Acta orthop. Scandinav. 43, 264–279, 1972

Department of Orthopaedic Surgery, Århus County Hospital,
University of Århus.

MEASUREMENTS OF STABILITY OF CRURAL FRACTURES TREATED WITH HOFFMANN OSTEOTAXIS

3. *The uncomplicated, terminal phase of healing of crural fractures*

TORBEN EJSING JØRGENSEN

Accepted 5. iv. 72

In previous papers (Jørgensen 1972 a, b) a review was presented of a mechanical method of measuring the deflection on crural fractures treated with Hoffmann apparatus. On the basis of these measurings it was possible, within a reasonable safety margin, to appoint the time when a fracture is not damaged by partial weight-bearing with the support of two crutches.

The object of the present paper is to give a graphic picture of the terminal healing phase of crural fractures by measuring the deflection systematically, and by means of these measurings to estimate the safety of a loading criterion. The terminal healing phase is the period during which the fracture is increasingly loaded until full weight-bearing at normal walking is tolerated.

The present paper describes the normal, uncomplicated, terminal healing phase in a material where the patients during the above phase were neither exposed to pain-provoking traumas against the fracture nor to mechanical defects in the fixation of the fracture, nor is there any information on breaches of the prescription concerning the loading.

If an objective estimation of the fracture healing can be obtained by measuring the deflection systematically, it may be possible to point out factors that either inhibit or promote the healing.

To illustrate some of the items in the fracture healing discussed in the present paper, a brief survey will be given of healing from a mechanical point of view.

Aided by a grant from the Foundation of P. Carl Petersen.

Notation and Formulae (Jørgensen 1972 a, b)

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. $1^\circ = \frac{2 \times \pi}{360}$ rad $= 1.745328 \times 10^{-2}$ rad. 1 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 bone end is: $\pm$ 5 kgf $\times$ 0.18 m = $\pm$ 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: $\pm$ 5 kgf $\times$ 0.12 m = $\pm$ 0.6 kgfm.

Fracture Healing

In theory, the healing of a fracture may be said to have been effected when the fractured bone shows the same physical properties as before the fracture. In practice these properties do not exist, and what is required in theory may never be fulfilled because of the mechanical changes which take place in the bone after the fracture. Changes may occur in the thickness of the bone and in the loading axes. Secondary changes in the loading conditions of the bone may be caused by alterations in the soft parts, in the surrounding tissue and in neighbouring joints.

Is is known that the ability of a bone to tolerate the forces of compression is reduced during the healing of a fracture (Nilsson & Smith 1969).

Increase of temperature and oedema of the tissue surrounding the fracture change the modulus of elasticity of the bone, so that the bone tissue is more resilient (Sedlin & Hirsch 1966).

Changes in the physical properties of the bone structure itself are small compared with changes occurring in the fracture. Initially after the occurrence of the fracture, callus may be compared to a viscoelastic mass allowing rather great deformations without breaking the continuity.

Lindholm et al. (1970) demonstrated on fractured rat tibiae that daily vigorous movements in a fracture caused a compensating increase of the callus. When the fracture was immobilized the histologic picture changed from a fibrous-hyaline stage to the stage of mineralization and resorption. From a mechanical point of view, this means that at the stage of mineralization the callus is changed from an amorphous to a crystalline mass. When the fracture has reached the crystalline phase Hooke's law is likely to be applied, i.e. that the fractural deformation is proportional to the force administered, provided the limit of proportionality is not exceeded. If this limit is exceeded the continuity will be broken and a micro fracture will occur. This means that once more the tissue of the fracture has to pass through the fibrous-hyaline stage to the stage of mineralization. This causes a delayed healing. Owing to the risk of micro fractures, callus may thus be said to be more sensitive to overloading in the crystalline stage than in the amorphous stage.

It is possible to obtain a primary fracture healing, i.e. to avoid the amorphous-hyaline healing phase by making an exact reposition and compression of the fracture (Charnley 1952, Perren et al. 1969).

Henry et al. (1968) demonstrated in rabbit bones that when the deflection of a healing fractured tibia, at identical bending moments, equals the deflection of a non-fractured tibia, the ultimate bending strength of callus is approximately half of the intact tibia at the same level. This means that when a fractured and intact tibia have identical stiffness, the fractured tibia has only "half the strength".

Wray & Goodman (1963) showed that 65 days after the fracture the breaking strength of callus in fractured rat tibiae was greater than the breaking strength of intact tibiae. It is assumed that the increased strength of the callus formation is due to the greater volume. Later in the resorption phase this increase in volume is reduced gradually, and after the resorption phase the strength of callus is supposed to verge on the strength of the normal bone. The exact estimation of a fracture healing is thus complicated by uncertainty about actual bone changes and the strength of the fracture.

A clinical estimation of the stability of the fracture and of the roentgenologic picture is all that is available in the daily clinic, in addition to information from the patients as to whether they have pain or not at the loading of the fracture.

By deflection measurements, Jernberger (1970) compared the stiffness of crural fractures with that of the counterlateral leg, and in this way he was able to set up an objective healing criterion. These measurings required, however, that at each examination 3 fixation screws be inserted in the healthy and in the fractured bone.

The measuring method and error are described in previous papers (Jørgensen 1972 b).

MATERIALS AND METHODS

The crural fractures of 2 patients were examined by deflection measurements at various times during the healing. The measurings were performed with increasing bending moment and the results are shown in Figures 1 and 2.

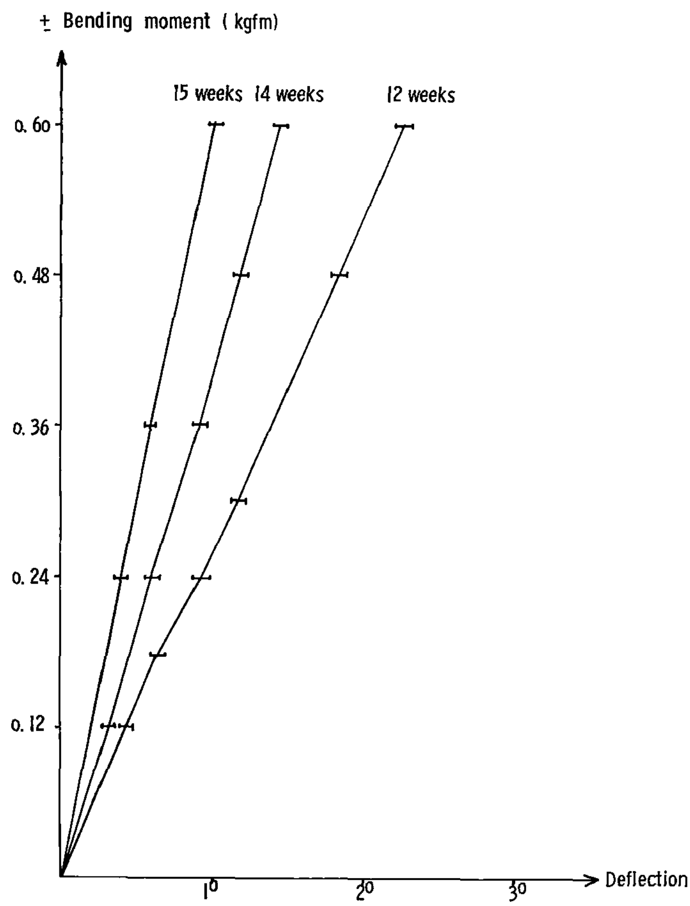
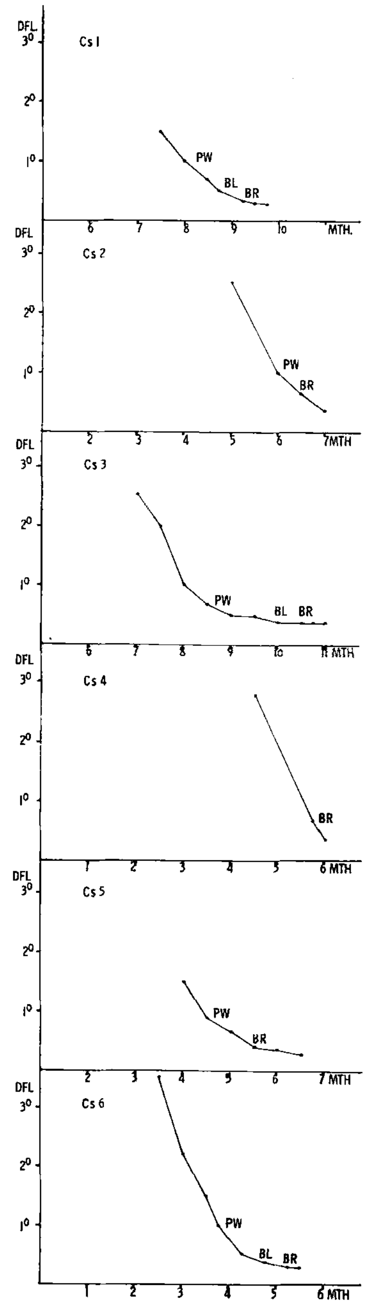


Figure 1. Measurements of the deflections carried out with increasing bending moment on a crural fracture 12, 14 and 15 weeks after the fracture.

Table 1.

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



Case no. 1: A 19-year-old man with an uncomplicated transversal fracture with an intermediary fragment. This fragment turned sclerotic and delayed the healing. Bone transplantation a.m. Phemister in the 6th month. The terminal healing phase was without complications.

Case no. 2: A 32-year-old woman with an uncomplicated transversal fracture. Training of walking was difficult because of a 10° equinus foot. No traumas in the terminal healing phase.

Case no. 3: A 25-year-old man with an uncomplicated transversal fracture. Primarily treated at another hospital with osteosynthesis a.m. Lane. After 3½ months the fracture was still unstable and without callus. The Lane plate was removed and osteotaxis a.m. Hoffmann was performed with resection of fibula. The terminal healing phase was uncomplicated.

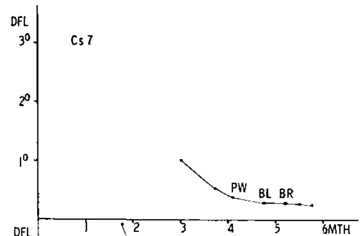
Case no. 4: A 62-year-old man, slightly physically aged, with a complicated transversal fracture. Primary skin healing. The healing phase is marked by a slight oedema due to inactivity. No trauma in the terminal healing phase.

Case no. 5: A 37-year-old man with an uncomplicated comminuted transversal fracture. Reposition of the fracture was performed 1 and 4 weeks after the accident, but a latero dislocation of half the diameter of the bone had to be accepted. The terminal healing phase was without complications.

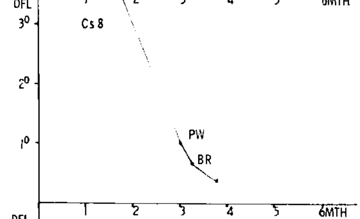
Case no. 6: A 25-year-old man with an uncomplicated transversal fracture. After reposition a latero dislocation of 1 cm in the fracture. No traumas in the terminal healing phase.

Table 1. (Cont.)

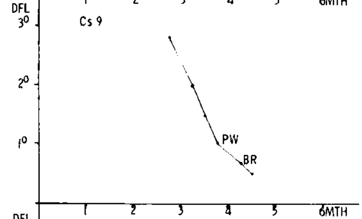
Case no. 7: A 58-year-old man with an uncomplicated transversal fracture. Re-reposition performed in the 6th week, but a latero dislocation of half the bone had to be accepted. For periods vigorous skin reaction around the Hoffmann screws, all of which were well-fixed, however. Loading postponed till the 4th month owing to the dislocation and to very sparsely visible callus on X-ray. No traumas in the terminal healing phase.



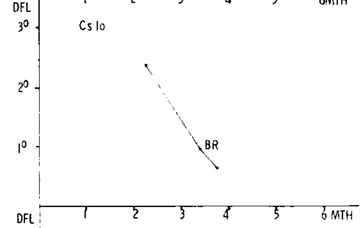
Case no. 8: A 72-year-old woman with a complicated transversal fracture. Loading of the leg one month after the accident resulted in a varus deformation of the fracture which could be adjusted, however. No complications in the terminal healing phase.



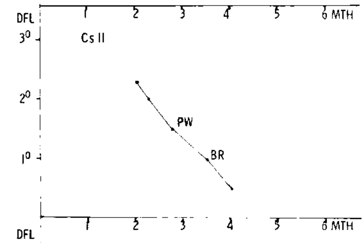
Case no. 9: A 23-year-old man with an uncomplicated transversal fracture. An ipsilateral femoral fracture was nailed a.m. Street Hansen. No traumas in the terminal healing phase.



Case no. 10: A 22-year-old man with an uncomplicated transversal fracture. An ipsilateral lesion of the foot prevented the loading for 10 months. No traumas in the terminal healing phase.



Case no. 11: A 16-year-old man with an uncomplicated transversal fracture. Cortisone treatment against bronchial asthma for 12 months prior to the accident. Shortly after the fracture the cortisone was discontinued. No complications in the terminal healing phase.



Case no. 12: A 22-year-old man with an uncomplicated longitudinal fracture. Bilateral femoral fractures were nailed a.m. Street Hansen. Loadings postponed due to the femoral fractures. No traumas in the terminal healing phase.

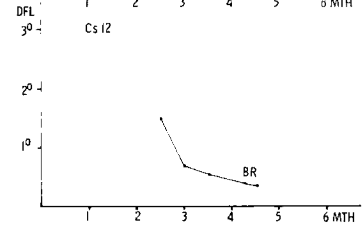
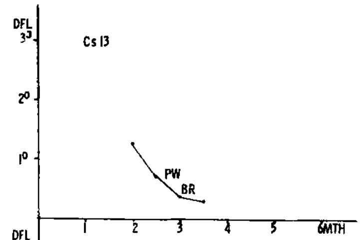
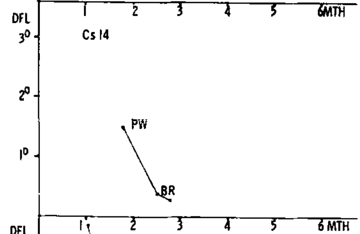


Table 1. (Cont.)

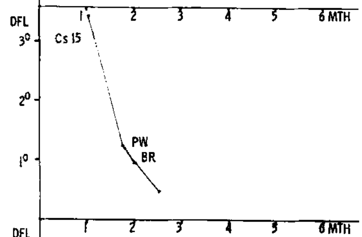
Case no. 13: A 28-year-old woman with an uncomplicated transversal fracture. The terminal healing phase without complications.



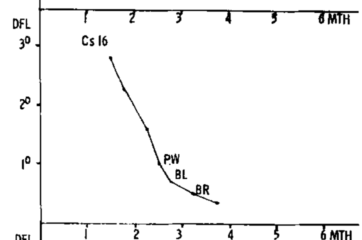
Case no. 14: A 16-year-old woman with an uncomplicated transversal fracture. Four days after the accident symptoms of a slight pneumonia or an embolus in the lung. Osteotaxis a.m. Hoffmann 13 days after the accident. Uncomplicated terminal healing phase.



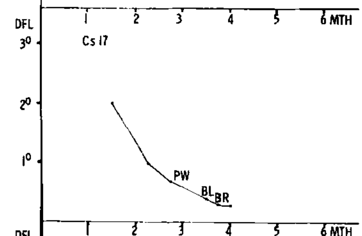
Case no. 15: A 17-year-old man with an uncomplicated transversal fracture. No complications in the terminal healing phase.



Case no. 16: A 24-year-old woman with an uncomplicated transversal fracture. No complications in the terminal healing phase.



Case no. 17: A 21-year-old man with an uncomplicated transversal fracture. No complications in the terminal healing phase.



Case no. 18: A 16-year-old man with an uncomplicated transversal fracture. No complications in the terminal healing phase.

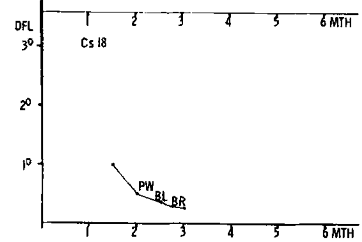
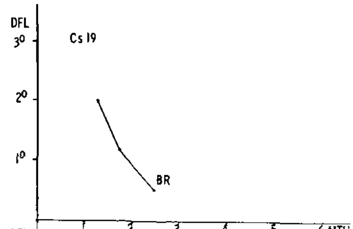
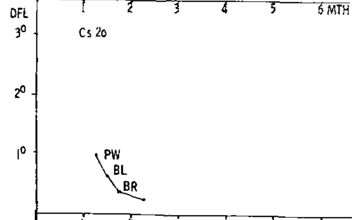


Table 1. (Cont.)

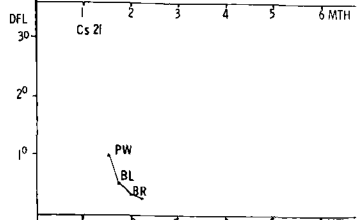
Case no. 19: A 22-year-old male oligophrenic spastic with bilateral crural fractures, one of which was complicated. Primary wound healing. Same rate of healing at identical deflection measurements. Loading could not be accomplished *till* after the removal of the Hoffmann apparatus. Full weight-bearing after 3 months.



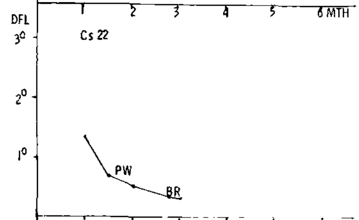
Case no. 20: A 20-year-old man with an uncomplicated transversal fracture. Counter-lateral crus had to be amputated. A counter-lateral femoral fracture was nailed a.m. Street Hansen. The terminal healing phase was without complications.



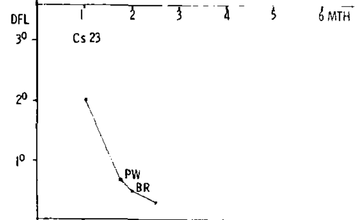
Case no. 21: A 15-year-old man with an uncomplicated transversal fracture. No complications in the terminal healing phase.



Case no. 22: A 17-year-old woman with a complicated transversal fracture. No complications in the terminal healing phase.



Case no. 23: A 45-year-old man with an uncomplicated longitudinal fracture. No complications in the terminal healing phase.



Case no. 24: A 44-year-old physically aged man with an uncomplicated transversal fracture. An ipsilateral femoral fracture was nailed a.m. Street Hansen. Because of deficient healing fibula was resected in the 7th month. From the 11th month electrical stimulation of the fracture. The terminal healing phase was without complications.

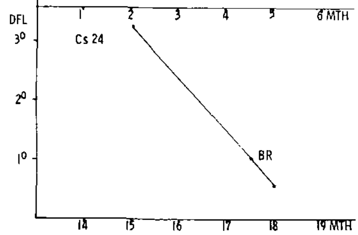
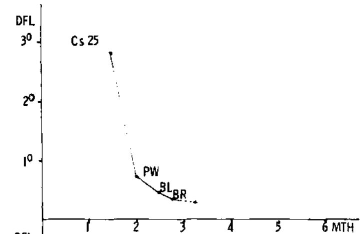
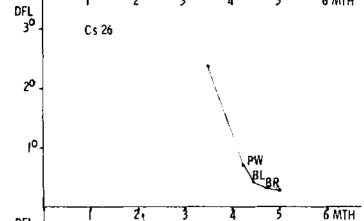


Table 1. (Cont.)

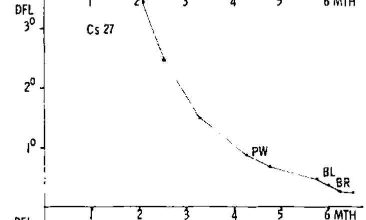
Case no. 25: A 20-year-old man with a complicated transversal fracture. No complications in the terminal healing phase.



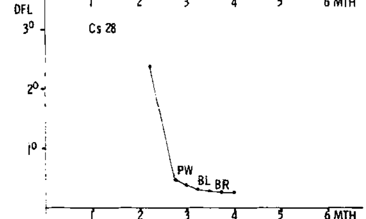
Case no. 26: A 72-year-old man, previously in good health, had a complicated transversal fracture with an intermediary triangular fragment. A concomitant pelvic fracture was treated with Hoffmann apparatus. The terminal healing phase was without complications.



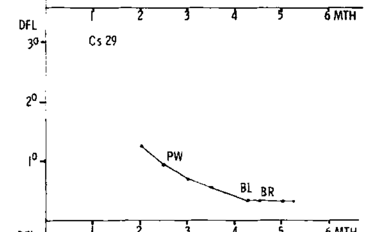
Case no. 27: A 16-year-old man with a complicated transversal fracture with an avascular fragment, which was removed. Because of the missing triangular fragment, the fracture had a tendency towards varus position. Counter compression prevented this and the defect was then slowly re-filled. No traumas in the terminal healing phase.



Case no. 28: A 19-year-old man with an uncomplicated transversal fracture. Re-reposition in the 3rd week. Two months after the accident the distal screws were slightly loose, but by using a compression bar sufficient fixation could be obtained. No traumas in the terminal healing phase.



Case no. 29: A 52-year-old man with an uncomplicated transversal fracture. After reposition a latus dislocation in the fracture of 1 cm had to be accepted. No traumas in the terminal healing phase.



Case no. 30: A 69-year-old woman with an uncomplicated transversal fracture of crus and a pelvic fracture. The bones were slightly osteoporotic. The terminal healing phase without complications.

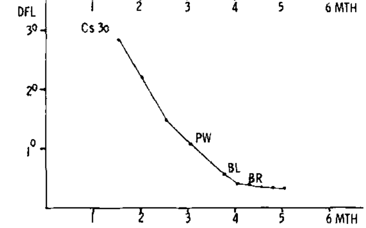
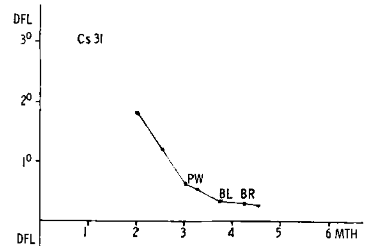
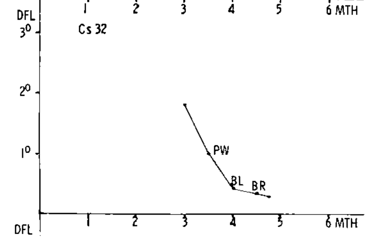


Table 1. (Cont.)

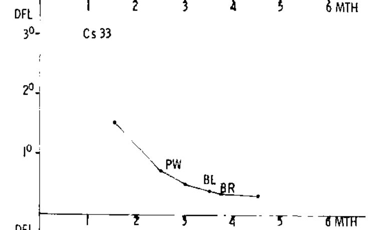
Case no. 31: A 36-year-old man with an uncomplicated transversal fracture. A counter-lateral subcondylary tibia fracture was osteosynthetized a.m. A.O. No complication in the terminal healing phase.



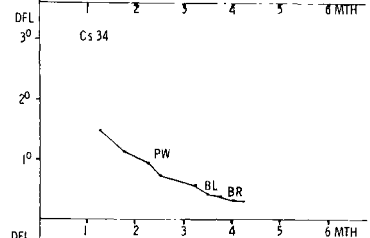
Case no. 32: A 17-year-old man with a complicated longitudinal fracture with 3 fragments torn off. In the 5th week a slight valgus position was adjusted. No complications in the terminal healing phase.



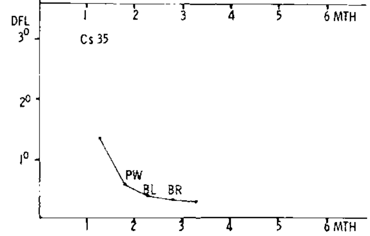
Case no. 33: A 39-year-old man with a complicated transversal fracture. Primary wound healing. A slight valgus position was adjusted in the 5th week. No complications in the terminal healing phase.



Case no. 34: A 57-year-old woman with an uncomplicated longitudinal fracture with several small fragments, which were not appreciably dislocated. No complications in the terminal healing phase.



Case no. 35: A 14-year-old boy with an uncomplicated transversal fracture. No complications in the terminal healing phase.



Thirty-five patients with crural fractures were examined with deflection measurings weekly or every second week during the normal, uncomplicated, terminal healing phase. The material and the healing curves are found in Table 1.

Loading Principles

The following loading principles were observed whenever possible, provided each measurement showed a reduced deflection (Figure 3).

Partial weight-bearing with crutches was initiated when the deflection was approximately 1°. The loading was then gradually increased to full weight-bearing during 1 to 2 weeks. When the patients were familiar with walking with full weight-bearing, the fixating steel bar was loosened or removed.

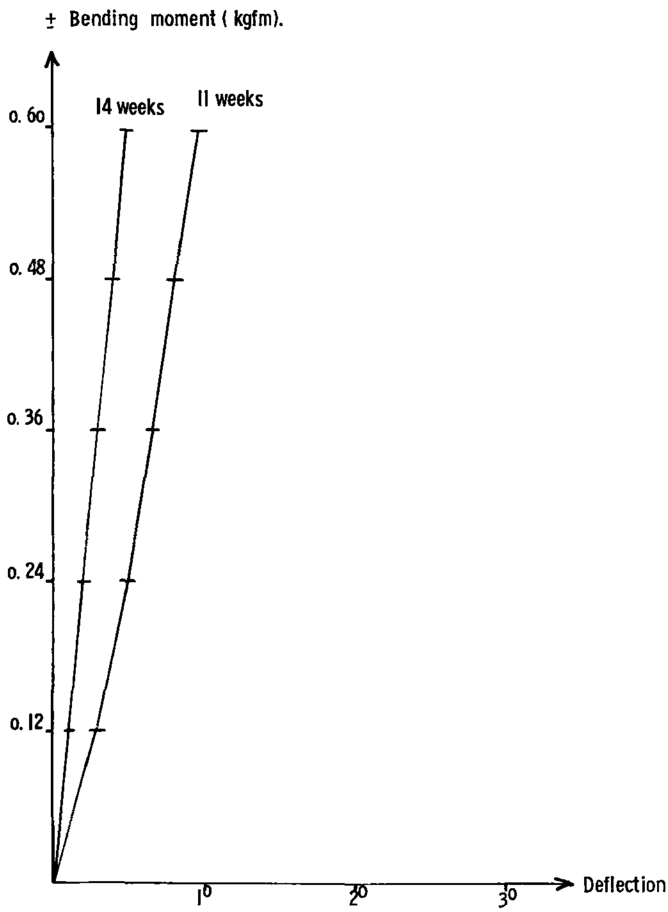


Figure 2. Measurements of the deflections carried out with increasing bending moment on a crural fracture 11 and 14 weeks after the fracture.

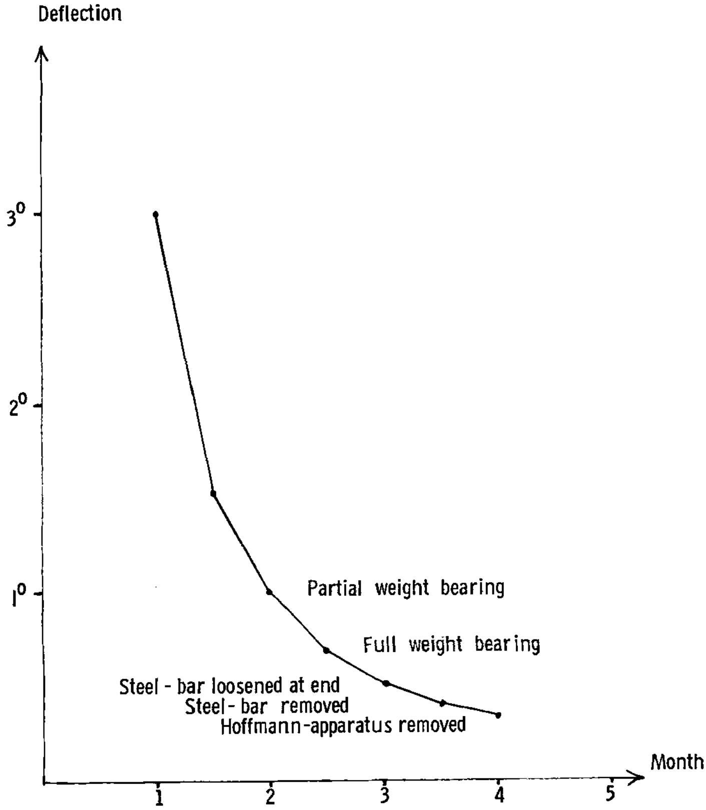


Figure 3. A healing curve of a crural fracture. The progressive loading programme is shown on the graph.

At the last examination the Hoffmann apparatus was removed and the patients were then assumed to be able to walk with full weight-bearing at quiet walking, if necessary with the support of one crutch.

Deviations from the Loading Principles

This was found in the following patients: Patient no. 7 had a latero dislocation of half the diameter of the bone at the fracture site, and very sparse callus formation, and thus loading was cautious.

Patient no. 10 could not go through with the loading due to an ipsilateral lesion of the foot which only permitted loading 10 months after the accident.

Patients nos. 11, 25, 24 were among the first examined patients, and due to the inexperience of the examiner loading was permitted too early.

Patient no. 12 could not go through with the loading due to a bilateral femoral fracture.

Patient no. 19 was an oligophrenic spastic with bilateral crural fractures. Loading could not be accomplished before removal of the Hoffmann apparatus.

Patient no. 28 had partially loose Hoffmann screws with consequent delayed loading.

RESULTS

The loading curves in Figures 1 and 2, showing the ratio between deflection and bending moment, make it probable that when the deflection does not exceed 2°, a proportionality of at least up to ± 0.6 kgfm exists between the deflection of the crural fracture and the bending moment administered.

On the basis of systematic deflection measurings on 35 crural fractures during the uncomplicated, terminal healing phase, a series of healing curves could be plotted (Table 1). These curves show that:

1. Initially the decrease of the deflections is rapid and rectilinear. In one half of the curves, however, the deflections seem to verge on the marginal values (nos. 1, 3, 5, 6, 7, 17, 18, 22, 25, 27, 28, 29, 30, 31, 33, 34, 35).
2. The healing curves do not show greater "breaks" than can be accounted for by measuring errors. Estimating from the healing curves, the loading prescribed has not caused stagnation in the healing of the fractures nor reduction of the stability of the fractures.
3. At an early stage in the measuring period a preliminary prognosis may frequently be obtained of the healing time for the fractures. In practice this proves to be of very great mental support to the patients.

The measurings did not cause the patients any inconvenience, and there has been no tardive pain in the fractures following the examinations.

DISCUSSION

The healing curves picture the terminal healing phase of the fractures. It is a question, however, whether repeated measurings damage the fracture, just as it must be taken into consideration what information is obtained from the healing curves and how this information can be applied.

Will the Loading at the Measurings Exceed the Breaking Strength of the Fracture?

The curves in Figures 1 and 2, showing the ratio between deflection and bending moment, are rectilinear, i.e. the deflections of the fractures were proportional to the bending moments administered. The fractures have thus not been loaded above the limit of proportionality, and therefore breach in the continuity of the fractures har hardly occurred. If the breaking point of the fractures was exceeded during the measurings, resulting in refractures, the healing curves might be expected to show "breaks". However, this could not be demonstrated. If the loadings at the measurings caused re-fracture the patients would have been likely to have had pain following examinations, but this has not been the case.

What Information is Obtained from the Healing Curves?

When the deflection in the same fracture is reduced between two measurings, the fracture is less resilient, or in other words the stiffness of the fracture has been increased. The reduction of the deflection, however, does not offer an exact measure of the progression of breaking strength (Jørgensen 1972 b).

When the fractures are followed for a sufficiently long period with deflection measurings, the healing curves will verge on the marginal values. This means that the fracture deflection is very close to zero and that the marginal value equals the bone deflection itself.

When the course of a curve is without "breaks", this must be interpreted as a smoothly progressive healing of the fracture. Because of the time interval between the measurings and the lack of acquaintance with the course of the ideal curve, the curves cannot disclose any brief stagnations in the healing process.

Is it Possible to Use the Healing Curves for a Graduation of the Fracture Loading?

The healing curves do not offer any reliable information on the breaking strength of the various fractures at bending, but only a relative measure of the changes of the stiffness within the individual fracture. It is likely, however, that when the stiffness of a fracture is increased, the breaking strength at bending is also increased. When the loading is begun, no exact measure exists of whether the individual fracture can tolerate the loading. In a previous paper (Jørgensen 1972 b) it is rendered probable that if partial weight-bearing with two crutches is generally prescribed at a deflection of 1°, a reasonable security is obtained so that a fracture is not overloaded.

The following items in the course of the loading must be supplemented with a clinical estimation, as caution must be shown for a marked dislocation, for comminuted fractures and for patients with a heavy gait. The progression of the loading must be supplemented by frequent deflection measurings, disclosing a reliable reduction before the next stage of the loading is initiated.

If the healing curve does not show "breaks", it is reasonable to conclude that the fracture was able to tolerate the loading administered. The course of the healing curve does not exclude, however, that the loading has caused a delayed healing.

SUMMARY AND CONCLUSION

Systematic deflection measurings have been performed in 35 patients during the last part of the healing phase, which in the present paper has been without notable complications. On the basis of consecutive deflection measurings, healing curves have been plotted. In the uncomplicated healing phases these curves seem to have a smoothly decreasing course, with values verging on marginal values that probably express the pure bone deflections.

The healing curves picture the relative stiffness of the fractures, but give no reliable information on the breaking strength of the fractures.

Simultaneous with the deflection measurings, the fractures were exposed to a progressive loading, beginning cautiously with partial weight-bearing with two crutches and gradually proceeding to full weight-bearing at quiet walking and with the entire fracture fixation removed.

The examinations showed that progressive loading did not reduce the stability of the fractures, and it was thus most unlikely that the course of the healing curves was affected. It is concluded from this that the fractures could tolerate the loading prescribed and that the loading criterion demanded has been fulfilled.

The ratio between the fracture deflection and the bending moment is proportional up to $\pm$ 0.6 kgfm, and it is thus concluded that the measurings did not damage the fractures.

The systematic deflection measurings on crural fractures proved to be of great value in the daily clinic, particularly when decisions were made as to when and how much a fracture could be loaded or whether the fracture could tolerate a loading at all.

During the healing phase the curves very often made it possible to estimate a prognosis of the healing of a fracture.

REFERENCES

Charnley, J. (1952) Compression arthrodesis of the knee: A clinical and histological study. *J. Bone Jt Surg.* **34**-B, 187.

Henry, A. N., Freeman, M. A. R. & Swanson, S. A. V .(1968) Studies on mechanical properties of healing experimental fractures. *Proc. roy. Soc. Med.* **61**, 40–44.

Jernberger, A. (1970) Measurement of stability of tibial fractures. *Acta orthop. scand.*, Suppl. 135.

Jørgensen, T. E. (1972 a) Measurements of stability of crural fractures treated with Hoffmann osteotaxis (1). *Acta orthop. scand.* **43**, 188–206.

Jørgensen, T. E. (1972 b) Measurements of stability of crural fractures treated with Hoffmann osteotaxis (2). *Acta orthop. scand.* **43**, 207–218.

Lindholm, R. V., Lindholm, T. S., Toikkanen, S. & Leino, R. (1970) Effect of forced interfragmental movements on the healing of tibial fractures in rats. *Acta orthop. scand.* **40**, 721–728.

Nilsson, B. E. R. & Smith, R. E. (1969) The influence of breaking force of osteoporosis following fracture of the tibial shaft in rats. *Acta orthop. scand.* **40**, 72–79.

Perren, S. M., Huggler, A., Russenberger, M., Allgöwer, M., Mathys, R., Schenk, R., Willenegger, H. & Müller, M. E. (1969) Cortical bone healing. The reaction of cortical bone to compression. *Acta orthop. scand.*, Suppl. 125.

Sedlin, E. & Hirsch, C. (1966) Factors affecting the determination of the physical properties of femoral cortical bone. *Acta orthop. scand.* **37**, 29–48.

Wray, J. B. & Goodman, H. O. (1963) Postfracture vascular changes and healing process. *Arch. Surg.* **87**, 801–804.

Correspondence to:

T. Ejsing Jørgensen
Agernvej 17, 8330 Beder
Denmark