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MEASUREMENTS OF STABILITY OF CRURAL FRACTURES TREATED WITH HOFFMANN OSTEOTAXIS

4. *The complicated, terminal phase of healing of crural fractures*

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In a previous article (Jørgensen 1972 c) the uncomplicated, terminal healing phase was illustrated by systematic measurings of the deflection in 35 crural fractures treated by the Hoffman apparatus. By means of these measurements the healing curves of the individual fractures could be made. The courses of these curves were smooth without demonstrable "breaks".

In this paper 20 crural fractures are presented, the healing curves of which deviate from previously described normal curves. The deviations are considered in the light of occurring conditions and incidents to which the fractures have been exposed.

The aim of the present paper is to demonstrate what diagnostic and therapeutic aspects the systematic measurements of the deflections will reveal in the treatment of crural fractures. The measuring principle and the loading programme have been described previously (Jørgensen 1972 a, b, c).

Notation and Formulae (Jørgensen 1972 a, b, c)

Bending moment: Force in kgf $\times$ lever in metre $=$ kgfm. Bone deflection $+$ fracture deflection $=$ total deflection. The deflection is expressed in figures as radians to simplify the calculation and in degrees to get a generally known measure. $1° = \frac{2 \times \pi}{360}$ rad $= 1.745328 \times 10^{-2}$ rad. 1 rad $= 57.29579°$.

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Bone deflection: 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 bone end is: ± 5 kgf × 0.18 m = ± 0.9 kgfm.

The fracture deflection: The angle described in the plane of the force when a fracture is moved from one position (+) to the opposite (—). The bending moment of the fracture, provided this is found in the middle of the bone specimen is: ± 5 kgf × 0.12 m ± = 0.6 kgfm.

MATERIALS AND METHODS

The case histories and the healing curves are listed in Table 1. The crural fractures of 20 patients have been followed by systematically measuring the deflection in the terminal healing phase, which has been marked by complications given in Table 2.

The patients were followed as out-patients and simultaneously with each measur-

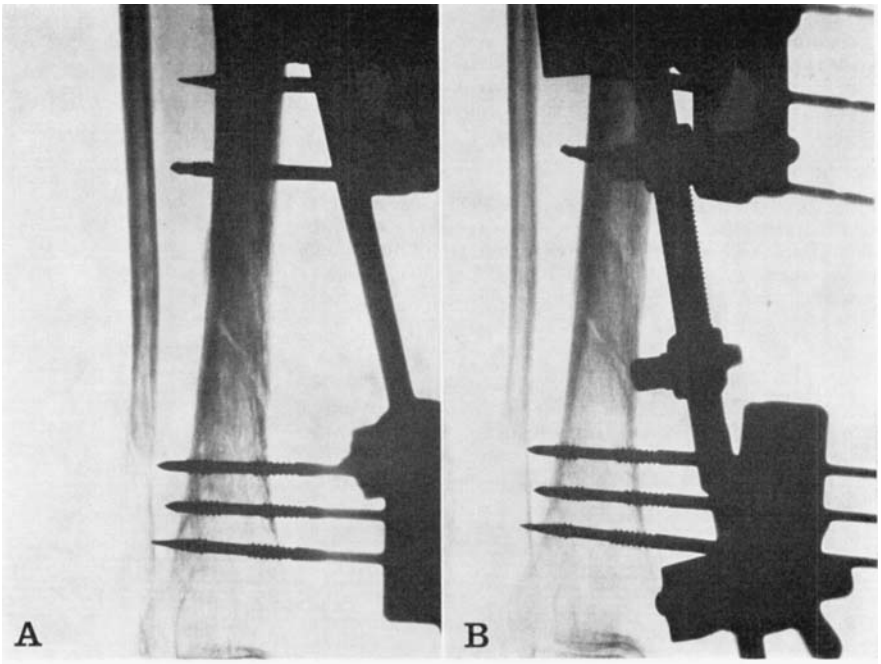

Figure 1. X-ray examination of the crural fracture in case no. 1. A: 5¼ months after the fracture development of a severe reflex sympathetic dystrophy. B: The clinical signs of dystrophy and the X-ray visible osteoporosis disappeared after 3 weeks of axial compression of the tibia.

Table 1.
PW: Partial weight-bearing. BL: Bar loosened at one end. BR: removed.

Case no. 1: A 58-year-old woman with an uncomplicated longitudinal fracture in the distal part of crus. In the 3rd month development of a clinical reflex sympathetic dystrophy and osteoporosis. 5¼ months after the fracture, axial compression was applied by means of a compression bar. The dystrophy and the osteoporosis disappeared within 2 to 3 weeks. Figure 1 shows the fracture just before and after the compression.

Case no. 2: An 80-year-old man with a complicated double fracture in the middle of the crus. The skin was severely dilacerated and skin transplantation and sequestrectomy had to be performed several times. Four months after the fracture, the stabilizing bar was removed by mistake and the patient loaded the fracture. Consequent pain and increased instability of the fracture occurred. The fracture was refixed by means of a straight bar and loading postponed till the 7th month. Thus the skin and fracture healed.

Case no. 3: A 44-year-old man with an uncomplicated transversal fracture of crus and an ipsilateral fracture of the medial malleolus. In the 3rd month reflex sympathetic dystrophy developed. The increase in the callus formation was very small and the patient had several attacks of renal calculus. Laboratory examination revealed no signs of hyperparathyroidism. Six and a half months after the fracture, when the healing stopped, electrical AC-treatment was started. The dystrophy disappeared, the stability of the fracture increased and healing occurred.

Case no. 4: An 18-year-old man with a complicated transversal fracture. Primary skin healing. Two months after the fracture, the patient fell and hit the fractured leg. Consequent pain in the fracture for 2 days, but X-ray revealed no signs of refracture.

Case no. 5: A 44-year-old woman with a complicated longitudinal fracture. Primary skin healing. Three months after the fracture, the patient bumped the leg against the ground and had fractural pain for 2 to 3 days. X-ray showed no refracture.

Case no. 6: A 20-year-old man with a complicated transversal fracture. Primary skin healing. Hit the leg 2 and 2½ months after the fracture, each time with pain for 2 days. X-ray showed a doubtful fissure in the callus.

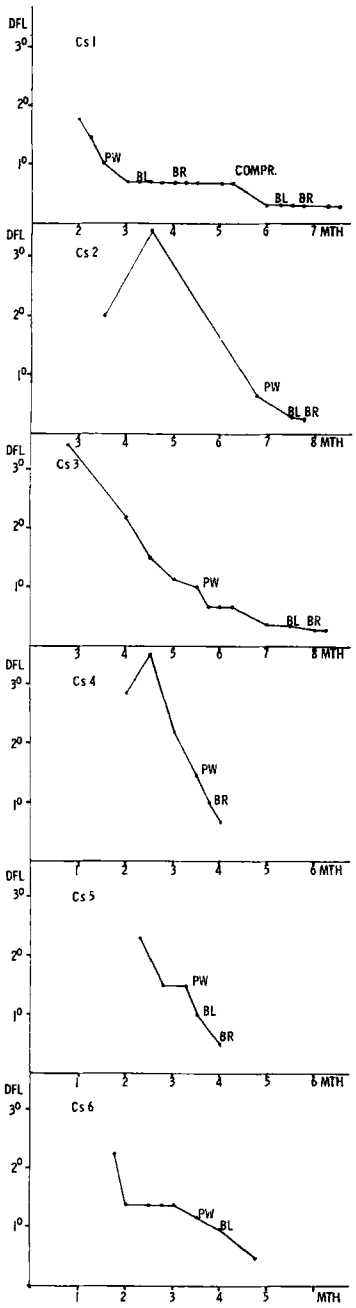

Table 1. (Cont.)

Case no. 7: A 37-year-old man with a complicated, comminuted transversal fracture. Skin necrosis was transplantated. Osteosynthesis a.m. Rush was performed on an ipsilateral femoral fracture. Five months after the fracture the stabilizing steel bar was removed and partial weight-bearing started. In a few days pain and increased instability of the fracture occurred and the fracture was refixed and relieved for 1 ¾ months. X-ray showed no refracture.

Case no. 8: A 25-year-old man with an uncomplicated transversal fracture. Four and a quarter months after the fracture the patient hit his leg by alighting from a taxi. This small trauma was followed by fractural pain for one day. X-ray showed no refracture.

Case no. 9: A 17-year-old man with an uncomplicated transversal fracture. Two months after the fracture the patient had an accident with his motorbicycle and had a severe refracture, which was repositioned. Because of infection around the Hoffmann screws these were removed 3½ months after the fracture, which was then immobilized in a plaster of Paris. Clinical and roentgenologic healing was obtained 6 months after the fracture.

Case no. 10: A 43-year-old man with an uncomplicated longitudinal fracture. Two months after the fracture there was a small push trauma against the leg. Pain for few hours. The control examination at 3 ¾ months revealed that all the Hoffmann screws were loose with skin infection. The screws were removed and the fracture immobilized with a plaster of Paris. The fracture was clinically healed in the 10th month. By mistake the Hoffmann screws were primarily inserted in the tibia by means of a mechanical drill.

Case no. 11: A 23-year-old man with uncomplicated transversal fractures in the distal and in the proximal part of crus. Osteotaxis was performed with 2 sets of Hoffmann's apparatus. Due to defective crutch sticks the patient fell 2½ months after the fracture and had fractural pain for 2 to 3 days. At the 3rd month control local infection was found around the proximal screws, which were slightly loose. The stability was still sufficient and the infection remained localized until the fracture healed. X-ray showed no refracture.

Case no. 12: A 32-year-old man with an uncomplicated transversal fracture. Two and a half months after the fracture partial weight-bearing was permitted, but he started long walks with full weight-bearing at once. A few days later fractural pain and all loads were prohibited. At the following control the Hoffmann screws were loose with local skin infection. The Hoffmann apparatus was removed and substituted with a plaster of Paris.

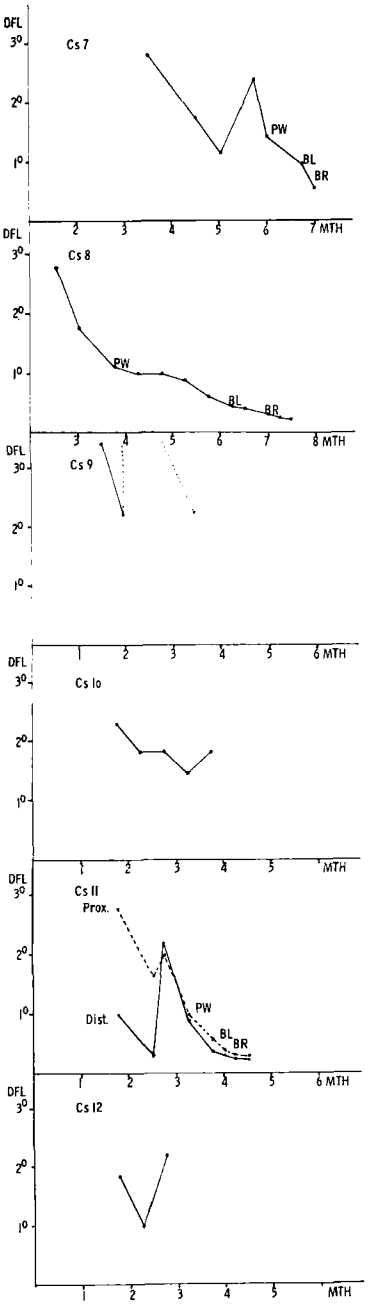

Table 1. (Cont.)

Case no. 13: A 15-year-old boy with an uncomplicated transversal fracture. Three and a half months after the fracture the patient had a trauma against the leg and pain for 1 day. By mistake the fixating steel bar was not tightened for 2 weeks. The control at 4½ months showed that the distal Hoffmann screws were loose and thus a compression bar was mounted. Sufficient stability could not be obtained and the Hoffmann apparatus was replaced with a plaster of Paris.

Case no. 14: A 24-year-old man with an uncomplicated transversal fracture. The healing curve was abnormal at the control at 3 and at 3½ months. The patient then confessed having driven his car for 1 month and operated the brakes and the accelerator with his broken leg without fractural pain. All loading was then prohibited. At the 6-month control the patient had used his car again. The X-ray showed no refracture.

Case no. 15: A 17-year-old man with an uncomplicated longitudinal fracture. Two months after the fracture the patient himself stopped using his crutch sticks and at the 2 ¾ month control he demonstrated jumping on his broken leg without fractural pain. The measurement of stability just after revealed decreased stability of the fracture, which had to be refixed for 9 weeks. X-ray showed a small fissure in the callus.

Case no. 16: A 30-year-old man with an uncomplicated transversal fracture. One and a half months after the fracture the patient began bicycling without pain. The measurement of stability revealed a halt in the healing and all loading was prohibited. At the 3-month control infection was found around the distal Hoffmann screws, which were loose and were removed. The stability of the fracture was so good that no plaster was needed. X-ray showed no refracture.

Case no. 17: A 19-year-old man with a complicated longitudinal fracture. Two and ¾ months after the fracture the steel bar was removed and the patient went with full weight-bearing, but fell on a concrete floor, hitting his leg violently, and had pain for 2 days. At the next control the stabilizing steel bar was remounted for 1 month. X-ray showed no refracture.

Case no. 18: A 24-year-old man with an uncomplicated transversal fracture. The patient had osteopsathyrosis with 25 previous fractures. The stability of the actual fracture was soon excellent, but the healing evidently stopped from 2¼ to 3 months after the fracture when the stabilizing steel bar was loosened. There was no fractural pain nor X-ray visible refracture. Full weight-bearing was permitted and in spite of this the stability increased so much that the Hoffmann apparatus could be removed.

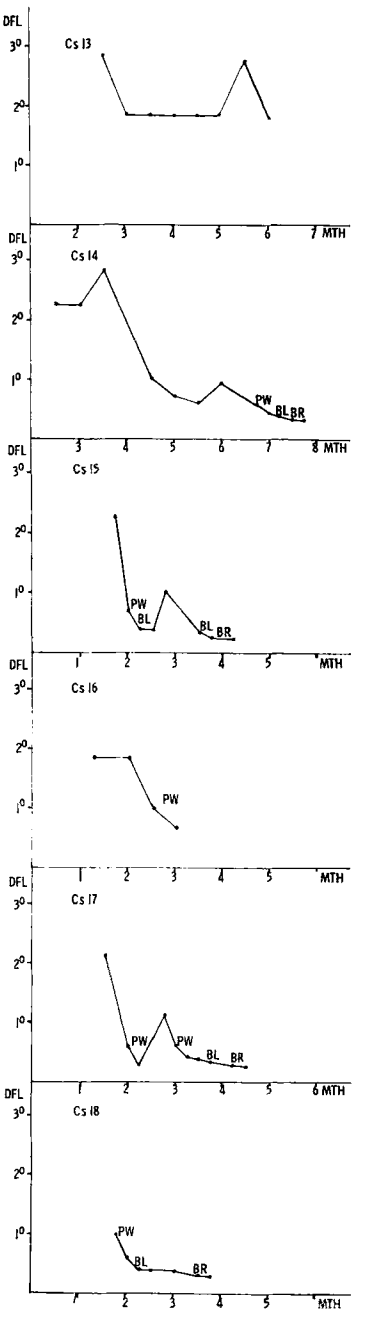

Table 1. (Cont.)

Case no. 19: A 74-year-old man with an uncomplicated transversal fracture with an intermediary fragment. Cortisone treatment through several years due to asthma-bronchiale. X-ray showed slight osteoporosis. Partial weight-bearing was permitted 3¼ months after the fracture. Hereby the stability of the fracture decreased and the loading was prohibited. There was no fractural pain. In the 5th month the patient had an acute cholecystitis and was operated. Postoperatively a short period of respiratory treatment. He recovered and was able to follow the loading programme. X-ray showed no refracture.

Case no. 20: A 34-year-old man with a complicated, comminuted transversal fracture with secondary skin necrosis and infection of the fracture. In 3 to 4 months the infection ceased and the fracture was covered with skin. An ipsilateral femoral fracture was osteosynthesized a.m. Rush and an uncomplicated counterlateral fracture of crus was treated with a plaster of Paris. The patient lost his temper and loaded the leg with full weight-bearing 10 months after the fracture. Showing him the consequences on the healing curve the patient realized the importance of following the loading programme.

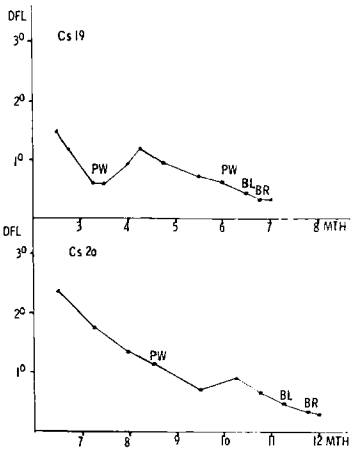

Table 2. Complications delaying or impeding the healing of the fractures. The numbers correspond to the case histories in Table 1.

Premature loading permission	Contravention of the loading prescribed	Mechanically poor fixation of the fracture	Reflex sympathetic dystrophy	Traumas with slight transient fractural pain. No X-ray visible refracture	Overloading without fractural pain	Traumas with X-ray visible refracture
2	12	10	1	4	14	9
7	14	13	3	5	15	
18	15	16		6	18	
19	16			8	19	
	20			10		
				11		
				13		
				17		

ing, the Hoffmann apparatus was checked for mechanical defects such as loose screws in the apparatus or in the bone. The screw holes in the skin were also checked for infection. The patients were questioned about pain at loading, about the way they loaded and the time for traumas, if they had been exposed to any. As far as possible the patients demonstrated the loading prescribed. X-ray examination was performed every month on an average, more frequently if overloading of the fracture was suspected.

Treatment of the Complications

Stagnation or reduction of fracture or bone stability were treated according to the following principles:

1. If the curve disclosed a heavy reduction in the stability due to overloading or trauma, all loading and remedial exercises were prohibited till the stability was so good that the previous loading criteria could be applied (Jørgensen 1972 c) (Patients nos. 2, 4, 7, 9, 14, 15, 16, 17, 19, 20).

2. If the reduction of the stability was due to the fact that the Hoffmann screws were loose in the bone, compression was applied by means of a compression bar, so that the screws were pressed in the holes towards the fracture (Patients nos. 10, 11, 13).

If this did not improve the stability within 2 to 3 weeks, or if infection occurred around the screws, the Hoffmann screws were removed and plaster applied (Patients nos. 9, 10, 12, 13, 16).

3. If the healing had ceased because of temporary overloading, the patients were told to be cautious regarding loading or remidial exercises till the curve showed improved stability (Patients nos. 5, 6, 8, 18).

4. At a reflex sympathetic dystrophy with so heavy an osteoporosis that the total deflection increased considerably, bone compression was used. By means of a compression bar a strong axial compression was applied to the bone section between the two sets of Hoffmann screws (Patient no. 1).

RESULTS

1. The healing curves show distinct "breaks" with temporal correspondance to recorded complications.

2. A single brief trauma delays the healing for 2 to 3 weeks (Patients nos. 4, 5, 8, 10, 11, 14, 17).

3. Two brief traumas at an interval of two weeks seem to add up in the delay of the healing (Patient no. 6).

4. Daily repeated overloadings of a fracture result in a marked delay of the healing (Patients nos. 2, 7, 15, 19, 20).

5. Reflex sympathetic dystrophy with osteoporosis seems either to delay the fracture healing or to increase the bone deflection (Patients nos. 1, 3).

6. The courses of the pathological healing curves seem to be due to overloading of the fracture apart from cases with reflex sympathetic dystrophy.

7. Fractures in patients with weak bone matrix (osteopsathyrosis or induced by cortisone) seem to be more vulnerable than other fractures (Patients nos. 18, 19).

8. Poor mechanical fixation of the fracture need not cause pain in the fracture, but may cause a marked delay in the healing (Patients nos. 10, 12, 13).

9. Overloading of a fracture is most frequently accompanied by transient pain (Patients nos. 14, 15, 19, 20). Occasionally there is no pain, however, even though a callus fracture is revealed on X-ray (Patient no. 14).

DISCUSSION

The results of these examinations positively support the classic principles for fractural treatment, where the crucial points are sufficient reposition, retention, immobilization and avoidance of all loading pain. Unfortunately all these points cannot be checked constantly at the traditional follow-up of fractures, but we must satisfy ourselves by noting that if a fracture heals, the points have been fulfilled. If a fracture does not heal, however, only a long period of latency may reveal that the points have not been fulfilled, and this may delay the therapy inappropriately.

By means of deflection measurements, Jernberger (1970) was able to plot healing curves of 40 crural fractures. At least 10 of these healing curves showed distinct "breaks", which were not commented, however, nor related to traumas or any other kind of overloading.

The present examinations have shown that by measuring the deflection systematically, important information is obtained regarding the course of the healing and the disturbing factors, if any. The healing curves give an objective picture of the course of the healing. Apart from reflex sympathetic dystrophy, the causes recorded for the pathological curves may be traced back to overloading of the fractures. Brief overloadings thus delay the healing for 2 to 3 weeks. The cause for this is probably micro fractures in the callus mass, which in the weakened part has to go through a fibrous-hyaline phase again before the phase of mineralization is reattained. If a fracture is constantly overloaded, the healing seems to cease for a rather long period. Human material is unsuitable for deciding for how long the healing is stopped, but some fractures will probably react by a very vigorous callus formation, so that the stability is gradually increased and the fracture heals after all. In practice it is well known, however, that some unstable fractures pass into a pseudoarthrosis. Some patients in the material maintained that they did not have pain at overloading, although this was accompanied by increased instability as well as callus fractures visible on X-ray.

The pathological healing curves were the only objective signs of

overloading of the fractures in 11 patients (Patients nos. 4, 5, 6, 8, 11, 14, 16, 17, 18, 19, 20).

A normal clinical estimation would have disclosed the overloading in 8 patients (Patients nos. 2, 7, 9, 10, 11, (distal) 12, 13, 15).

One-fourth of the patients did not have pain in the fracture in connection with the overloading (Patients nos. 14, 15, 16, 18, 19).

Three-fourths of the patients thus had transient pain following overloading, but the pain frequently disappeared in spite of continued overloading.

It will thus be inadvisable to graduate the loading of the fracture based only on the symptom of pain, which is very often of a rather diffuse nature and may be found even though the fracture has not been overloaded.

If the material in Table 2 is regarded retrospectively, an estimation of a possible prophylaxis against complications may be obtained.

Premature Loading Permission

If the patients nos. 2 and 7 had followed the previously described loading criteria, the fractures would probably not have been overloaded. Patient no. 18 followed these criteria, but according to the healing curve there must have been a slight overloading, which was diagnosed in the next to last stage of the loading programme. The patient had an osteopsathyrosis, which does not normally result in delayed fracture healing, but the disease causes impaired connective tissue and consequently impaired bone matrix (Watson-Jones 1952).

Patient no. 19 also followed the prescribed loading programme, but nevertheless with consequent increased instability of the fracture, which at that time was filled with sufficient X-ray visible callus. This infirmity of the fracture may be explained by the fact that for several years the patient had had medium cortisone doses, which change the connective tissue. Abnormal connective tissue changes the dual-component construction of the bone structure (Knese 1958), so that this may be less resistant to tension and thus to bending tensile strength.

The only two patients with an assumed defect in the connective tissue were thus exposed to overloading. The prophylaxis must be to consider the fractures of these patients as particularly frail and postpone the loading till a later stage than that prescribed by the programme.

Contravention of the Loading Prescribed

The loading principles ought to have been pointed out to patients nos. 12, 15, 20. The patients might then have abstained from the almost provoking overloadings. The complications in patients nos. 14 and 16 must be put down to the vigorous active exercises of the ankle joint, which must be avoided.

Mechanically Poor Fixation of the Fracture

The three patients nos. 10, 13, 16 in this group had all overloaded their fractures before the Hoffmann screws were loose in the bone. It is most likely that the screws were worked loose by the trauma. When the screws are loose in the bone, the looseness will increase, eventually resulting in a local osteitis in the screw holes.

If these complications are to be eliminated, traumas must be avoided and the aim must be a technically correct insertion of the Hoffmann screws. If slightly loose screws are found at an examination, a temporary, improved fixation may occasionally be obtained by means of a compression bar, so that the screws are pressed in the screw holes.

Reflex Sympathetic Dystrophy

As the aetiology of reflex sympathetic dystrophy is not known for certain, no prophylaxis can be made in advance. When reflex sympathetic dystrophy occurs, however, it must be treated actively. Patient no. 1 had a considerably large total deflection for an unreasonably long period. If axial compression had been applied to the bone at an earlier stage with consequent removal of the pain, the bone and the fracture might have been declared stable 2 to 3 months earlier.

In patient no. 3 the reflex dystrophy was stopped by electrical stimulation for 4 weeks (to be described in a later paper).

Traumas with Slight, Transient Pain with and without X-ray Visible Re-Fracture

This group comprises 9 patients (nos. 4, 5, 6, 8, 9, 10, 11, 13, 17) or almost half the material. The prophylaxis in this group is the most important and the most difficult. The possibility of defective crutches must be checked with care, just as it must be impressed on the patients that having an unplastered fractured leg is freedom with responsibility.

The Clinical Value of the Measurements

By measuring the deflection systematically, an objective measure is obtained of the effect of the complications on the course of the healing. Stagnation, i.e. unchanged deflections at 2 follow-up examinations, may be revealed within a week, and thus it is possible to trace the cause quickly and commence the correct therapy against it. In the same way a reduction in the stability of the fracture may be revealed and treated.

The effect of a therapy administered may be estimated from the healing curves.

From a mental point of view it is of great importance to the patients that a measure for the course of the fractural healing may be provided, together with a preliminary prognosis. Furthermore, it is a strong argument when the importance of avoiding traumas and contravention of loading principles is explained to the patients.

If the above principles for loading are followed, and the Hoffmann apparatus is checked and the complications treated as mentioned, a standard programme is provided which can be applied on all crural fractures treated with the Hoffmann apparatus.

A sufficiently large safety margin is included in the programme to make reasonable allowance for the "weak" fractures.

SUMMARY AND CONCLUSION

A material is presented in which the deflection has been measured systematically on 20 crural fractures treated with the Hoffmann apparatus. The healing phase in the material has been marked by clinical or subclinical complications which delayed the healing of the fractures.

By plotting the healing curves of the fractures as a function of the stiffness of the fracture and of the duration of the fracture, factors may be demonstrated which delayed or inhibited the healing.

The healing curves give an objective measure for the overloading of the fracture and the effect or lack of effect of any therapy.

It is demonstrated that single traumas and constant overloading of a fracture in particular cause a delay or an impediment of the healing.

Overloading is generally accompanied by transient pain in the fracture. At prolonged overloading, the loading pain disappears.

Reflex sympathetic dystrophy with vigorous osteoporosis seems to be accompanied by decreased stiffness of the bone or the fracture.

Axial compression on the bone clearly had a rapid and good effect on this.

Fractures in patients with impaired connective tissue (one patient with osteopsathyrosis and one patient in cortisone treatment of long standing) seem to be particularly sensitive to overloading.

It is concluded that by systematically measuring the stability combined with a standardized loading programme, an important support is provided for the normal clinical control of fractures.

The prophylaxis against delay of healing has to be directed towards overloading of fractures. In the present material the majority of the overloadings were caused by traumas not brought on by the patients themselves.

Loading pain must be regarded as a danger signal, but cannot be used with sufficient reliability for graduation of the loading of the fractures.

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