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THE RIGIDITY OF FRACTURE IMMOBILIZATION WITH PLATES

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Received 8.VI.66

In two earlier papers (6, 7) the author has reported experimental tests of the rigidity obtained with various techniques of osteosynthesis for fracture of the femoral shafts; these included the use of one or 2 Sherman plates. In the present study a more thorough comparison is made of the rigidity of immobilization obtained with various plates that are commercially available. The general principles for immobilization of fractures by this technique are also examined and discussed.

MATERIAL AND METHODS

As in the earlier studies, the tests were performed on femoral shafts from autopsies in which a transverse fracture had been produced by sawing. This was then immobilized with the various types of plates, and measurements of the rigidity were carried out by the same method as before (6), except that the specimens were not subjected to axial compression.

Plates tested

1. Sherman*	7. Wenger (13, 14)*	13. A. O.†
2. " "	8. " "	14. A. O.†
3. " "	9. Ordinary Standard*	15. Experimental
4. Eggers (3)*	10. Ordinary Slotted*	16. Lindahl§
5. " "	11. " "	17. Haggland*
6. Venable (12)*	12. A. O.†	

The appearance, shape, dimensions and material are given in Figure 1 and Table 1.

* Manufactured by AB Stille-Wernar, Stockholm.

§ Manufactured by Kifa, Stockholm.

† Obtained from Forschungsinstitut, Davos, A.O.-Instrumente, Switzerland.

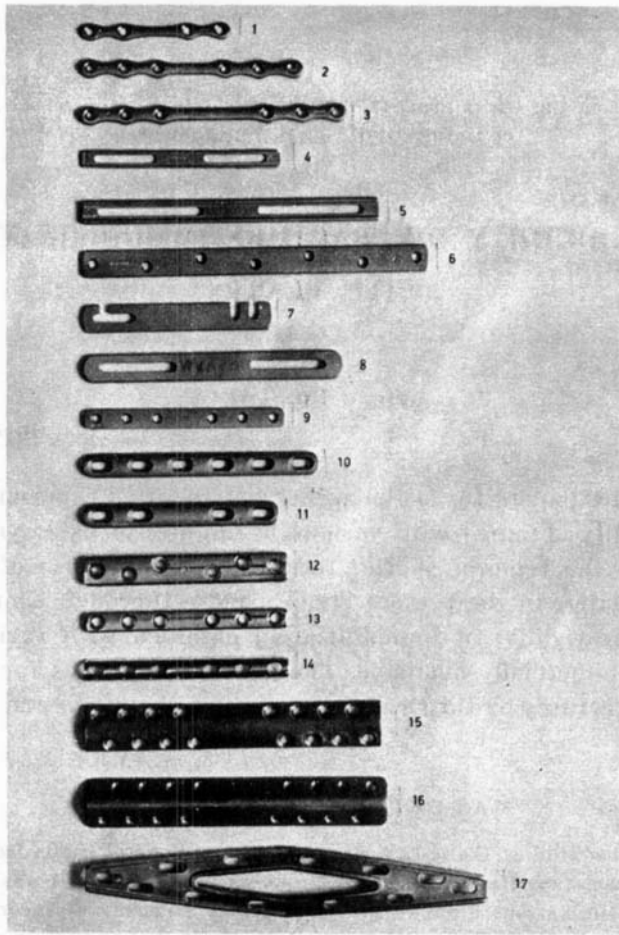


Figure 1. The fracture plates tested.

RESULTS

As in the previous studies, the rigidity of immobilization was tested by bending in 3 or 4 directions and by torsion. The poorest rigidity was obtained for bending towards the plate so that the fracture space opened up. It is not intended here to give a full account of all the values obtained for the relation between the applied force and the deflection, it sufficing for the present purpose to compare the various plates in respect of the lowest strength recorded (Figure 2). The rigidity of immobilization for the various plates varied widely and was, of course, lower for the thinner than the thicker ones.

Table 1. Material and dimensions of the plates tested.

No.	Name	Material	Length (mm)	Width (mm)	Thickness (mm)	Shape	Radius (mm)
1	Sherman	Vitallium	76.5	5.0	2.1	curved	17
2	"		114.2	6.1	2.9		26
3	"		136.2	6.8	2.9		26
4	Eggers		101.5	9.6	1.5-2.3	plane	-
5	"		152.2	12.5	2.3-3.2		-
6	Venable		175.9	14.2	1.2-3.1	curved	15
7	Wenger modified		96.0	15.2	1.7-3.0		30
8	Wenger original		132.2	15.3	2.2-4.3		19
9	Standard		102.4	10.8	2.2-2.8		37
10	Slotted		119.2	12.6	3.1-3.7		13
11	"		98.6	12.6	3.1-3.7		13
12	A.O. heavy	Stainles steel	102.3	16.0	4.7		25
13	A.O. weak		102.3	11.0	3.7		36
14	A.O. thin		103.0	11.8	0.8		4
15	Experimental		149.0	24.2	1.0		20
16	Lindahl	Kifilium	152.2	25.0	0.9-2.3		16
17	Haggland	Vitallium	203.0	14.9-35.5	2.8-3.6		40

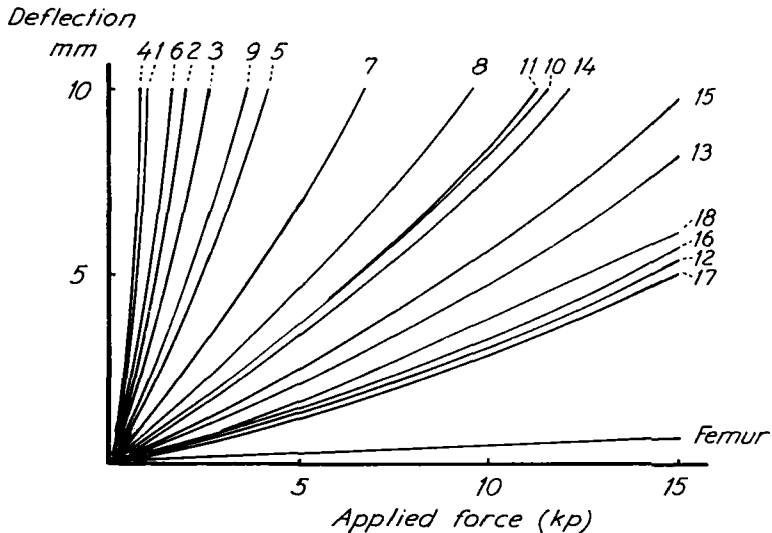


Figure 2. The relationship between the bending force applied 10 cm from the fracture and the deflection at the point of application of the force. For each plate the values used were those for the lowest strength. The figures relate to plates in Table 1. No. 18 relates to immobilization with 2 Sherman plates (no. 3) at right angles to each other. The lowermost curve relates to the deflection for an intact femoral shaft.

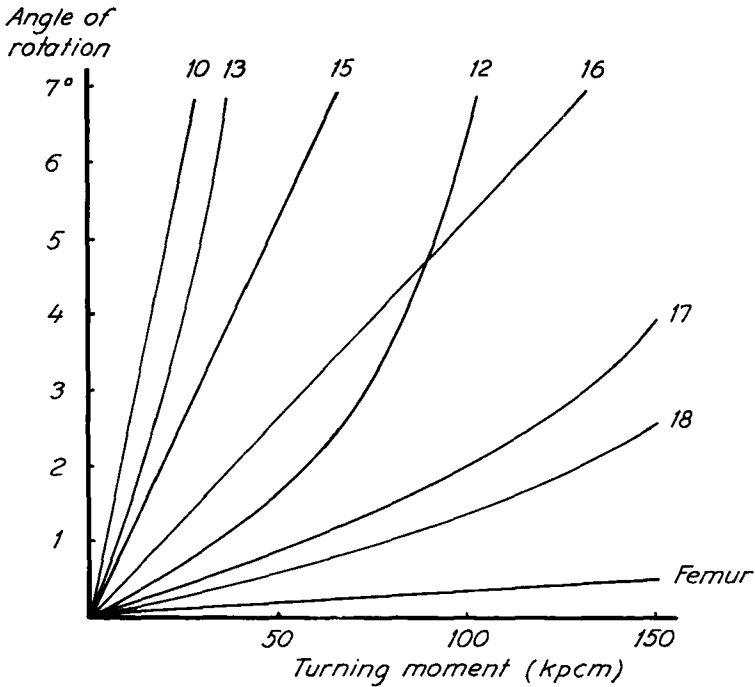


Figure 3. Relationship between torsional force and the corresponding angular rotation in the fracture. The figures relate to the same plates as in Figure 2.

A corresponding comparison of the rigidity as tested by applying torsion is presented in Figure 3. Since the torsional rigidity was extremely poor for the weaker plates, only the strongest have been included in the figure. While this property was largely parallel to the resistance to bending, there were certain differences, and these will be discussed below.

DISCUSSION

From the mechanical aspect the best method of immobilization is that which gives the greatest rigidity of the fragments. There is no technical difficulty in designing devices that provide practically "complete" immobilization, with the same rigidity as that of the femur itself, the strongest of the bones in the body. Such rigidity could be attained if the fragments were immobilized with, for instance, 4 plates placed perpendicular to one another in pairs and fixed together with bolts (Figure 4); even one such dual-plate system would suffice, and plates of this type have been used (1, 9, 11).

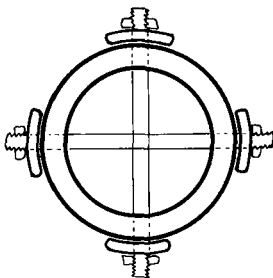


Figure 4. How to obtain "complete" immobilization with 4 plates.

For immobilization of a fracture in the patient, however, account must be taken of other factors besides strength. For instance, it must be decided whether internal immobilization shall be used at all, in view of the risk of infection, the interference with the healing caused by the foreign material and surgical trauma, and the scarring—even after an "atraumatic" operation. The author tends to prefer the closed fracture treatment, but there are situations in which an open reduction of the fracture and internal immobilization are to be preferred (10), and with improvement in the surgical technique in the widest sense such conditions may well become increasingly common.

It is therefore necessary to weigh the pros and cons, and it is assumed below that for some reason internal immobilization has been chosen. As regards choice of material for the device, it will suffice here to note that if the irritant effect is the same for stainless steel of the best quality as for Vitallium-type alloys (Vitallium, Kifilium, Nobilium) then the former is to be preferred on mechanical grounds. It usually has a greater elastic limit, greater resistance to fatigue failure and greater toughness (elongation at rupture), and hence is capable of undergoing deformation without failure.

Of particular significance in an assessment of various immobilizing devices is the greater interference with normal healing that may be caused by large than by small devices. Three factors are probably involved in this respect: (i) the difference in the amount of material and hence in the area of contact with the tissues; (ii) the extent of surgical exposure; and (iii) the prevention of normal vascularization and callus formation by the plate.

In the case of immobilization with 2 plates facing each other and joined by bolts all 3 of these factors are involved, and it is commonly considered that the sum of these disadvantages outweighs the initially

better immobilization. Conclusive factual support for this view is lacking, however, and in the assessment account must be taken of a number of other circumstances, not the least important being the surgeon's ability to perform an atraumatic operation and to avoid infection. The failures subsequent to extensive operations are perhaps due less to the above factors than to complications, and then chiefly infection (8).

As has been discussed elsewhere (6, 7), the mechanical rigidity provided by other immobilizing devices than plates is generally poor, with the exception of screws for oblique fractures. In a discussion as to the best internal method it is therefore difficult to avoid the conclusion that, for the moment, some type of plate provides the best mechanical immobilization for a transverse fracture. This has been shown clinically by Dencker (2), among others. If dual plates are deemed unsuitable, however, it may be considered whether 2 plates at right angles provide a biologically acceptable solution or whether a single but stronger plate is to be preferred. At present it is impossible to decide which is the technique of choice, neither of them have material disadvantages. What is not acceptable, however, is for the plate to be so poorly designed that movement occurs that results in bone resorption and then prevents contact between the resorbed fragments. This is presumably the explanation for the bad repute in which plate immobilization is held among many surgeons.

It has been proposed that this disadvantage can be eliminated by using plates with slots instead of holes (Eggers, Wenger), so that the resorbed fragments can move close together. This, however, requires that the screws shall not be locked, but then the immobilization will be further impaired and a vicious circle is entered where the whole apparatus serves more as a coaptation than an immobilizing device. There are thus both theoretical and practical grounds for believing that this device does not function well in practice.

Of the various plates intended primarily for the femur, the Haggland, A. O. and Lindahl plates are about on a par so far as resistance to bending is concerned. Two quite weak Sherman plates set at 90° give almost as good immobilization (Figure 2). For torsional stability the relative rank of the 3 plates is the same but the difference between them is slightly accentuated. Two Sherman plates are slightly better in this respect. Under the circumstances it is difficult to decide which of these 4 methods is best from both the "biological" and mechanical aspects.

A factor to be considered in this connection is the shape of the

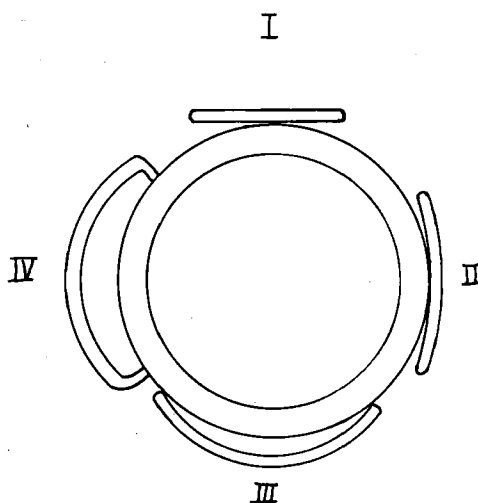


Figure 5. Various shapes of plates, and the contact between them and the femoral shaft.

plates. In Figure 5 the application of 4 types to the femur is illustrated in cross-section. Plane plates of type I are fairly uncommon and afford poor torsional stability. Whether a plate shall be classed as type II or III will depend on the curvature of the bone (the femoral shaft, in the present context) as well as on the shape of the plate. Except in the case of large shafts the Haggland and A. O. plates will fall in group II and they will then not be very effective in preventing rotation. The Lindahl plate is of type IV, and has two advantages. First, the edge of the plate makes contact with the shaft, so that it will not rock; second, callus will probably form under the plate so that the "biological" disadvantage of the device will be overcome to some extent. Despite its theoretically better shape, from the mechanical aspect this plate is slightly less rigid than the A.O. and Haggland types and torsionally less stable than 2 Sherman plates. This is because the material is extremely thin—0.9–2.3 against 4.7 mm for the A. O. plate. It was designed thus to enable the plate to be deformed and adapted to femoral shafts of different diameters, but it has since been found that such adaption can hardly be obtained even with material of this thickness, and in future the plate will be made thicker; the greater strength so obtained will provide greater rigidity than is possessed by the other plates discussed here.

SCREW IMMOBILIZATION BETWEEN PLATE AND BONE

In the test performed in this investigation none of the screws fractured or worked loose in the bone. To fasten the weaker plates it was usually only the outer and inner holes on each side of the fracture that were used. The same applies to plate no. 12. For nos. 15 and 16 the 2 outer and inner holes on each side were used, and for no. 17 one outer hole and 2 inner holes on each side. The screw, or the fixation between the screws and the bone, was thus not the weakest point of the immobilization device in these single tests on dead bone.

For vital bone different conditions will obtain, and apart from the weakening of the bone through necrosis and demineralization there will also be repeated application of stress, which can lead to fatigue fracture of both screws and bone. In clinical practice the screws sometimes can break off and loosen.

To examine these factors a series of tests was made of the strength of the actual screws and of their anchorage in the bone under various conditions.

MATERIAL AND METHODS

To test the strength of the anchorage between the bone and the screws femoral shafts obtained at autopsies were used. The thickness of the compact bone was 8-9 mm in the tested areas. Three types of screws were inserted in one cortical wall, namely, ordinary self-threading Vitallium Sherman screws, A. O. screws of stainless steel, intended for insertion after threading, and an experimental self-threading screw of stainless steel. The outside diameter, root diameter, pitch, pressure area per thread, and shear area on an 8 mm length (the thickness of the cortical bone) are given in Table 2.

To find the differences in strength on screwing through one and 2 cortical walls

Table 2. Material and dimensions of the screws tested.

	Material	Outside diameter (mm)	Root diameter (mm)	Pitch (mm/turn)	Pressure area per thread (mm ²)	Shear area on 8 mm length (mm ²)
Sherman	Vitallium	3.7	2.7	1.3	5.5	92.9
A.O.	Stainless steel	4.5	3.1	1.8	8.0	113.0
Experimental	„ „	4.8	4.0	0.8	5.6	120.6

* The theoretical maximum shear area. It is usual to count with a loss of 15 per cent owing to the thickness of the screw at the periphery, but this does not affect the comparison of the various screws.

a comparison was made for Sherman screws applied in each way. In addition, the effect of different drill diameters on the strength of anchorage was tested using the Sherman screws. Finally, the screws themselves were tested for their tensile strength.

Pre-boring, any threading, and insertion of the screws were performed with the usual surgical instruments. Since the tests were performed on specimens it was possible to handle the instruments with greater accuracy than would have been the case on the patient. The strength tests were carried out at the National Testing Laboratory, Stockholm, with standard methods.

RESULTS

The experimental screw proved to be on average the most securely fixed in the bone, followed by the A. O. and, last, the ordinary Sherman screw (Table 3).

The anchorage was about twice as great for screwing in 2 cortical walls as one (Table 4). The resistance to withdrawal for screws in 2 walls of a tube is usually only slightly better than for one wall, owing to the elasticity of the tube. There was thus a favourable difference between the bone and, for instance, a steel tube in this respect.

In a comparison of the strength of screws after different types of

Table 3. Strength of anchorage in the femoral cortical bone 8-9 mm thick, for various screws.

Type of screw	No. of test	Tensile strength (kp*)	
		Mean	Range
Sherman	30	178	45-270
A.O.	20	232	78-315
Experimental	20	240	75-315

* kp (kg f) = kilopound = 9.80665 newtons = 2.2046 pounds force.

Table 4. Comparison of anchorage strength on application of Sherman screws through one or both cortical walls of femoral cortical specimens (8-9 mm thick walls).

	No. of test	Tensile strength (kp)	
		Mean	Range
One cortical wall	10	181	45-250
Two cortical walls	10	351	290-405

pre-boring it was found that a narrower centre drill than that recommended by the manufacturer gave a slightly greater strength (Table 5).

In a comparison of the actual screws with respect to their own strength the larger steel ones were much stronger than the narrower Vitallium ones (Table 6). The mean strength of the Vitallium screws was greater than that of the anchorage between the screw and the bone (8 mm cortical bone, 2 walls), but there were a few screws that were weaker than the anchorage, so that the screws might sometimes break simply because they are weaker than the bone in which they are placed.

Table 5. Comparison of anchorage strength for Sherman screws in femoral cortical bone (8-9 mm thick) where the pre-boring was done with 2.8 and 3.0 mm centre drills.

Centre drills (mm)	No. of tests	Tensile strength (kp)	
		Mean	Range
3.0 mm	10	181	45-250
2.8 mm	10	201	70-290

Table 6. Comparison of tensile strengths of various screws.

Type of screw	No. of tests	Tensile strength (kp)		Lowest ultimate strength (kp/mm ²)
		Mean	Range	
Sherman	20	409	255-475	45
A.O.	10	511	415-620	55
Experimental	10	710	635-815	51

DISCUSSION

As in the discussion on the rigidity of the plates, it is necessary here, too, to distinguish between the purely mechanical conditions in a single experiment and the results for vital bone, which undergoes gradual change in calcification during healing.

The screws should be considerably stronger than their anchorage in the bone; but this does not apply to the ordinary Sherman screws. Even if the plates are fixed with several screws the full tractive force will occasionally be borne by only one of them, and they will then rupture in turn. Screws may also break because they are inserted askew and

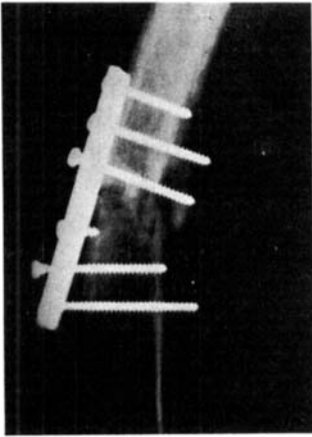


Figure 6. Radiograph of an A.O. plate (no. 12) used to immobilize a femoral fracture; the screws loosened owing to abnormal load.

are therefore subjected to a bending force rather than pure traction. The threads will then often act as notches, and the strength in the case of these bending forces will be low. In contrast to various stainless steels Vitallium has a low toughness, which renders the material extremely susceptible to rupture on bending.

The ordinary Sherman screws are probably too weak for their purpose. In mechanical calculations of strength it is common to specify a safety factor of 3; it would then be necessary for the screw to tolerate a tensile strength about 3 times greater than the strength of its anchorage in the bone.

The anchorage in the bone was strongest for the experimental screw, which, as is seen from Table 2, also has the greatest shear area in the bone by virtue of its greater outer diameter. It is, however, not so much stronger than the A. O. screw, as would be expected from its shear area, probably because it is self-threading, while the hole for the A. O. screw is made with a tap. This cuts much more exact threads than can be obtained with a self-threading screw, which to some extent crushes the bone and thus presumably reduces the strength of the anchorage. With an ideal plate-screw design the anchorage in the bone is certainly the weakest point. Even though in a single experiment it is possible to obtain an extremely strong anchorage between plate and bone by using many screws with a large shear area, in the long run it will probably be the weakening of the bone in the threads that will decide where the immobilizing device will most likely fail. Figure 6 shows a fracture of the femur in which the fragments were immobilized with an A. O. plate

with 6 screws. The anchorage was extremely good when tested at operation, but, when the patient was, in error, allowed to walk and work with the full weight on the leg 4 weeks after the operation, the screws loosened in the bone; but they were not fractured, nor was the plate bent. What are, then, the factors that are responsible for the weakening of the anchorage in the bone with time? It is conceivable that by virtue of its irritant effect on the tissue the actual material in the screw can cause resorption of the bone or demineralization in the threads. It is also known that during healing there is a general demineralization throughout the region of fracture, including the site for the screw holes. Moreover, under moderate pressure there is a tendency for calcification to occur, while at higher pressures there is resorption of the bone (4). For these reasons it is best to use materials that exert the smallest irritant effect, to use many screws so as to distribute the pressure, to insert them accurately so that they all bear their share of the traction, to thread the holes and to ensure that there is a fairly large shear area between the screws and the bone. What shape of screw is best can be decided only on the basis of practical tests. The screws now in common use (Sherman) probably do not satisfy these theoretical requirements, but the relatively new A. O. screws are satisfactory in this respect. Another factor that may be of importance so far as bone resorption in the threads is concerned is the temperature generated in the bone during drilling. As the drills are usually run at a high speed and the actual drill is not very sharp, a high temperature will result. It might be expected that a high temperature would be an advantage, since the bone is then devitalized and hence will not decalcify over a long period; but the opposite, a more rapid decalcification, might occur.

To summarize, the anchorage of a plate should satisfy the following requirements: the rigidity and shape of the plate should be such that the strength of immobilization is roughly equal to that of the bone; enough screws must be used (for instance, 4 on each side of the fracture) and the shear area should be large; the material should be as little irritant as possible.

These requirements are at present best fulfilled by the A. O. plate; when it has been modified the Lindahl plate will also meet these demands.

The above comments relating to tests on femoral shafts are probably applicable also to other long bones, though possibly not to the tibia, Owing to its triangular cross-section and proximity to the skin, immo-

bilization in this case presents special problems, which are not covered by the above discussion.

SUMMARY

Seventeen different types of fracture plates have been tested for rigidity against bending and torsion when affixed to femoral shafts obtained at autopsy, in which transverse fractures had been sawn.

The best fixation was obtained with the heavier plates (A. O., Haggland, Lindahl). An examination of the strength of the anchorage between the various screws and the bone, and of the strength of the screws themselves, was also performed. The usual Vitallium screws were found to be weak and to provide a poor anchorage in the bone, while the A. O. screws were satisfactory in this respect. The principles associated with the immobilization of fractures with plates are discussed, as is the design of the plates and screws in respect of the best possible mechanical and "biologic" conditions for healing of the fracture.

RESUME

Dix-sept différents types de plaques de fractures fixées à des corps fémoraux obtenus par autopsie dans lesquels des fracture transversales avaient été provoquées ont été soumis à des épreuves de rigidité contre la flexion et la torsion.

La meilleure fixation a été obtenu avec les plaques lourdes (A. O., Haggland, Lindahl). Un examen de la force de l'ancrage entre les différentes vis et l'os et de la force des vis elles-mêmes a également été pratiqué. On a trouvé que les vis courantes de Vitallium sont trop faibles et assurent un mauvais ancrage dans l'os, alors que la vis A. O. donne satisfaction à cet égard. Il est discuté des principes liés à l'immobilisation des fractures vissées au moyen de plaques et de la forme des plaques et des vis en vue de fournir les meilleures conditions mécaniques et "biologiques" possibles pour la guérison de la fracture.

ZUSAMMENFASSUNG

Siebzehn verschiedene Typen von Bruchplatten wurden auf Widerstandskraft gegen Beugung und Drehung geprüft, nachdem sie an bei der Autopsie erhaltenen Femurschaften, in die eine Querfraktur gesägt worden war, fixiert worden waren.

Die beste Ruhigstellung wurde mittels der schwereren Platten er-

halten (A. O., Haggland, Lindahl). Eine Untersuchung der Verankerungsstärke zwischen den verschiedenen Schrauben und dem Knochen und der Stärke der Schrauben selbst wurde ebenfalls ausgeführt. Die gewöhnlichen Vitalliumschrauben erwiesen sich als schwach und ergaben nur eine schlechte Verankerung im Knochen, während die A. O. Schrauben in dieser Hinsicht zufriedenstellend waren. Die Prinzipien in Verbindung mit der Ruhigstellung von Brüchen werden besprochen, ebenso die Konstruktion von Platten und Schrauben hinsichtlich der best möglichen mechanischen und "biologischen" Bedingungen zur Bruchheilung.

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