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Department of Orthopaedic Surgery,
Århus County Hospital, University of Århus, Denmark.
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MEASUREMENTS OF STABILITY OF CRURAL FRACTURES TREATED WITH HOFFMANN OSTEOTAXIS

2. *Measurements on Crural Fractures*

TORBEN EJSING JØRGENSEN

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A previous paper (Jørgensen 1972) about measurements of deflection on Hoffmann-treated crural fractures described a mechanical method of measuring the bone deflections during load bending. The method was used to estimate the stiffness of autopsy crura.

These preliminary examinations were performed as an introduction for measuring the stiffness of crural fractures, which is dealt with in the present paper.

The aim of the examinations is to estimate the maximum total deflection value of a crural fracture to allow quiet walking at full weight bearing.

MATERIAL AND METHODS

Notations and Formulae

Bending moment: force in kgf × lever in metre = kgfm. Bone deflection + fracture deflection = total deflection. The deflection is expressed in figures as radians to simplify the calculations and in degrees to get a generally known measure.

$$1^\circ = \frac{2 \times \pi}{360} \text{ rad} = 1.745328 \times 10^{-2} \text{ rad. } 1 \text{ rad} = 57.29579^\circ.$$

Bone deflection: the angle described in the plane of the force, when a 12 cm long bone specimen, fixed at one end, is moved from one position (+) to the opposite position (—). The bending moment at the fixed end is ± 5 kgf × 0.18 m = ± 0.9 kgfm (Figure 1). The fracture deflection: the angle described in the plane of the force, when a fracture is moved from one position (+) to the opposite position (—). The bending moment of the fracture provided this is in the middle of the bone specimen, is ± 5 kgfm × 0.12 m = ± 0.6 kgfm (Figure 1).

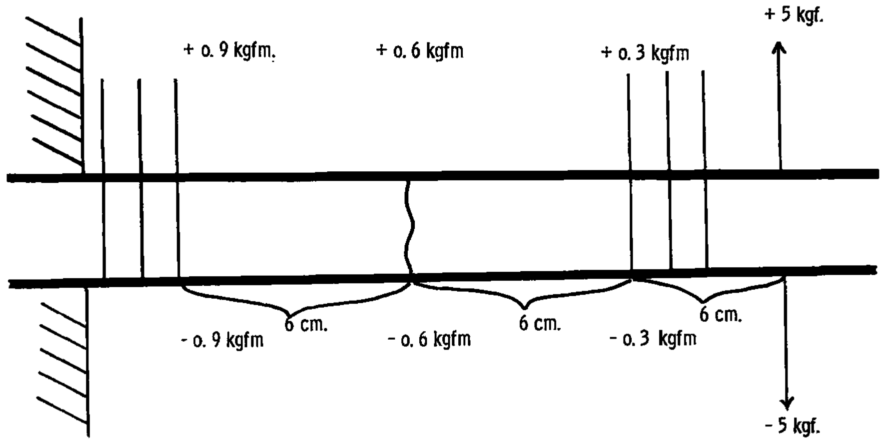

Figure 1. Diagram of a fractured bone. The left end of the bone is fixed. The right, free end is loaded with ± 5 kgf. The bending moments on the fracture and the bone are shown in the figure.

Principle

The principle of the method (Jørgensen 1972) was calculated on an intact bone specimen, fixed at one end and loaded at the unfixed end with a known force. In this way the bone deflection decreased gradually from the fixed end to the unfixed bone end. When the bone deflection was small and the bendings were performed to either side of the neutral point, it was possible in practice to calculate the bone deflection as if this took place at one point in the middle of the bone specimen.

When the measuring method is transferred to a fractured bone, the fracture is situated halfway between the two sets of Hoffmann screws (Figure 1). The measuring principle may thus be used on a crural fracture, provided that the fracture is in the middle of the bone specimen and that the bending of the fracture takes place in the axis of the bone (Figure 2).

When the deflection is measured on a crural fracture, the total deflection consists of a bone deflection and a fracture deflection.

Figure 1 shows how the force of the spring balance affects the bone and the fracture, respectively. The bone is loaded with a bending moment of ± 0.9 kgfm at the fixed end. At the unfixed end the bending moment is ± 0.3 kgfm. The fracture is loaded with a bending moment of ± 0.6 kgfm.

Measurements in Practice

The measuring equipment has been described previously (Jørgensen 1972). The patients are placed on a firm bed to reduce the muscle tension as much as possible. The steel bar, stabilizing the fracture, is substituted by the measuring equipment.

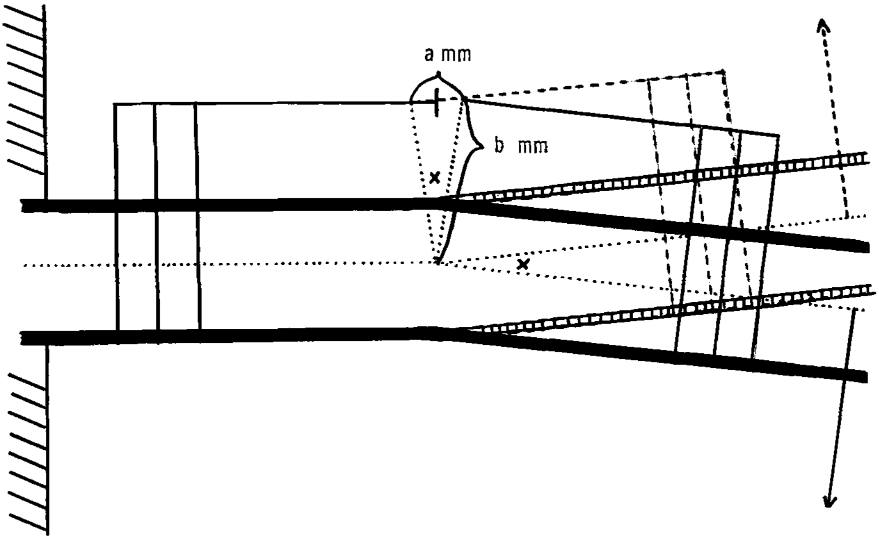

Figure 2. Diagram of a fractured bone loaded at the right end. The angle of deflection X corresponds to the total deflection = bone deflection + fracture deflection.

$$X = \frac{a}{b}$$

The axes of the instruments must be parallel to the axis of the bone. Proximally the leg is held by the examinator's one hand while 12 cm distally to the fracture a spring balance is pulled with 5 kgf, first in the anteromedial direction and in the posterolateral direction (Figure 3 and 4). The micrometer is read in either extreme position. The distance from the measuring bridge to the axis of the bone is measured by tape.

The total deflection may then be calculated as:

$$\frac{\text{Deflection on the micrometer}}{\text{Distance between bone and measuring axis}} \text{ rad.}$$

In the cases where it was impossible to obtain a distance of 12 cm from the load point to the fracture, the force administered was increased so that the bending moment remained ± 0.6 kgfm.

Measuring Error

In 3 patients repeated measurings were performed after the measuring equipment had been mounted on and dismounted from the Hoffmann apparatus. This showed that the error in reading in a single measuring μ was ± 0.023° (2.3 per cent) when the total deflection was 1°, ± 0.025° (3.6 per cent) when the total deflection was 0.67°, and finally ± 0.012° (4 per cent) when the total deflection was 0.30°. This degree of accuracy applies to comparisons of measurings in one patient where the Hoffmann apparatus is unchanged.

When measurements from different patients are to be compared, the inaccuracy in the distance from the measuring axis to the bone axis must be included when

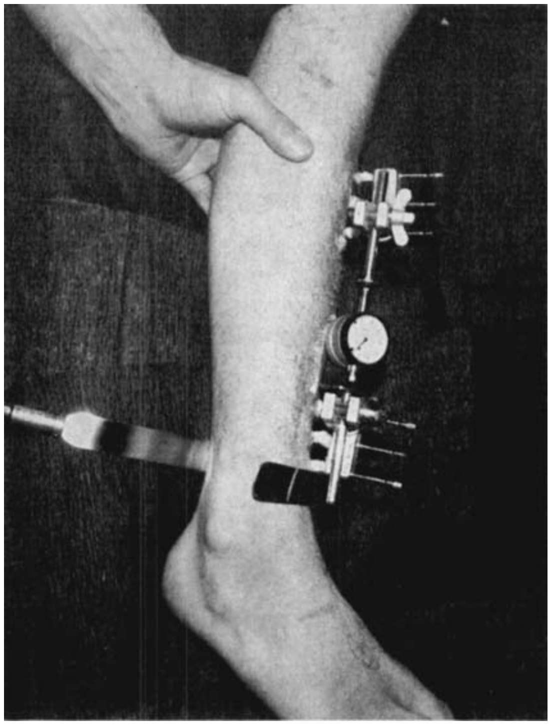

Figure 3. A crural fracture loaded by a spring balance in the posterolateral direction.

calculating the measuring error. The deviation of this distance is estimated to 5 mm, which means an error of ± 10 per cent.

When comparison is made between the measurements of two different patients, the total error amounts to:

$\sqrt{10^2 + (2 \times 4)^2} = 13$ per cent.

Patients

The material in Table 1 comprises 40 patients with crural fractures. The measurings were performed at the time when it was clinically estimated that the fractures permitted total weight bearing at quiet walking after removal of the stabilizing steel bar. When the examinations were started, the criterion for allowing full weight bearing was that the total deflection was approximately 1.5°. With growing experience this value was gradually decreased to below 0.5°. (Figure 5). In 4 patients (nos. 3, 13, 14 and 24) the condition of accompanying fractures and lesions caused weight bearing and deflection measurements to be delayed.

In patient no. 20 the crural fracture was considered stable after 5½ months. However, pain and instability occurred after 1 week's weight bearing, whereupon

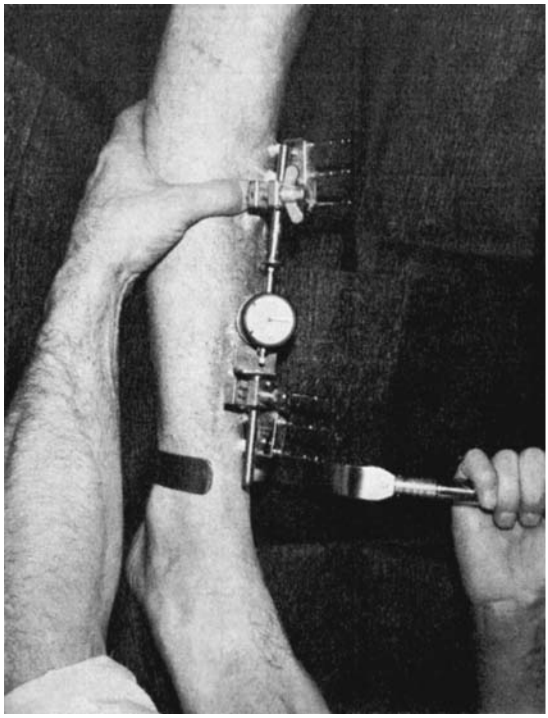

Figure 4. A crural fracture loaded by a spring balance in the anteromedial direction.

the steel bar had to be replaced for 1½ months before the fracture was stable. In patient no. 22 the crural fracture was considered stable after 4½ months, but pseudoarthrosis developed after 6 months.

After the measurements were taken the patients were generally allowed full weight bearing at quiet walking for 1 to 2 weeks. If neither prolonged fractural pain nor clinical instability occurred, the Hoffmann screws were removed.

RESULTS

1. Two out of 15 fractures with a total deflection of more than 1° were prematurely loaded with full weight bearing at quiet walking. Patient no. 22 developed pseudoarthrosis.

Patient no. 20 developed pain shortly after initiating the loading together with increased instability in the fracture.

2. 25 patients with a fracture deflection of: $\leqq 1°$ all tolerated the load of full weight bearing at quiet walking.

Table 1. Recorded total deflections in crural fractures, where the fractures are loaded with ± 0.6 kgfm.

Patient number	Age	Sex	Duration of fracture in months	Deflection in degrees	Primary and secondary complications of fracture
			Uncomplicated transverse fracture in the middle third of crus		
1	14	♀	5½	2°	Healing delayed by a sclerotic fragment in the fracture.
2	16	♂	3½	0.5	
3	17	♂	6½	0.20	Ipsilateral femoral fracture, intramedullary nailed. Delayed loading of crural fracture.
4	17	♂	3	1.43	
5	18	♂	5½	1.15	Ipsilateral femoral fracture treated with extension. Sclerotic fragment in the tibial fracture necessitated bone transplantation.
6	21	♂	4	1	
7	21	♂	2½	0.38	Contralateral amputation of crus, and femoral fracture nailed. Crural fracture not displaced.
8	22	♂	2½	0.57	Bilateral crural fractures, mentally retarded.
9	22	♂	3½	1	Ipsilateral lesion of the foot, which prolonged immobilization.
10	24	♀	3	0.72	
11	28	♂	6	1.43	Refracture in the third month, reposition.
12	44	♂	18	1	Ipsilateral femoral fracture, nailed. Resection fibulae in the 6th month due to non-union.
13	55	♂	5	0.5	Ipsilateral fracture of the knee.
14	79	♀	13	1	Ipsilateral pertrochantary femoral fracture treated with McLaughlin osteosythesis.
			Complicated transverse fracture in the middle third of crus		
15	18	♂	4	1	
16	20	♂	3	0.38	
17	22	♂	2½	0.57	Bilateral crural fractures, mentally retarded.
18	26	♀	4	1.43	
19	34	♂	5½	1	Ipsilateral lesion of the knee and femoral condyloid fracture.
20	37	♂	5½ 5¾ 7	(1.15) (2.36) 1	Postoperative skin necrosis towards the fracture, skin transplantation. At weight bearing after 5½ months pain and increased instability of the fracture. Stable fracture after 7 months.

(Table 1. Cont.)

Patient number	Age	Sex	Duration of fracture in months	Deflection in degrees	Primary and secondary complications of fracture
21	62	♂	6	0.30	
		Uncomplicated transverse fracture in the distal third of crus			
22	16	♀	4½	1.15	6 months after measurements clinical and radiological pseudoarthrosis.
23	17	♂	2½	1.15	3½ months following fracture new trauma with a fracture fissure proximally in tibia, no refracture in primary fracture.
24	21	♂	4½	0.38	Ipsilateral femoral fracture, nailed.
25	47	♂	2½	1	
26	56	♂	7½	0.76	The fracture was displaced in the 5th month and had to be reset.
		Complicated transverse fracture in the distal third of crus			
27	21	♂	5	0.76	
28	21	♂	4	0.76	
29	55	♀	6	1.43	
30	72	♀	3½	0.57	Patient loaded the fracture after 6 weeks, resulting in displacement, which was reset.
		Uncomplicated longitudinal fracture in the middle third of crus			
31	12	♂	3½	1.15	Pelvis fracture. Primary plaster of crural fracture, but at displacement osteotaxis.
32	20	♀	3	0.57	
33	26	♂	2½	1.15	
34	41	♀	3	1.15	
35	59	♂	4	0.76	
		Uncomplicated longitudinal fracture in the distal third of crus			
36	16	♂	3½	1.43	
37	26	♂	2	0.57	
38	30	♂	2½	1.43	The fracture line proceeded into the ankle
39	65	♂	2½	1.43	joint.
		Complicated longitudinal fracture in the distal part of crus			
40	44	♀	4	0.76	

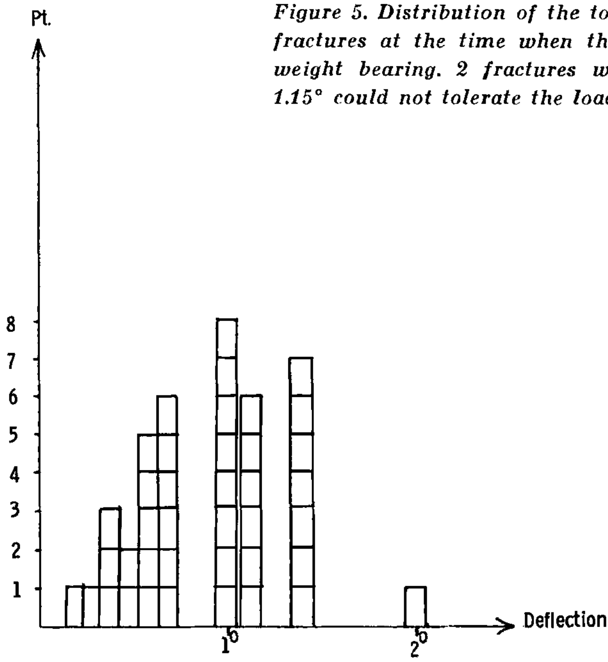

Figure 5. Distribution of the total deflection of 40 crural fractures at the time when they were loaded with full weight bearing. 2 fractures with a total deflection of 1.15° could not tolerate the load.

DISCUSSION

The results of the measurings seem to indicate that the fractures permit loading when they have a total deflection of 1° or below. But is this value of total deflection directly comparable within different fractures? If the deflection of the fractures in frail and strong bones are compared at identical total deflections, it must be taken into consideration that the bone deflection is greatest in the frail bones, and thus the fracture deflection will make up a comparatively smaller part of the total deflection. This means that at identical total deflections the smallest fractural deflection is found in frail bones.

When the ultimate strength of different fractures at bending is to be compared during healing, various uncertain factors are involved, mainly due to the fact that callus cannot be regarded as a homogeneous mass with identical physical properties all over. From the daily clinic it is well known that the thickness of callus does not offer a reliable measure for the ultimate strength. The ultimate strength of callus at bending loads is determined by the strength at compression and tension in the areas of the fracture where the applied forces have the greatest

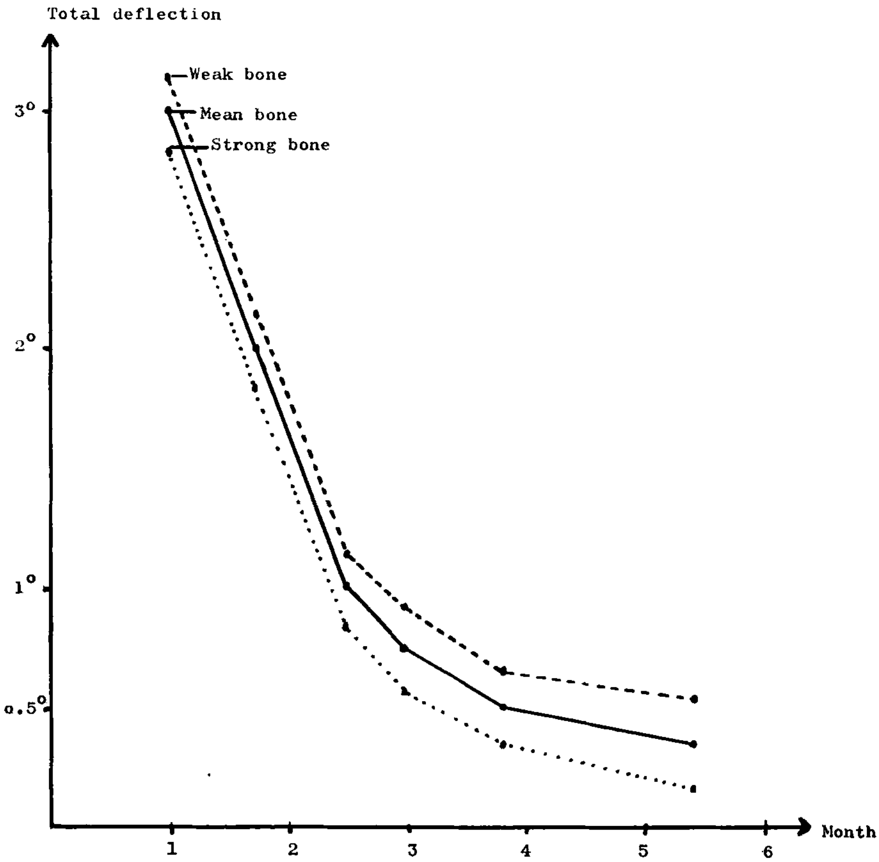

Figure 6. 3 normal fractural healing curves based on calculations in Table 2. At identical times the 3 fractures have the same stiffness. When the total deflection is more than 1°, the stiffness of the fracture can be compared within ± 1 week. At a total deflection below 1° no comparison can be made.

effect. These areas are found farthest away from the bending axis of the fracture. The ability of elastic deformation of the tissue here determines the maximum fractural deflection without damage to the callus. By measuring fractured rabbit bones, Henry et al. (1968) found that there was a linear relation between the stiffness and the ultimate strength of the fracture.

Compared with this, but with certain reservations as to diameter, length and quality of callus, a practical limit for the bending of a fracture without damage to callus is likely to be found. If this value

Table

Bone deflection of a 12-cm autopsy crus loaded at fixed end by ± 0.9 kgfm (Jørgensen 1972)	
Total deflection: 0.5° of the crural fracture	Fracture deflection at ± 0.6 kgfm
	Bending moment on fracture, when the fracture deflection is 4°
	Comparison of the total deflections of equally strong fractures (± 16 kgfm)
Total deflection: 1° of the crural fracture	Fracture deflection at ± 0.6 kgfm
	Bending moment on fracture, when the fracture deflection is 4°
	Comparison of the total deflections of equally strong fractures (± 3.7 kgfm)
Total deflection: 2° of the crural fracture	Fracture deflection at ± 0.6 kgfm
	Bending moment on fracture, when the fracture deflection is 4°
	Comparison of the total deflections of equally strong fractures (± 1.4 kgfm)
Total deflection: 3° of the crural fracture	Fracture deflection at ± 0.6 kgfm
	Bending moment on fracture, when the fracture deflection is 4°
	Comparison of the total deflections of equally strong fractures (± 0.90 kgfm)

is arbitrarily estimated at a fracture deflection of 4°, a theoretic picture of the problem may be advanced (Table 2, Figure 6).

Table 2 shows that the ultimate strength of the fractures in theory at a total deflection of 2° and 3° deviates only slightly. At a total deflection below 1°, however, there is considerable deviation in the ultimate strength of the fractures.

Figure 6 shows normal fractural healing curves which will be explained further in a following paper. The curves show the ratio between the total deflections and the time after the occurrence of the fractures. The 3 curves are made on the basis of theoretical calculations in Table 2, so that a certain theoretical fractural strength or stiffness corresponds to a certain time. The curves show that without

2.

Strong bone 0.16°	Mean bone 0.35°	Weak bone 0.52°
0.5 — 0.16 = 0.34°	0.5 — 0.35 = 0.15°	0
$\frac{0.6 \times 4}{0.34} = \pm$ 7 kgfm	$\frac{0.6 \times 4}{0.15} = \pm$ 16 kgfm	
0.16 + 0.15 = 0.31°	0.5°	0.52 + 0.15 = 0.67°
1.0 — 0.16 = 0.84°	1.0 — 0.35 = 0.65°	1.0 — 0.52 = 0.48°
$\frac{0.6 \times 4}{0.84} = \pm$ 2.9 kgfm	$\frac{0.6 \times 4}{0.65} = \pm$ 3.7 kgfm	$\frac{0.6 \times 4}{0.48} = \pm$ 5 kgfm
0.16 + 0.65 = 0.81°	1°	0.52 + 0.65 = 1.17°
2 — 0.16 = 1.84°	2 — 0.35 = 1.65°	2 — 0.52 = 1.48°
$\frac{0.6 \times 4}{1.84} = \pm$ 1.3 kgfm	$\frac{0.6 \times 4}{1.65} = \pm$ 1.4 kgfm	$\frac{0.6 \times 4}{1.48} = \pm$ 1.6 kgfm
0.16 + 1.65 = 1.81°	2°	0.52 + 1.65 = 2.17°
3 — 0.16 = 2.84°	3 — 0.35 = 2.65°	3 — 0.52 = 2.48°
$\frac{0.6 \times 4}{2.84} = \pm$ 0.84 kgfm	$\frac{0.6 \times 4}{2.65} = \pm$ 0.90 kgfm	$\frac{0.6 \times 4}{2.48} = \pm$ 0.96 kgfm
0.16 + 2.65 = 2.81°	3°	0.52 + 2.65 = 3.17°

knowing the bone deflection, it is possible in practice to compare the theoretical ultimate strength or stiffness of the fractures down to a total deflection of approximately 1°. When the total deflections are small (< 1°) the ultimate strength of the fractures differ so much that they are no longer comparable.

Provided deflection measurings exist of one crural fracture at different points, information is supplied of relative changes in the fractural strength. In order to set up a load criterion for fractures, the individual gait of each patient must be taken into consideration, even though this has no relation to the strength of the bones. A heavy man may very well walk inappropriately on thin bones, while a thin man may have an elegant and light gait on solid bones.

Thus the basis for stating a certain ultimate strength as a load criterion disappears. The following may then be set up as a load criterion, namely, that the fractures must tolerate a loading prescribed from repeated deflection measurings. These measurements are to be continued after the loading of the fractures.

In the following papers this criterion will be elaborated.

SUMMARY AND CONCLUSION

In continuation of a previous paper (Jørgensen 1972) on deflection measurements on autopsy crura, this paper describes and discusses bending measurements performed on crural fractures treated with the Hoffmann apparatus.

Bending measurements have been made on the crural fractures of 40 patients at a time when the fracture was loaded with full weight bearing at quiet walking. In the beginning of the examination the criterion for allowing full weight bearing was that the total deflection was approximately 1.5°. This deflection value was then gradually decreased to about 0.25°.

Of 15 patients having a deflection of more than 1°, one patient had clinically re-fracture within a few days, and another patient developed pseudoarthrosis 6 months after initiating the loading. 25 patients, with crural fractures with a total deflection of 1° and below, all tolerated full weight bearing at quiet walking. It is concluded that no load criterion can be set up based only on the stiffness of the fractured bone.

On the other hand, it is possible within a reasonable safety margin, to guard against re-fracture if, at a deflection of 1°, full weight bearing is allowed with support of 2 crutches and if the fracture is still fixed by the Hoffmann apparatus.

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Correspondence to:
Torben Ejsing Jørgensen
Agernvej 17, 8330 Beder
Denmark