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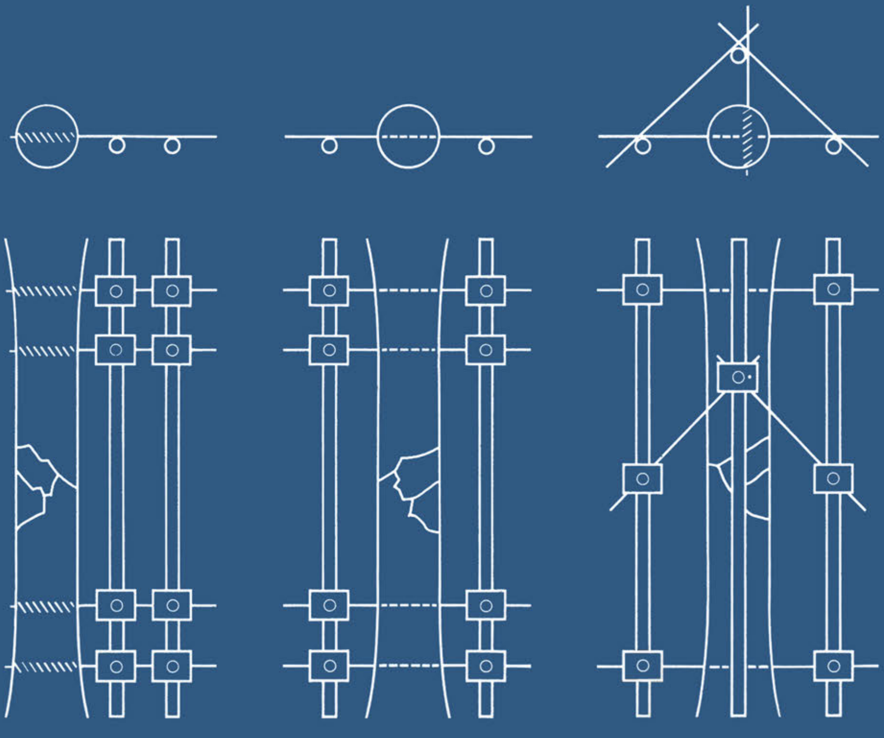
Manual on the AO/ASIF Tubular External Fixator



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Manual on the AO/ASIF Tubular External Fixator

With 104 Figures, Some in Colour

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Contents

1 Introduction and Basic Indications for the Use of External Skeletal Fixation

The history of external skeletal fixation begins in the middle of the 19th century with MALGAIGNE's [11] description of a simple unilateral frame. Since then considerable development has taken place. LAMBOTTE [10] pushed the development of the external fixator further and was the first to apply a simple unilateral frame in a systematic fashion. CODEVILLA [3] pioneered in describing the principles of the double-frame configuration, which was further developed by STADER [16] and HOFFMANN [6]. ANDERSON [1] described the half-pin "fracture units" with prestressing and recurrent compression of the fracture site. VIDAL and his co-workers [17] were the first to subject the various assemblies of the external fixator frames to mechanical testing. Their results were instrumental in gaining wider acceptance for this method. The external fixator was used in clinical practice to treat fractures and pseudarthroses, as well as in arthrodesis of the knee and ankle [13]. The advantages of this type of fixation – namely, fixation of the involved portion of the skeleton with sparing of the endangered soft and boue tissues – were recognized by the pioneers of external skeletal fixation.
The Association for the Study of Problems of Internal Fixation (AO) [5, 7–9, 12–15, 18] has also devoted itself to the problems of external skeletal fixation. Our early external fixation was characterized by the use of threaded bars in the assembly of the frames, which we applied – except in arthrodesis – without preload of the pins. Our clinical experience convinced us, however, that this type of external fixator frame did not provide sufficient versatility and stability for successful treatment of problem fractures, such as those with segmental bone loss or with a short metaphyseal fragment, or for treatment of the combination of instability and chronic osteitis. The introduction of the AO tubular system brought with it considerable improvements in the component parts [7, 15]. The greater stiffness of the tubes permitted bridging of greater distances with much more stability than with the early model. We will outline the principal features of the most important types of assemblies, as well as the indica-

tions for their use. Three basic indications for external skeletal fixation have specific biomechanical implications and should be considered separately:

1. Fresh fractures accompanied by severe soft tissue damage, particularly open fractures with second- or third-degree soft tissue injuries
2. Infected nonunion with badly compromised soft tissue cover
3. Corrective metaphyseal osteotomies and arthrodesis of various joints, mainly the knee and the ankle

In *freshly fractured cortical bone* of the diaphysis in long bones, even optimal biomechanical placement of the transfixing pins or Schanz screws may not permit sufficient stability for primary bone healing to take place. On the other hand, such fixation seems to be too rigid to exert a physiological stimulus for normal callus formation, because cases chosen for this technique have often had significant extra osseous soft tissue stripping. Externally fixed diaphyseal bone heals only slowly, or not at all, if no other surgical procedures are applied. Stabilization of fresh fractures by means of external skeletal fixation therefore has to take two other aspects into consideration. It must be clearly visualized as a means of coping with the soft tissue problem for the immediate post-trauma or postoperative period. When the soft tissue problem is under control, a second operative step, often such as bone grafting or even internal fixation, has to be considered. To carry out secondary internal fixation with maximum safety, the bone close to the fracture area should not be compromised by transfixing pins or screws. This results, of course, in a lesser degree of initial stability, because one must keep away from the fracture focus as much as possible. Another safety measure is to allow a 2–3 week interval between removal of the external fixator and the secondary procedure.
For fresh fractures there is one technique which can provide "absolute stability" in combination with external fixation: lag-screw fixation of the fracture plus neutralization by the external fixator.

In infected nonunions, where the soft tissue problems prevent the usual procedure of removing the dead bone in combination with cancellous bone transplant and internal fixation, we may have to rely on external fixation in conjunction with a cancellous autograft as a definitive means. In such cases we must strive for the reasonable optimum of mechanical stabilization by placing the Steinmann pins or Schanz screws in each main fragment at maximum distance from each other, thus coming close to the area of instability with the innermost pin or screw; in addition, we quite often use a three-dimensional frame, or an anterior and medial unilateral frame at a 60°–90° angle.

Where cancellous bone sections of the metaphysis are brought into contact in arthrodesis or osteotomy, compression fixation with an adequate two- or three-dimensional frame is so stable that very rapid bony union is achieved (8–12 weeks).

Under all three conditions it is most important to prevent loosening of pins and Schanz screws, which invariably leads to pin tract infection. Loosening is best prevented by putting the pins and Schanz screws under preload, by either *interfragmental compression* (across the focus of fracture) if bony support is warranted, e.g., in transverse fractures, osteotomies, or arthrodeses, or *intrafragmental compression* by prestressing the Steinmann pins and Schanz screws in cases with bony defects. Preload on the pins and Schanz screws is a most important ingredient of external fixation. Straight pins are under zero load and cause bone resorption and loosening due to micromovements. Adding a thread to Steinmann pins does not help much to prevent loosening; such pins are quite difficult to insert and remove, and should therefore be considered obsolete.
The main emphasis of this manual is on the application of the AO tubular system in fresh, open fractures of second and third degree; the other two indications are dealt with only briefly. The use of external skeletal fixation in pelvic and vertebral fractures is not covered here. Special indications are treated in the Appendix.

2 Mechanical Principles of External Skeletal Fixation

The point having been made that rigid stability is not the only, and often not even the main aim in using the external skeletal fixator, it is still important to explain the mechanics of its application and the relevance of application to stability.

The component parts of the tubular system allow various forms of assembly. We have tested the mechanical behavior of these assemblies and clinically defined their application. The horizontal and linear displacement of fragments were measured with strain gauges [7, 9] and the torsional stability was determined by means of "finite element analysis" [7]. The results obtained have led us to recognize three basic forms of assembly. We shall now discuss some of these mechanical features.

Once a fracture has been stabilized by an external fixator, the horizontal displacement of the fragments under load is used as one of the parameters for determining the achieved stability of fixation. Under eccentric load, which corresponds to the physiological conditions, we see that each main fragment is subject to a turning moment. This results in an almost exclusively horizontal displacement of the fragment ends. If we introduce one Steinmann pin in the frontal plane into the proximal fragment it becomes the centre of rotation of that fragment. If instead of one Steinmann pin we introduce two, the center of rotation is now found halfway between the two Steinmann pins. In the loaded system, the introduction of the second Steinmann pin causes a countermoment, which increases in magnitude as the distance between the two Steinmann pins increases. Thus, two pins are desirable because they give greater stability to the fragments in the horizontal plane. If one is dealing with a short metaphyseal fragment, and if it is impossible to introduce two Steinmann pins in the frontal plane, then the desired countermoment can be achieved by introducing a Schanz screw in a dorsoventral direction or in a sagittal plane. This considerably reduces the horizontal displacement of the fragments. The distance of the Schanz screw from the Steinmann pin which serves as the center of rotation should be as great as possible. This

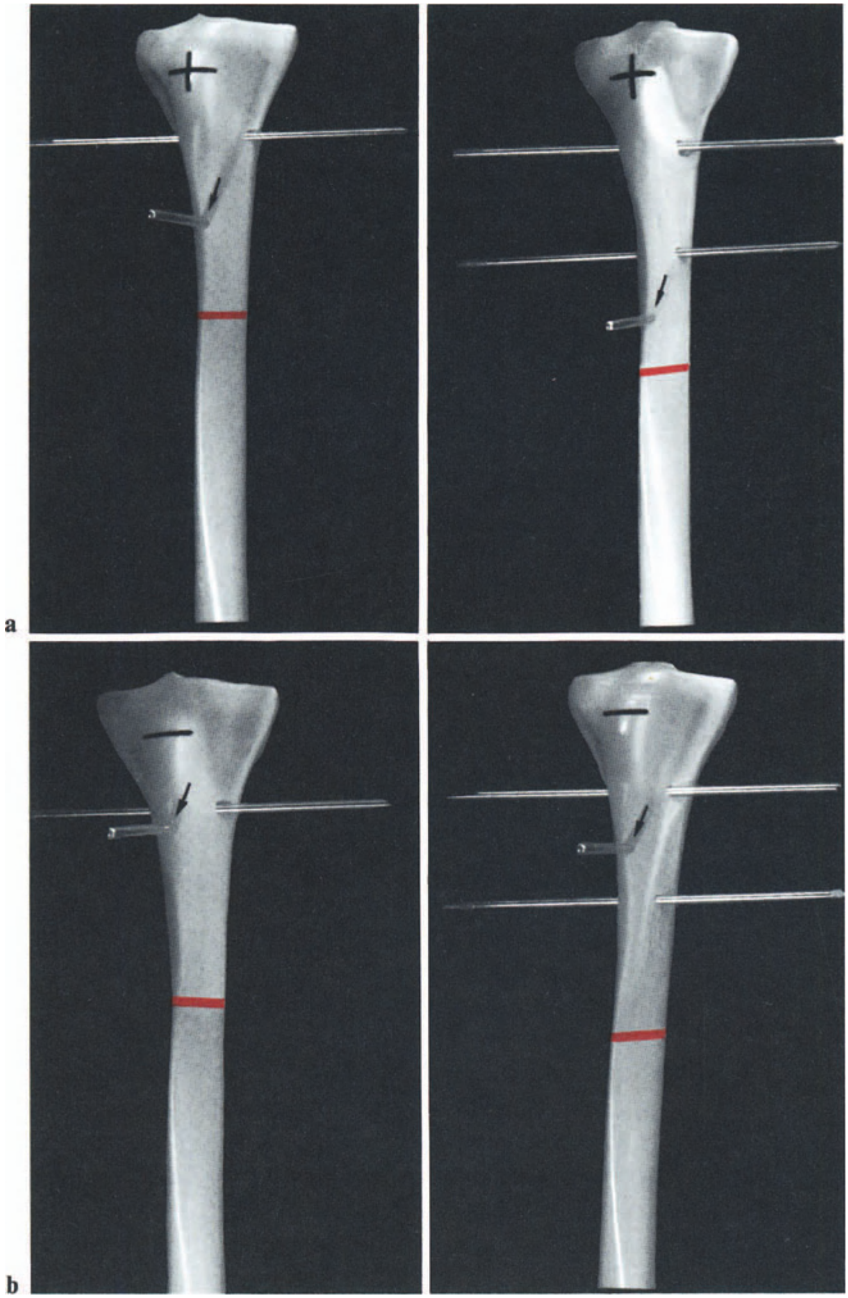


Fig. 1a, b Insertion of two parallel Steinmann pins, or an additional Schanz screw in a dorsoventral direction. Decrease in horizontal displacement after production of a countermoment under eccentric load. **a** Correct position (+) of the additionally inserted Schanz screw, as far from the center of rotation of the fragment as possible; **b** incorrect position (−)

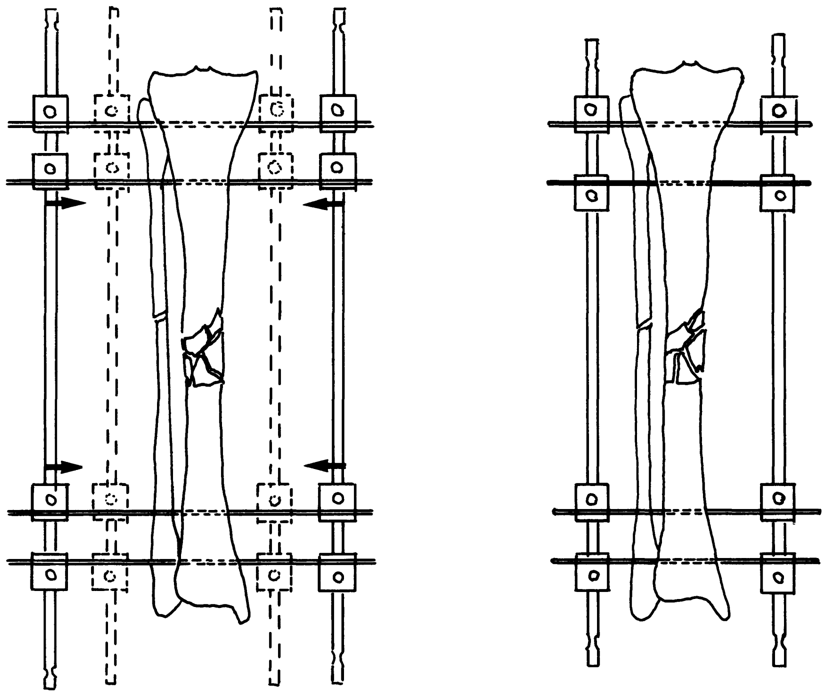


Fig. 2 Fixing the tubes as close to the limb as possible. Increase in the stability of the assembly with decrease in the free segment of the Steinmann pins and Schanz screws

means that the Schanz screw should be introduced as close to the fracture as is compatible with the overall treatment plan (Fig. 1a).

The degree of horizontal displacement of the fragments can be further reduced by triangulation, in which a bilateral frame in the frontal plane is joined by means of oblique Steinmann pins with a unilateral frame which has been inserted ventrally in the sagittal plane. The stability is increased because the triangulation neutralizes both tensile and compressive forces. The triangulation also counteracts bending of the tubes. The stability of the system also depends on the free segments of the tubes, the Steinmann pins, and the Schanz screws, which can be subjected to bending and buckling. The shorter this segment for all component parts, the greater the stability and the lesser the displacement of the fragments. Therefore, if the external fixator is used to bridge long distances, the tube segment between the Steinmann pins adjacent to the fracture must be kept to an absolute minimum. Furthermore, the tubes should be fixed as close to the limb as possible in order to decrease the free distance of the Steinmann pins and of the Schanz screws (Fig. 2).

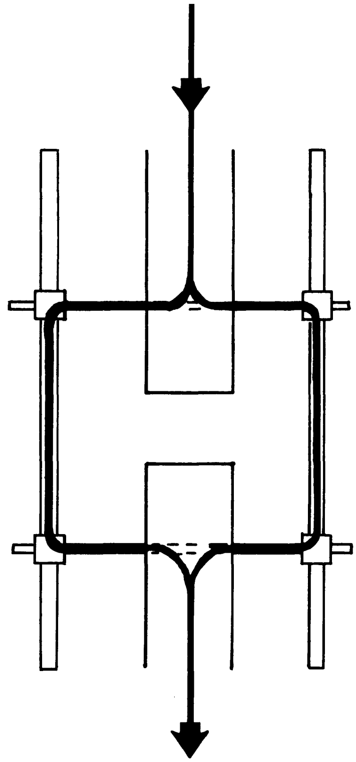
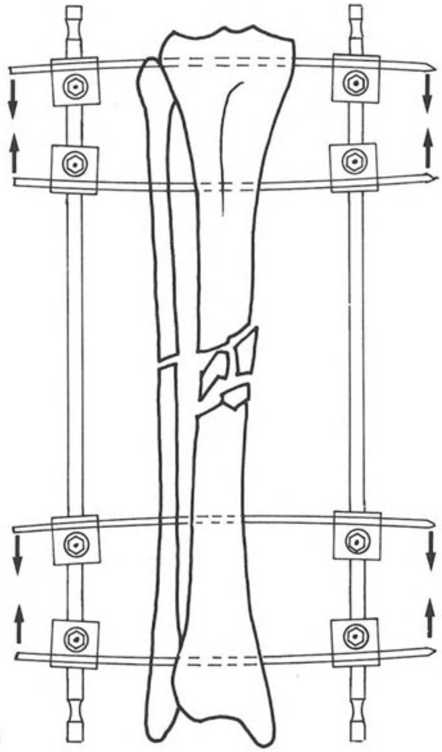


Fig. 3 When subjected to load, the direction of force in an assembly follows indicated path

One further important parameter used in the evaluation of the stability of an assembly is the linear or axial displacement of the fragments when subjected to load. The direction of force follows chiefly the path indicated in Fig. 3. The linear or axial displacement of an assembly is determined by the degree of bending of the Steinmann pins. This bending is in turn determined by the distance between the tubes, the diameter of the Steinmann pins, and their rigidity. The rigidity is dependent on the metal used. Our experiments have shown that preloading of the Steinmann pins by bending them towards one another can reduce the linear displacement of each main fragment by 45% (Fig. 4a, b). The horizontal displacement of the fragments is also reduced by preloading the pins, although to a much lesser degree, as was pointed out by ANDERSON [1] years ago. Preloading of the Steinmann pins in bone leads to a significant decrease in the

Fig. 4a, b "Intrafragmentary" preloading of two Steinmann pins by bending them together in each main fragment. Reduction of the linear and horizontal displacement, as well as of metal loosening in bone



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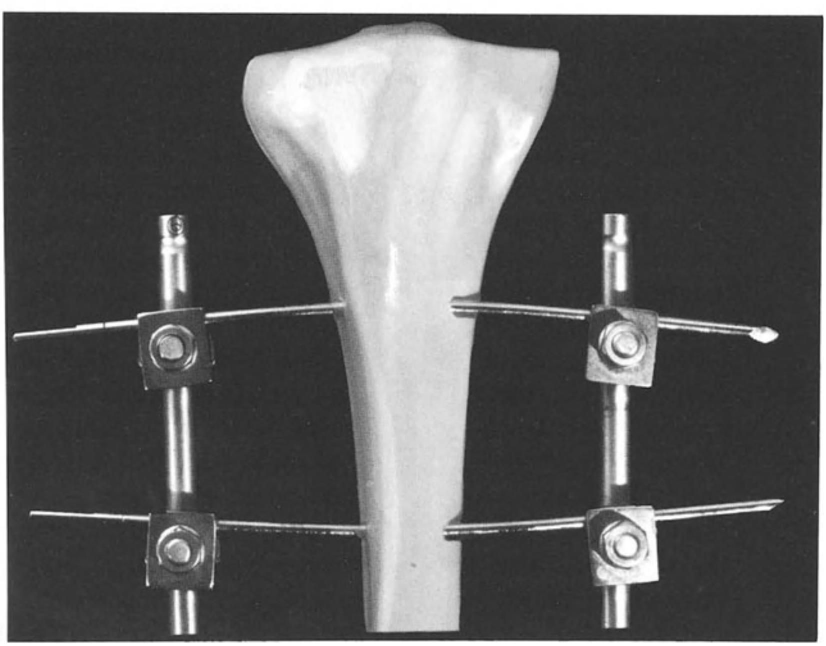

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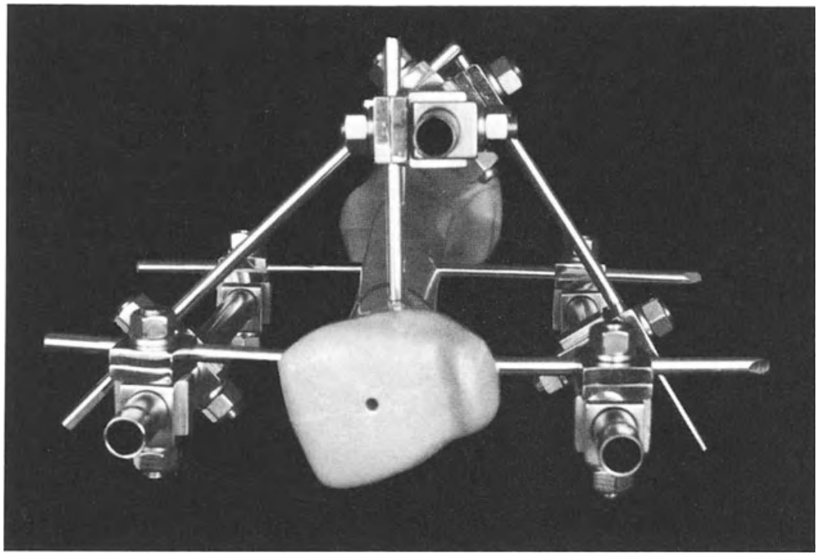

Fig. 5 Triangulated configuration of the assembly by linking the unilateral frame inserted in the sagittal plane to the bilateral frame inserted in the frontal plane, increasing rotational stability

incidence of loosening and to a considerable reduction in the danger of side slippage; it has made the use of threaded Steinmann pins obsolete.

In addition, the stability of an external fixator assembly is determined by its resistance to rotation or torsional moments. This is best measured by means of finite element analysis. Finite element calculations [7] have shown that a ventral tube can neutralize the torsional moments only in a three-dimensional configuration (Fig. 5). This means that the unilateral frame inserted in the sagittal plane must be linked to the bilateral frame inserted in the frontal plane. Triangulation leads principally to rotational stability. Its influence on the degree of horizontal displacement of the fragment is low.

The fixation of the tubes to the Steinmann pin results in a certain degree of eccentricity of the system. Because the load is applied eccentrically we must aim, when we lock the tubes in position, at minimizing the distance between the point of force application and the load axis. The reduction of this distance means the reduction of a lever arm which, if too long, could cause a bending of the tubes. The practical consequence of this is that in assembling the frame the side tubes should be fixed posterior or dorsal to the Steinmann pins (Fig. 6a, b).