement. In those cases where over-distraction cannot precipitate delayed union, *i.e.*, the long oblique fractures where slight over-pulling does not abolish bone contact, methods using continuous traction are rational and acceptable.

In reviewing the action of traction we must consider the nature of the elements which offer resistance to elongation. The most obvious resistance to traction is that of muscular tone; but the difficulty which is so often encountered in securing full length under anæsthesia shows at once that muscular tone cannot be the most important factor.

In some cases a *hydraulic element* is present which resists elongation. Closed fractures, in which there has been a large effusion of blood, demonstrate this hydraulic mechanism; for in these the fibrous compartments of the limb, becoming distended and turgid, offer a rigid barrier to elongation. This mechanism is best seen in fractures of the shaft of the femur where, following hæmorrhage into the muscles, the thigh tries to adopt a spherical shape (because a sphere has the greatest capacity for a fixed surface area) and therefore in order to become greater in width the thigh must become shorter in length (Fig. 45). In such cases the effusion is sometimes so great that it is difficult to slide the ring of a Thomas splint over the swollen thigh. By allowing a period of a week or ten days to elapse before a second attempt at remanipulation it may be possible to secure a reduction when the thigh has become soft by the fluid being partly resorbed; open reduction, however, would be the ideal procedure.

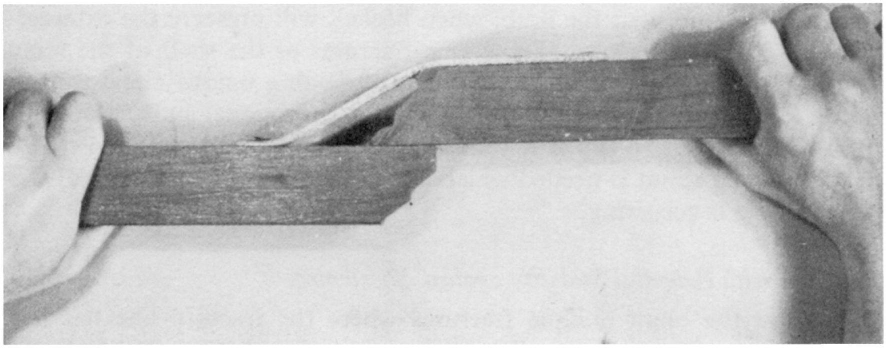


FIG. 46

Showing obstruction to traction by the soft-tissue hinge when the fragments are interlocked. Strong traction will rupture the periosteal bridge with possible serious consequences to union. By increasing the initial deformity this interlocking can be released without using traction.

Another mechanism offering a rigid barrier to elongation results from the *interlocking of soft tissues*. This mechanism was demonstrated by Beveridge Moore (1928) in experimental fractures of fresh, periosteum-covered, animal bones. The model in Fig. 46 illustrates this mechanism; reduction of this artificial fracture can be obtained only by increasing the original deformity in order to release the bone ends. Violent axis traction could reduce this fracture only by rupturing the last remaining strands of periosteum connecting the bone ends, a factor which has often been suggested as a reason for non-union.

Classification of Fracture by the Mechanics of Fixation

It is instructive to classify fractures according to the physical conditions best suited to their fixation. Three groups can be distinguished by their **varying degrees of stability to a telescoping force applied after reduction:**

1. *Fractures without Stability against Shortening*

These comprise the oblique or spiral and the comminuted fractures. In these some form of traction would be necessary if it were desired to prevent the shortening which results from the unopposed action of muscular tone (unless the fracture is strutted by another bone lying at its side).

2. *Fractures with Complete Stability against Shortening*

These are the transverse fractures. Once the bone ends of a transverse fracture are manipulated into some degree of end-to-end contact, the fracture immediately becomes stable against shortening. **Transverse fractures need splintage only to control angular deformity.** If plaster of Paris be used, the cast will act merely as a mould to ensure that the limb, when healed, will preserve the external shape imposed on it by the splint. Transverse fractures of the shaft of the femur are, however, unsuited to this form of treatment through a unique circumstance: the shrinkage of the thigh muscles, which possess exceptional bulk, would allow a fracture of the femur to slip if it were treated from the outset in plaster; in the fractured femur a splint is needed which can retain continuous control of the thigh while shrinkage is occurring.

3. *Fractures with Potential Stability against Shortening*

These are the blunt oblique fractures where the fracture line lies less than 45 degrees from the transverse line. These are the commonest of all fractures and therefore some knowledge of theoretical mechanics is valuable, even though this theory may not be capable of practical application on every occasion.

It is in this group that stability against shortening can be obtained by using knowledge gained from an understanding of the soft-tissue ' hinge.'

If a blunt oblique fracture is reduced by manipulation and is then slightly *angulated in the direction of over-correction*, the intact soft-tissue hinge will be put into slight tension. Under these conditions the bone ends will be pressed together *and the fracture will retain some stability to a telescoping force while the hinge is in tension.* This action of the soft-tissue hinge, assisted by an almost intact fibula, is well illustrated in the fractured tibia in Fig. 47. Tension in the soft-tissue hinge can be maintained by applying a plaster moulded to *over-correct* the original angulation. This is illustrated in Fig. 48, A and B, which also demonstrates **the paradox that a ' curved ' plaster is necessary in order to make a straight limb.** In this type of fracture it is erroneous to regard a plaster merely as a passive mould exerting an even pressure over the whole surface of the contained limb. **The ' three-point ' plaster exerts pressure at certain precisely determined points on the skeleton and none at others.** Typical examples of plasters demonstrating three-point systems are illustrated in Fig. 49 for the Pott's, Colles', and Bennett's fractures where the pressure points are indicated which constitute three-point systems.

In localising the points of a three-point system it will be seen that *two of the three points are those where the surgeon's hands moulded the plaster while setting;*

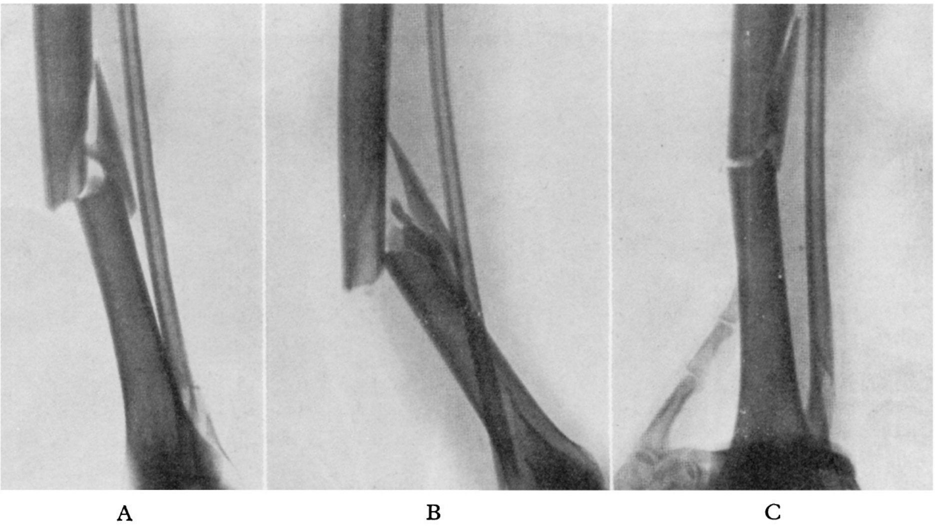


FIG. 47

A, Fracture of the tibia and fibula before reduction.
B, Appearance on applying a valgus force to distal fragments.
C, Appearance on applying a varus force to distal fragments.
The ruptured tissues are therefore situated on the medial aspect and the intact tissue hinge is on the lateral aspect. (*Essex-Lopresti, Birmingham Accident Hospital.*)

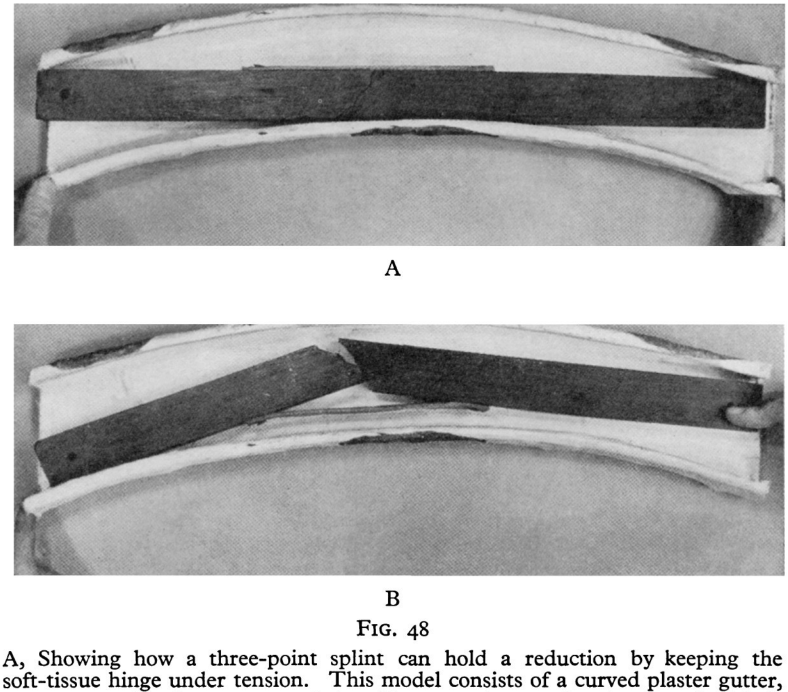


FIG. 48

A, Showing how a three-point splint can hold a reduction by keeping the soft-tissue hinge under tension. This model consists of a curved plaster gutter, to represent the plaster cast, and thus illustrates the paradox that on principle it is necessary to have a curved plaster in order to secure a straight limb.

B, Showing how a fracture will redisplace if the three-point splint is applied in the wrong direction, *i.e.*, allowing the soft-tissue hinge to become slack.

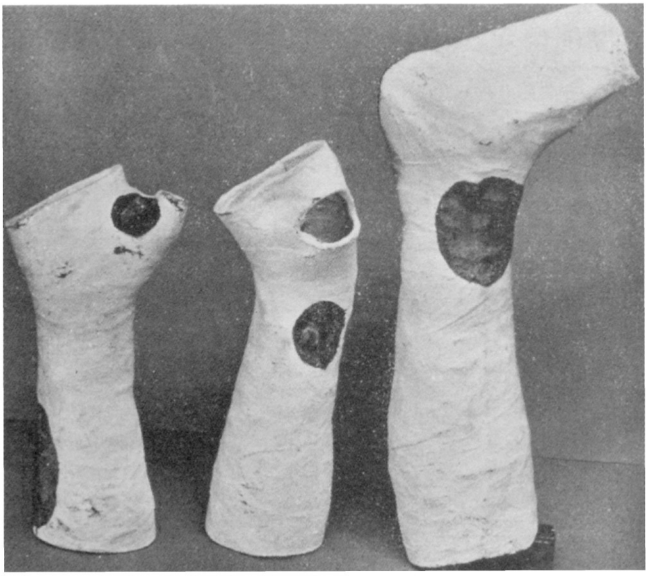


FIG. 49

Examples of three-point action in common plasters—Bennett's, Colles', and Pott's fractures. The small areas on the distal parts of the casts represent the forces applied by the surgeon's hands to the proximal and distal fragments. The large areas on the proximal parts of the casts represent the third point which renders the reduction stable when the surgeon's hands are removed.

one is applied to the proximal fragment while the other is applied to the distal fragment. But though the action of the surgeon's hands maintains a reduction by *two* forces, it is impossible to hold a reduction by *two* forces alone if these are applied by an inanimate object such as a splint. If a splint is applied which exerts pressure at only two points, the reduction will slip because the splint can move away from the fracture (rotating in the opposite direction to the ' couple ' produced by these two forces) (Fig. 50). It is necessary, therefore, to introduce a third force in order to neutralise this turning couple and so to prevent the plaster from rotating away from the limb. In the plasters illustrated in Fig. 49 it will be seen that *the third point extends over a diffuse area at the proximal part of the cast.*

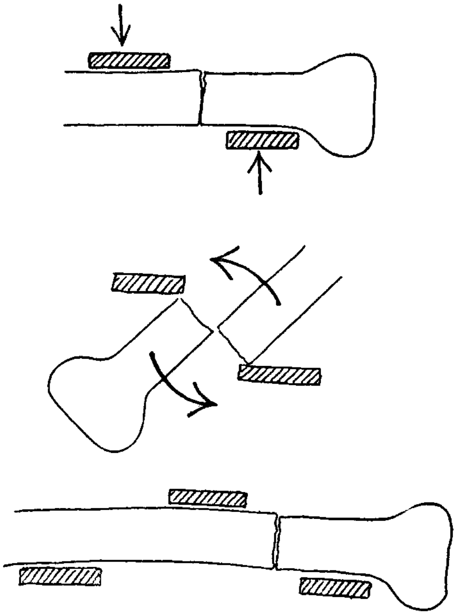


FIG. 50

Showing how a two-point system (*i.e.*, forces applied only to the proximal and distal fragments) is unstable. If the fracture rotates in the direction of the ' couple ' produced by these two forces, then redisplacement will occur. By introducing a third force to neutralise this couple the system becomes stable.

Padded and Unpadded Plasters

An understanding of the three-point action of a plaster splint elucidates the similarity of padded and unpadded plasters. There has been a tendency in some quarters to regard the unpadded, or ' skin-tight,' plaster as the only logical form of fixation, and to regard padded plasters as outmoded and ineffective. In actual fact the only *mechanical* difference between padded and unpadded plasters is one of degree, and concerns the amount of ‘molecular’ movement possible at the fracture line. The skin-tight plaster provides better immobilisation of the fracture, as judged by the amount of movement which is possible between the cells of the healing callus. But even in a skin-tight plaster the amount of immobilisation is only relative, owing to the movement which can occur between the skin and the skeleton. True immobilisation can only be secured by some form of internal fixation. Even in the accurately fitting plaster which is usually applied for a fracture of the carpal scaphoid, a patient can wriggle his wrist by at least ⅛ inch in relation to the cast.

As regards the prevention of massive movement at a fracture line (*i.e.*, complete redisplacement of the fracture), there is no essential difference between padded and unpadded plasters, *provided that they both exhibit three-point action.* If a fracture of the radius and ulna were to slip in a padded plaster, it is erroneous to think that this accident might have been prevented had the cast been unpadded. **If a fracture slips in a well applied padded plaster, then that fracture was mechanically unsuitable for treatment by plaster and another mechanical principle should have been chosen.**

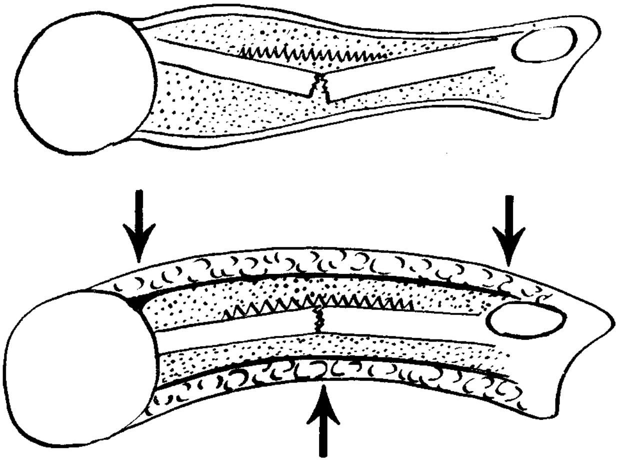


FIG. 51

Showing that a skin-tight plaster, beautifully moulded to the external shape of a limb, is capable of allowing redisplacement to occur because it does not exert a three-point action. On the other hand, a padded plaster is capable of preventing redisplacement, provided that it is moulded into the correct three-point forces.

Perhaps the most common example of failure to understand the three-point action of plaster is seen in the treatment of greenstick fractures of the forearm by skin-tight plasters. A greenstick fracture illustrates more clearly than any other the action of a strong fibrous tissue ‘hinge’ on the concave side of the ‘lead-pipe’ deformity (Fig. 51). It is obvious that three forces must be applied to manipulate such a deformed forearm into correct alignment; but it is often not appreciated that **alignment cannot be safely controlled by a plaster slab applied only to one aspect of the forearm.** It is quite true that hundreds of such cases throughout the country are every week successfully treated by this procedure even though mechanically it is essentially unsound; but in many other cases serious recurrence of the original deformity will occur. **A single plaster slab is incapable of three-point action.**

But even if a complete plaster is applied to a greenstick fracture of the forearm, *the lead-pipe deformity can still recur inside the plaster unless the cast is moulded to have a slight curvature in the direction of over-correction of the original deformity.* This recurrence of angulation inside an unpadded plaster can be imagined as being caused by the tissue hinge behaving as though it were a piece of stretched elastic; the tension of the hinge forces the bones towards their original deformity, and the soft muscles interposed between the bones and the cast offer no resistance to this displacement, even though the plaster is skin-tight. This movement in the direction of the original displacement shows that **a padded plaster positively moulded into a three-point action is mechanically superior to an unpadded cast with a neutral or simple ‘ encasing ’ function.**

It is instructive to compare the two plaster casts illustrated in Fig. 52 in which one is a good copy of the external shape of the ankle and the other looks to be a very clumsy and inexpert product. As will be explained in the treatment of the Pott’s fracture, the ugly cast is in reality the better cast, because it bears the impress of the surgeon’s hands moulding the displaced fragments into position.

The tendency to recurrence of the original deformity in a greenstick fracture of the forearm can be prevented by deliberately completing the greenstick fracture, thereby rupturing the intact soft parts which in a child act like a spring to reassert the original deformity. I am often asked whether or not one should make a greenstick fracture of the forearm complete as a routine procedure. The answer is that one must always *over-correct* any fracture during reduction; if a greenstick fracture of the forearm cannot be overcorrected without completing the fracture, then the fracture must be completed. If the deformity can be over-corrected without the fracture being complete, it need not be completed if the surgeon understands how to model the plaster to keep a three point system acting on the reduced fracture.

Late Deformity

In fracture treatment *late deformities* are a constant hazard; they cause anxiety for both surgeon and patient alike. Here, to be forewarned is to be forearmed. If a surgeon maintains a conscious anticipation of late deformity throughout the post-reduction phases of treatment he will almost always be able to prevent it; it is when the surgeon is unaware of the latent dangers of the method he is using that late deformity takes him by surprise. To anticipate late deformity it is necessary to know the *common patterns* of deformity as they present themselves in particular instances, as well as to have an understanding of the mechanism of late deformity in general.

Late deformity is rendered more than ordinarily probable whenever delayed

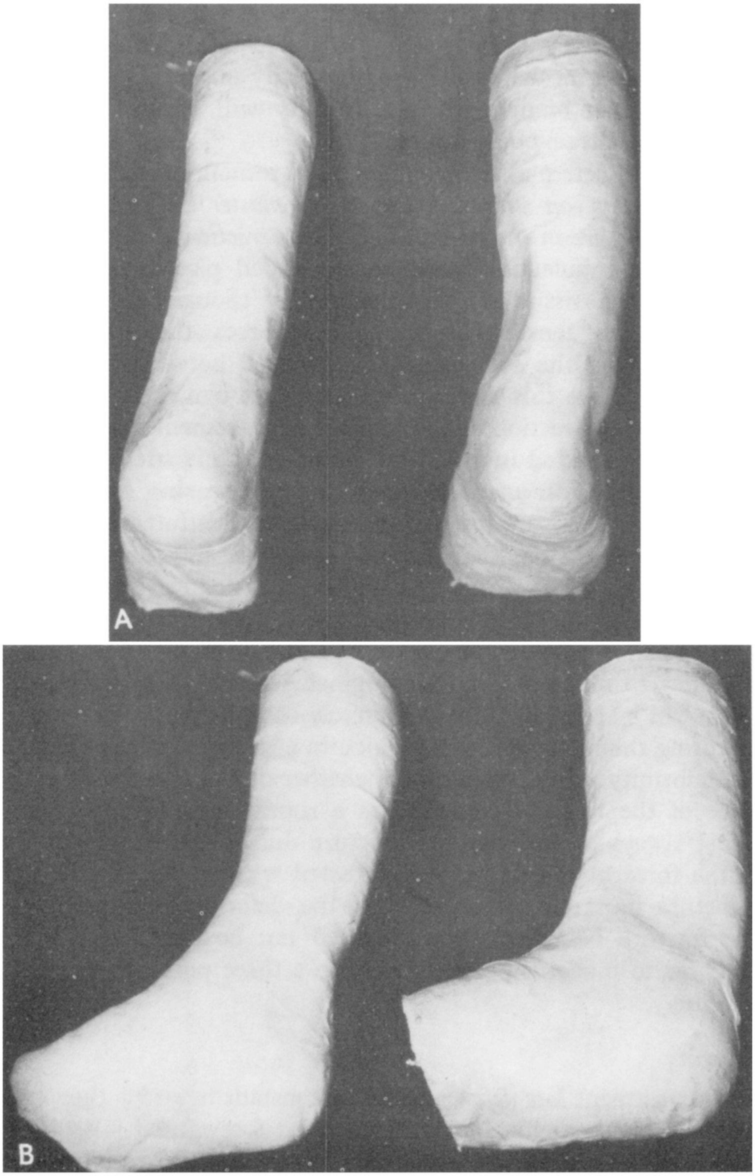


FIG. 52

The plaster on the left, used for a Pott's fracture, is more elegant than that on the right ; it is however much less effective because that on the right is moulded to produce a 'three-point' system of forces. The indentations caused by the moulding force of the surgeon's hands can be seen above and below the ankle.

consolidation complicates the healing of a fracture. If a fracture consolidates rapidly, a good result is practically certain even in an apparatus of second-rate mechanical design. If delayed consolidation supervenes, the same apparatus may permit late angulation, because the patient becomes restless and active just at the stage when the apparatus is beginning to reveal its mechanical faults. The maintenance of correct alignment in the presence of delayed union is a very stringent test of sound design in any system of splintage. If delayed union were to be more common even than it is, unsuspected mechanical defects would be revealed in many of the routine methods which give good results in everyday practice. In the weight-bearing extremities *late angulation due to the action of superincumbent body weight is so obvious that it will be omitted from this analysis.* The late deformity to be considered here is the 'spontaneous' late deformity which develops while the patient is still in bed or still in a plaster.

There are two main factors to be considered in spontaneous late deformity: (1) the force of gravity and (2) the force of muscular tone. Gravity can act in various ways according to the method used for treatment; the action of muscular tone results from the *superior pull of one muscle group over another.* Both these forces can generate enhanced power to bend the callus through the action of leverage systems, which can roughly be calculated from measurements of the length of the bony fragments, as will be demonstrated in subsequent paragraphs.

In addition to these causes of late angulation, experience shows that certain types of apparatus have a tendency to modify the late deformity according to certain constantly recurring patterns. It is unnecessary to anticipate late angulation towards any of the four directions of the compass but merely to anticipate it in those directions for which the fracture and the method of treatment are notorious. A few examples of common late deformity patterns can be enumerated:

Pertrochanteric fractures of femur (any splint)	late varus.
Midshaft femur (on Thomas splint)	late varus.
Lower quarter shaft of femur (Thomas splint)	often a late valgus.
Radius and ulna (in plaster)	late ulnar convexity, radial concavity.
Humerus (in hanging cast)	late varus.
Colles' fracture (dorsal slab)	late valgus.

Example 1

It is a clinical fact that transverse fractures of the shaft of the femur are prone to late angulation far more frequently than long oblique fractures. This can be explained by comparing the relative forces exerted on the callus in these two types of fracture as the following analysis will show.

In Fig. 53 is depicted an oblique fracture of the femur A and a transverse fracture B, which are both held rigidly by their proximal ends while an angulating force X is applied to the femoral condyles.

In case A the oblique fracture occupies a length of the shaft equal to six times its diameter. The upper limit of the fracture is situated twelve times the diameter of the shaft from its lower end. C represents the levers involved, if it be assumed that the fulcrum is sited at the proximal part of the fracture. The leverage acting under these assumptions is, therefore, in the proportion of 12 to 6, and thus the force on the callus at the distal part of the fracture is 2X.

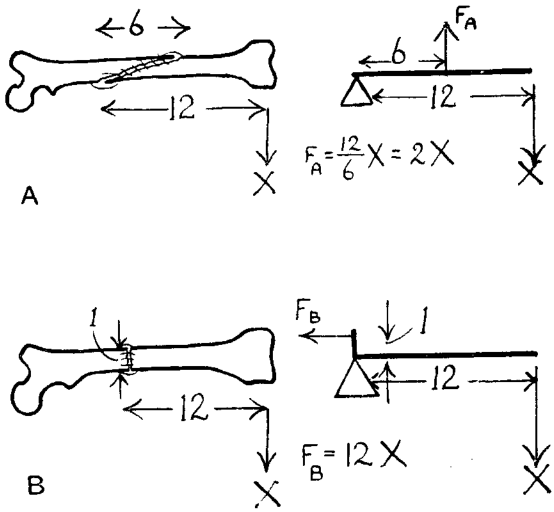


Fig. 53

In the case of the femur B, the transverse fracture is situated at twelve times the diameter of the shaft from the lower end. D represents the levers involved, if it be assumed that the fulcrum is situated at the cortex under compression. Thus a leverage in the proportion of 12 to 1 is available to separate the callus at the part of the cortex which is under tension. The angulating force is thus six times greater in the transverse case than in the oblique case.

This enhanced leverage in the transverse case acts, moreover, on a fracture which has only a sixth of the area of the oblique case; *thus each unit area of callus in the transverse fracture is subjected to thirty-six times the strain in the oblique fracture* in the hypothetical case under consideration.

Applying the same type of mechanical analysis, it is instructive to contrast the magnitude of the forces causing late angulation in a fracture of the shaft of a femur with those causing angulation in a fracture of the proximal phalanx of a finger.

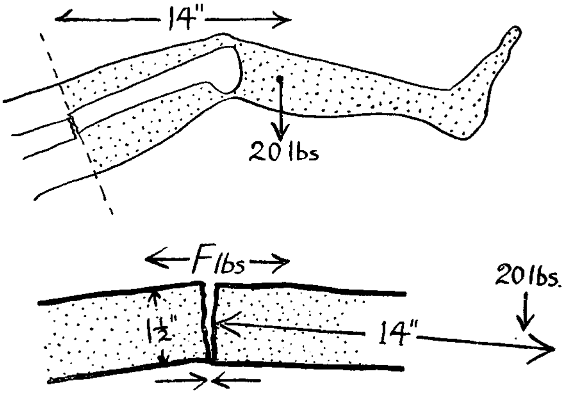


Fig. 54

Example 2

Consider the case of a transverse fracture at the junction of the middle and upper thirds of the shaft of the femur (Fig. 54). If a guillotine amputation were to be performed through the line of the fracture, the detached limb might weigh some 20 lb. The centre of gravity of this mass would lie about 2 inches below the knee joint which, in turn, would lie about 14 inches below the fracture line in a person of average height. If the diameter of the shaft of the femur be taken as 1¼ inches, and if it be considered that the shaft angulates by pivoting at the cortex under compression (the concave side), then a linear force will be present at the cortex under tension (the convex side) of:

$$\frac{14}{1\cdot25} \times 20 = 220 \text{ lb.}$$

It is not difficult to understand, therefore, why plates bend, screws pull out, and grafts break, if the fracture is not united by the time the force of gravity, uncounterbalanced, takes hold of the weight of the limb distal to the fracture.

This explanation shows how a badly designed plaster, by increasing the weight of the distal fragment and failing to take a secure hold of the proximal fragment, can in some cases actually increase a natural tendency to late angulation. If a plaster support were to be needed for a fracture of the lower third of the femur, it is then obvious that a ‘ long leg ’ plaster would be worse than useless because its weight would invite late angulation.

Example 3

Consider now the forces acting on a transverse fracture of the proximal phalanx of a *finger* calculated in the same way as the preceding. The distal fragment is to be taken as 1 inch in length and the diameter of the bone as $\frac{1}{4}$ inch. The weight of the digit, estimated as if it were amputated by guillotine through the fracture line, can be taken as $\frac{1}{16}$ lb. Gravity will thus exert an angulating force on the unsplinted fracture which tends to separate the cortices on the convex side with a force of:

$$\frac{1}{\cdot 25}\times\frac{1}{16}=\tfrac{1}{4}\text{ lb.}$$

It can thus be argued that callus in a fracture of a finger is subjected to forces (*as a result of gravity alone*) of only one eight-hundredth part of the forces acting on a fracture of the shaft of the femur *even before weight-bearing is allowed.*

Example 4

Some idea of why nature depends for union of the shafts of long bones on the production of periosteal callus can be gleaned from the following mechanical study.

Consider again the figures calculated for the transverse fracture of the femoral shaft in Example 2. With the shaft of the femur measuring $1\frac{1}{4}$ inches in diameter and the total weight of the limb distal to the fracture weighing 20 lb., it was shown that a tearing force of 220 lb. is exerted on the callus on the convex side of the deformity. But if nature encloses the fracture site in a bulky mass of periosteal callus which measures a total diameter of 3 inches, it will become evident that the strain on the most peripheral part of the ensheathing callus is much reduced and becomes only:

$$\frac{14}{3}\times 20=90\text{ lb.}$$

This principle of placing a weak structure at a considerable distance from the centre of angulation is well known to constructional engineers and underlies the principle of the ‘ stressed skin ’ construction of aircraft, by which a thin sheet of metal placed on the outside of an aircraft wing becomes as strong as a heavy girder of steel used as a central spar. From such considerations one feels that endosteal callus cannot be an important element in the early healing of fractures of the shafts of the long bones.