Germany (Territory under Allied Occupation, 1945- U.S. Zone) Office of the Naval Advisor Projects

EXPERIENCES WITH THE MARROW NAIL OPERATION ACCORDING TO THE PRINCIPLES OF KUENTSCHER

PART II

by

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III.

Fractures healed with deformity, old fractures with deficient callus formation and pseudarthroses

1. The hazards of marrow nailing with exposure of the fracture site

Fractures which have healed in a bad position and the greater part of old fractures and pseudarthroses must be nailed with exposure of the fracture site. This operation is also referred to as "open marrow nailing". The exposure facilitates the technique, since the nail can be visualized when it is driven into the distal marrow cavity as is the case in fresh compound fractures. As compared with other methods of bone surgery, the marrow nail offers the advantage that a wide separation of the periosteum is avoided. It is only removed in the immediate proximity of the fracture regardless of considerable masses of callus that might adhere to the ends of the fragments. In favor of the marrow nailing method it may also be said that extensive resections can be avoided in most of the cases. It is entirely sufficient to provide two new joining surfaces and to open the closed marrow cavity with gimlet or awl wide enough to allow the nail to enter. The callus adherent to the fragments is left in position, unless it is not obstructive, as it constitutes an important element in the regeneration and protection of the periosteum.

The exposure involves, however, the hazard of infection and as has been demonstrated in fresh compound fractures, the marrow nail may prove more hazardous in case of an infection than a wire suture or a LANE's plate, especially so if the osteosynthesis is not stabile.

The hazard of infection appears to be rather important as is set forth in Table IV. Today we have 35 infections in 219 open nailings, that is 15,6%, a figure which is alarmingly higher than that of our patient material in 1944.

In my own clinic, including the special ward, the percentage of infections was considerably lower, (not quite 5%) and severe consequences could be avoided in most of the cases. It must, therefore, be concluded that special circumstances are responsible for this high infection rate.

The fact that the osteotomies of thigh fractures comprise almost 30% of the infected cases whereas there was only 1 infection in old fractures is particularly striking.

This one case was caused by the negligence of the surgeon. As a matter of fact we found a swab in the cavity of the abscess of the patient who had been nailed in another hospital 2 months before.

T a b l e IV

Infections of the fracture cleft in the open nailing of aseptic fractures.

	Fresh Fractures		Osteotomies		Old Fractures & pseudarthr.		Total
	Number of cases	Number of infect.	Number of cases	Number of infect.	Number of cases	Number of infect.	
Thigh	3	0	32	9	44	1	
Tibia	0	0	5	0	46	20	
Upper Arm	2	0	3	0	58	0	
Fore Arm	1	0	6	0	23	5	
Total	6	0	46	9	171	26	223:35 = 15.6%

Insufficient stability of the osteosynthesis cannot be considered as the only reason, although infections developed in both the osteotomy nailings in which the osteosynthesis was not stabile, because there were 3 old thigh fractures with incomplete fixation which healed primarily, whereas infections developed in 7 cases with a perfectly stabile osteotomy.

In 7 of the nailings it was neglected to apply a drain. This is definitely hazardous, since an infection developed in 5 of the patients. An inflammation developed in four other cases in spite of proper drainage and stabile osteosynthesis.

Apart from more or less extensive damage, the soft parts and vessels will be put under considerable tension, if, in case of an extraordinary shortening and deformity, a marrow nailing operation is performed immediately following osteotomy. This may have an unfavorable effect on the nourishment and resistance of the tissue and thus create a specific proneness to infections. And yet, it could be observed that it was by no means the areas of the most apparent damage which became infected first, but on the contrary the old long healed fractures, the operation of which was difficult and tedious, rate first in the infection statistics.

We considered it the main objective of the marrow nailing osteotomy and so did many of our colleagues, to restore the anatomic conditions as accurately as possible and, above all, to compensate for shortenings. The marrow nail offers excellent possibilities in this respect, since it will not be necessary to resect the

bone until the marrow cavity is freely exposed. It will rather be possible to provide a canal through the obstructing callus by means of a gimlet and chisel which affords a particularly good hold for the nail. A complete restoration can thus be achieved by severing the bone in the old fracture line. This is, however, difficult in the old long healed fractures. The old contours can well be distinguished on the X-ray picture when exposing the site, however, one will find a homogenous incredibly hard bone substance which does not offer any indication whatsoever as to what is old and new. If one has finally succeeded in severing the bone in approximately the old fracture line, new difficulties crop up in that it is not easy to determine the direction of the marrow cavity in the abundant callus formation and to secure the path for the nail, which not infrequently will stick in such a manner that it will not move backward or forward. So, the operation often lasts for several hours and different X-ray pictures become necessary. This all constitutes a serious hazard to asepsis. If in addition to this, the soft parts are under tension, if a drain is omitted, or if split off callus is used to fill still remaining gaps and if no solid junction was attained after all, it is really not surprising if the infection sets in.

All these difficulties do not come into consideration if the fracture is still movable or recently healed. A badly healed thigh fracture should, therefore, be operated upon as early as possible.

In case that the fracture has healed some time ago, and the exact location and severance at the fracture line offers considerable difficulties, the bone should be resected (as conservatively as possible of course) as to establish sufficiently large joining areas and the ends of the marrow cavity should be opened. Under these conditions one has to put up with a shortening, but this is the lesser evil to the patient as compared to an infection. The marrow nail is still advantageous in these cases over the other bone fracture methods, since the resection can definitely be performed under more favorable conditions and above all a long lasting immobilization can be avoided and the joints be moved early.

After a thorough study on my patient material, I deem it advisable to accept even a shortening of 2 centimeters and to shorten the other leg accordingly using the marrow nail, rather than to force the compensation and expose the patient to the risk of an infection which might be synonymous with sacrificing the limb or even prove fatal.

The infection rate in old fractures of the tibia is still higher(43%). In our own clinic and special ward, however, not one infection occurred in the nailing of old aseptic fractures of the tibia.

(I here include those fractures, the wounds of which are healed for more than 6 months). Thus we are entitled to say that the infection can be avoided. As a matter of fact, the indication for an open marrow nailing was always considered with special care.

In the military hospital one was obviously too liberal in this respect and it could be observed that the greater part of the infection cases had been nailed by surgeons without or with little experience of the method. (Authors Note: To their excuse it must be said that a particularly high number of old and badly healed fractures was seen in military hospitals at home. Fascinated by the new method and desirous of giving it a tryout, many a surgeon overlooked a few words when reading KUENTSCHER who writes that the marrow nailing is the simplest surgical approach that can be thought of, namely the words "in typical cases". The nailing of an old fracture of the tibia is not such a typical case of marrow nailing.) So it may be said that lack of experience and of technique are responsible for a considerable percentage of the infections. And still the hazard must be greater than for instance in old fractures of the upper arm of which a great many were nailed with exposure of the fracture site by surgeons with little experience.

The position at rest without doubt plays an important role. In 19 of the 20 infected cases the osteosynthesis (as is so often the case in tibia fractures) was only relatively stabile and it was considered sufficient to splint the leg. If an additional plaster cast is applied in such cases, as we do and always have recommended, there is considerable prospect that no infection will occur. 12 fractures with only a relatively stabile fixation healed primarily with a plaster cast. These cases included 7 originally infected fractures, the wounds of which had been closed for more than 6 months.

The door wings incision seems to be particularly hazardous and lead in 4 cases to a skin necrosis from which the infection spread to the fracture cleft. We have abandoned it completely. A longitudinal incision along the lateral edge of the tibia suits the purpose and has a better chance in the final healing because it is padded by soft parts.

The absence of a sufficient padding of the skin increases the infection hazard because the suture easily becomes subject to considerable tension due to post-operative swelling. The suture then is likely to cut into the skin and to disturb the nourishment and resistance.

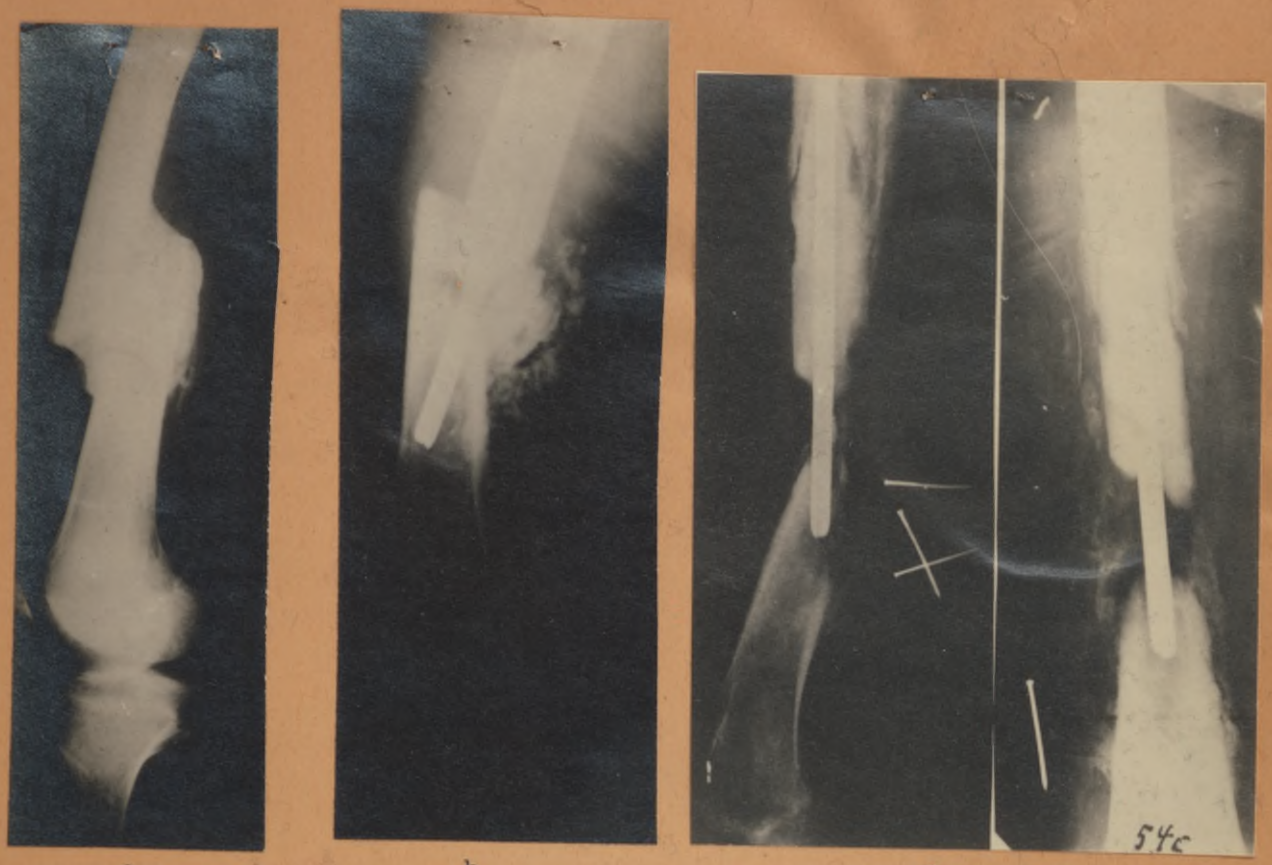
These two factors: insufficient stability and lack of padding by soft parts do as a rule not come into consideration in the upper arm which consequently does not present the same infection hazard.

On the forearm the hazard is again greater that the suture will be under tension, especially if the suture is applied next to the bone. In this case and if both bones are broken considerable technical difficulties may arise which may quite easily break sepsis.

If the temperature rises after the operation it is imperative to open the wounds widely (including the entrance opening of the nail) to allow the secretion to drain off. The limb must (if not performed in the very beginning) be immobilized by a plaster cast. If this is done, an infection is generally avoided. These points were neglected in the majority of the cases referred to above and valuable time was lost instead with the administration of sulfonamides and wet compresses during which the swelling constantly increased and the infectious secretion is forced in to the fracture cleft and marrow cavity.

A descriptive example:

In an osteotomy of a 10 weeks old fracture, healed with a shortening of 6 centimeters (in an axially correct position (Ill. 54a)) the periosteum was widely severed. The surplus callus was cut back and shifted into the wound cavity at the end of the operation. Since the shortening could not be compensated by extension, the fracture ends were brought in proper position when the nail appeared at the fracture cleft and was driven a little bit into the distal marrow canal. After that the nail was hammered in further and a piece of bone at the posterior part of the distal fragment broke off, so that the nail did not find a proper hold. (Ill. 54b). The wounds were sutured without previous drainage. A BRAUN's splint was applied. Although the temperature rised to 39° the day following the operation and did not return to normal the following days, the wound was opened only on the eighth day and an abundant amount of pus came out. Inasmuch as the fracture was freely movable, a wire extension was applied through the tibia which caused distraction. A long tubular sequestrum developed on the proximal fragment, apparently to the extent to which the periosteum was previously severed. (Ill. 54c). The joining of the fracture ends was finally achieved by plaster cast thanks to the formation of a strong capsule about the dead bone and after 9 months, the nail and the sequestrum could be removed. A few abscesses had to be opened and sequestra had to be removed later on, but after 20 months the fracture had healed with a shortening of 2 centimeters, a stiffening of the knee joint in 175 degrees and a 2/3 stiffening of the ankle joint.



a b c

Illustration 54

a) 10 weeks old fracture of the femur which had healed with a shortening of 6 centimeters. Osteotomy - marrow nailing, during which a large area of the periosteum was separated. After the insertion of the marrow nail into the proximal marrow cavity the fragments were put together at an angle and at the same moment when the nail slipped into the distal marrow cavity the fragments were straightened. Compensation for the shortening by traction forces alone was not possible. Surplus callus chips were placed in the open wound at the end of the operation. Wound suture without drainage. Application of a BRAUN's splint.

b) The same fracture two days after the operation. The nail is too short. At the rear part of the distal fragment a large part of the bone has broken off. Consequently the nail did not find sufficient hold and a displacement of the fragments has occurred. Temperature around 39° C. In spite of this the wound was opened only on the eighth day after the operation and a marked extravasation of pus was observed. Wire extension of the tibia.

c) Same fracture 8 weeks p.op. The fracture is distracted. In the proximal fragment a long (total) sequestrum is observed which extends up to the end of the area of periosteum which had been separated. Nine months after the operation an involucrum was observed around the sequestrum which strongly united both fragments. Consequently the nail as well as the sequestrum were removed. During the following period several more abscesses had to be drained and some more sequestra were removed. The total period of treatment amounted to 21 months. The final result was a shortening of 2 cm. and a completely stiff knee joint which was in a straight position. The impediment of the foot joint amounted to 66 % (the X-rays were destroyed).

As a matter of fact the operation on this patient was fully justified because a shortening of 6 centimeters especially in young persons, is likely to imply severe damage to the hip joint. The fracture was suitable for nailing as far as the location was concerned, and a stabile osteosynthesis could definitely be expected. When it was seen, however, that a proper reduction met with difficulties due to an excessive shrinkage of the soft parts, it was indicated to apply a wire extension and to wait until the damage to the soft parts had subsided. That would have been the case in 1 to 2 weeks and there was considerable chance that the marrow nailing could have been performed then uneventfully. After the nailing had been performed prematurely it would have been absolutely necessary to secure a position at rest for the leg by a plaster cast, because the nail had no grip due to the breaking off of a piece of bone. Furthermore drainage was imperative. When temperature was observed, the wound should have been opened widely without delay. This would have prevented the pus from being forced into the proximal marrow cavity along the nail. The large sequestrum could have been avoided in all probability and the abscess of the entrance wound with certainty. The excessive severance of periosteum is very likely to have favored the bone necrosis. As a matter of fact the sequestrum extends almost exactly as far as the fragments had been shifted. The reintroduction of the callus at the end of the operation was superfluous and was liable to increase the infection hazard. The same is true for the wire extension, all it did, was to cause a distraction. A plaster cast would have fitted the case far better.

It was repeatedly asserted that an exposure of the fracture will delay the formation of callus. Fritz KOENIG refuted this concept as early as in 1931 and we could never observe a delayed callus formation in the great many patients who were operated upon with exposure of the fracture site. Where such a delay was observed, the reason could always be traced back to a faulty technique, such as insufficient position at rest, obstructing bone, faulty position of the fracture etc. Neither have we observed a delayed healing due to an open marrow nailing operation. But it must be emphasized that the nail per se does not stimulate the callus formation, it only assures favorable conditions to this end. Where these favorable conditions do not prevail (lack of stability, defects etc.) the nail will not only be of no use, but it may even prove hazardous.

Fat embolisms may occur in both, the open and closed nailing operations. While I was originally of the opinion that the overpressure developing in the marrow cavity was the main reason for fat embolisms, I have now to revise this opinion after a careful study of my patient material. It is rather surprising that the case histories pertaining to fat embolisms always speak of a sticking of the nail and of force that was necessary to drive the nail in. It is reported again and again that the pulse rate is affected and that collapses occur after vigorous hammering, so that the operation must be interrupted.

The maltreatment of the bone thus seems to be the main cause. As a matter of fact an obstruction of the marrow cavity by connective tissue or callus may favor the development of an overpressure in old thigh fractures, since the incidence of fat embolisms is particularly frequent in this type of fracture. It is, therefore, recommended to perform an open marrow nailing operation in case of old fractures.

2. Thigh Fractures

a) Osteotomies of obliquely healed fractures.

As mentioned before, the osteotomy nailings of obliquely healed thigh fractures lead to infections in more than 30% of our patient material and had rather severe consequences for the patients.

We have seen that the difficulties and the long duration of the intervention are mainly responsible for the increased infection hazard. The operation should therefore, take place as early as possible before the bone solidifies in the faulty position. This is, however, in most cases beyond our control and depends on when the patients turn up for treatment.

The forcible compensation of shortenings and angulations usually accompanied by considerable damage to the soft parts and vessels constitutes another important infection hazard. It is recommended to perform the operation in such cases in two sessions. In the first session only the osteotomy will be performed and a wire extension be applied. Only if the shortening is compensated by these measures and after complete healing of the operation wound (that is after 2-3 weeks) the marrow nailing will follow.

The osteotomy should be performed as conservatively as possible. The periosteum will be removed only very sparingly at the line where the bone is going to be cut, which should be if at all possible identical with the old fracture line. The bone should be cut in such a manner, as to provide a smooth abutment of the ends. In the second session the marrow cavities will be opened and the canal for the nail will be drilled, obstructing bone parts will be resected.

As a rule, drainage must be provided in this operation which has to be applied at the physically correct spot (that is posteriorly in the septum intramusculare fibulare) and led off by a special skin incision. We use a long drainage tube which is led outside the bandage into a small sterile flask. This arrangement has in some way the effect of a syphon and allows the elimination of the wet space in the bandage, which often forms an ideal stratum for germs. The tube must sutured on to the

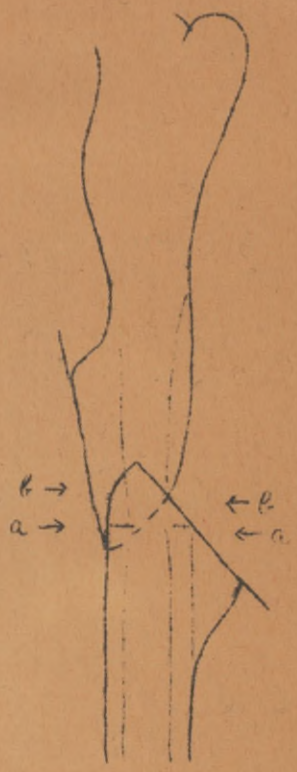
skin to prevent its withdrawal or shifting from the wound cavity due to the movements of the patient.

BOEHLER emphasizes the necessity of operating in two sessions for all cases in which the shortening exceeds 4 centimeters. We were guided in the first place by the force necessary to correct the position after osteotomy. If no unusual maneuvers were necessary we did not refrain from nailing shortenings up to 6 centimeters primarily, including old fractures due to gunshot injuries, and no infections have ever occurred. On the other hand we performed the operation in two sessions in cases where the shortening was less than 4 centimeters if the compensation was difficult. In all 4 cases in which the operation was performed in two sessions we observed primary healing and this procedure is certainly more agreeable to the patient than a one session operation.

If the fracture has not healed long before the operation and if a cloudy callus is seen on the X-ray picture, it can in most cases be easily chiseled off and the operation will not present any difficulty. If, however, we deal with a fracture that has healed for more than 8 weeks and which has even been put under stress, we do not waste our time trying to locate the old fracture line. This will in most cases not be successful and presents too many hazards of breaking asepsis. We make a tracing of the X-ray picture showing also the limitation of the marrow cavities and mark the proposed cut. The tracing will then be cut accordingly and superposed in such a manner that the shifting is compensated. It can then be seen how much must be removed of the bone ends to provide proper abutments and to open the marrow cavities at least partly. The cut will be performed so as to cause no or little shortening (Ill. 55)

It is perfectly possible to use the newly formed bone as part of the elongation, as is illustrated in Ill. 56 concerning an obliquely healed fracture due to gunshot injury with a shortening of 6 centimeters. This possibility constitutes an important advantage of the marrow nailing osteosynthesis over other methods.' And yet, we have abandoned the use of the newly formed bone because it is often difficult and especially so in old fractures, to find the marrow cavity and to provide the canal for the nail through the hard callus and the hazard to piercing the corticalis in the wrong direction is ever present. The result is seen in Ill. 57. The osteosynthesis will nevertheless be stabile, since the nail is firmly engaged for a long time in the hard bone, but the difficult and tedious manipulations are a serious hazard to asepsis.

In some instances it is the best solution to accept a shortening. If it is important, there is always the possiblity of shortening the other leg as was proposed by BAUER. That is incomparably less hazardous to the patient than an infection and recovery is faster too.



a b c

Illustration 55

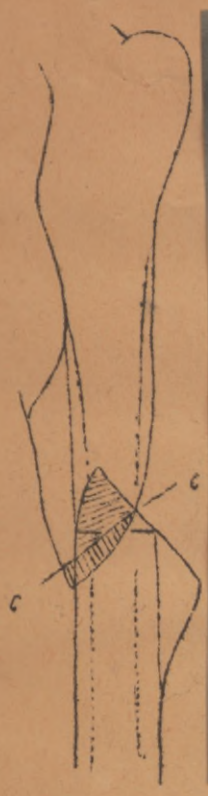
a) 14 months old closed fracture of the thigh which has been stabil for 10 months. The patient was released from the hospital 8 months previously. The shortening amounted to 3 centimeters. The patient limps and tires quickly. The movements of the knee joint are limited by about 50 %.

b) Sketch of the X-ray showing the separation line and indication of the old ends of the fragments.

c) The two parts of the cut sketch are superposed in such a way that the lines indicating the ends of the fragments are lying upon one another and the angulation is corrected. In this way the original shape of the bone would be restored in an exact manner.

If the bones are cut across at point (a) the ends of the fragments touch each other on the medial side for only 1/3 of the circumference. In this way they are not protected against rotation and consequently the osteosynthesis will not be stabil.

If the bones are cut across at point (b) a broad plane of contact is obtained but the callus of the distal fragment must be drilled through and there will be considerable difficulty in finding the marrow cavity and in inserting the nail.



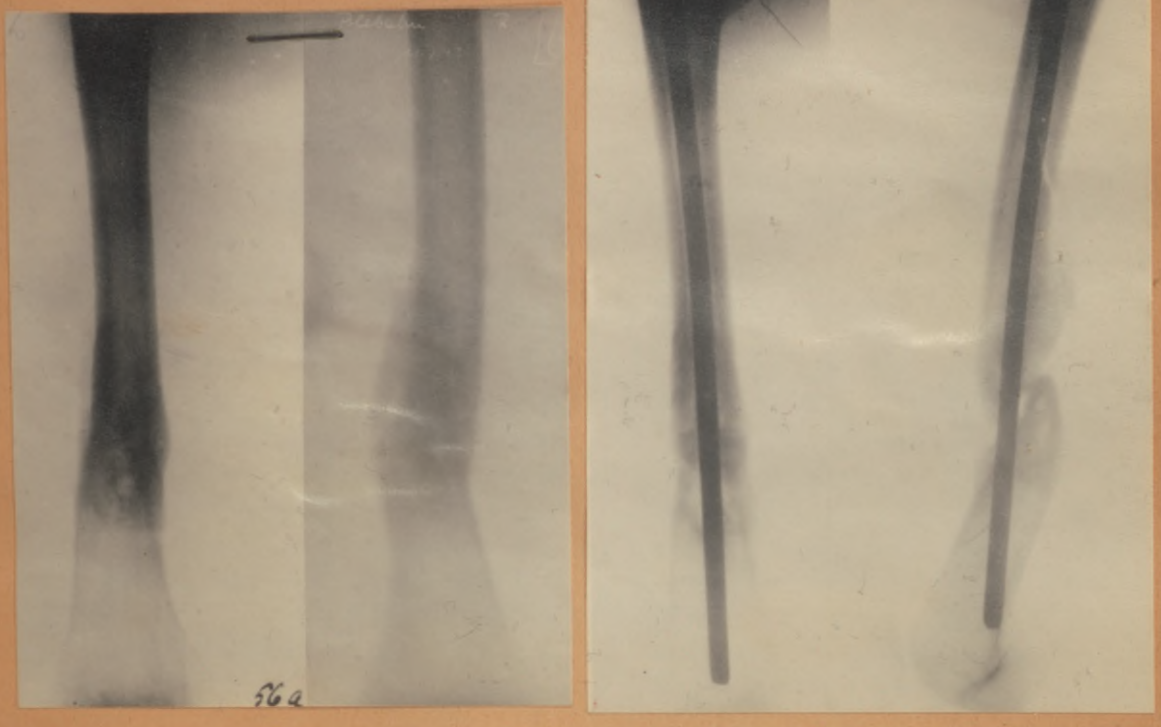
d e f

Illustration 55

d) Therefore the sketches were superimposed in such a way that a slight shortening existed. If after that the bone is cut across along line (c) both marrow cavities are open. In this way it will be easy to enlarge them enough so that a nail can be driven in. Furthermore, we have the advantage of a broad plane of contact of the bone and with this better stability.

e) The same fracture after the nailing. The nail could have been somewhat longer but it finds sufficient hold in the marrow cavity which has become narrower because of the callus. The osteosynthesis was stabil, the shortening amounted to ½ centimeter. Drainage in the dorsal direction.

f) Same fracture five months after the operation. The nail was removed and the fragments had healed in good position. No measurable shortening. The flexibility of the knee joint amounts to 80 - 180°.



a b

Illustration 56

a) 11 month old gunshot fracture of the right thigh which has been treated with a traction bandage for 11 weeks and with a plaster cast for 4 weeks. The wounds have been healed for 9 months. The shortening amounts to 6 centimeters. We had to deal with a typical genu recurvatum with a 50 % limitation of the movements. The patient tires quickly.

b) Osteotomy along the old fracture line. In order to obtain a prolongation the tip of the distal fragment was not resected. Because of this it was very difficult to find the marrow cavity and the nail does not lie in the proper axial direction, but it is firmly seated in the callus canal. The osteotomy planes on the flexor side stand one upon the other over a broad area. Satisfactory position of the axis. The shortening amounts to 1 centimeter. Drainage was applied in the dorsal direction for two days with the plaster cast kept in place for 3 weeks. Primary healing.

With the opening of the marrow cavity in the sound part, as required by the old methods of osteosynthesis, the shortening would have amounted to at least 5 centimeters.

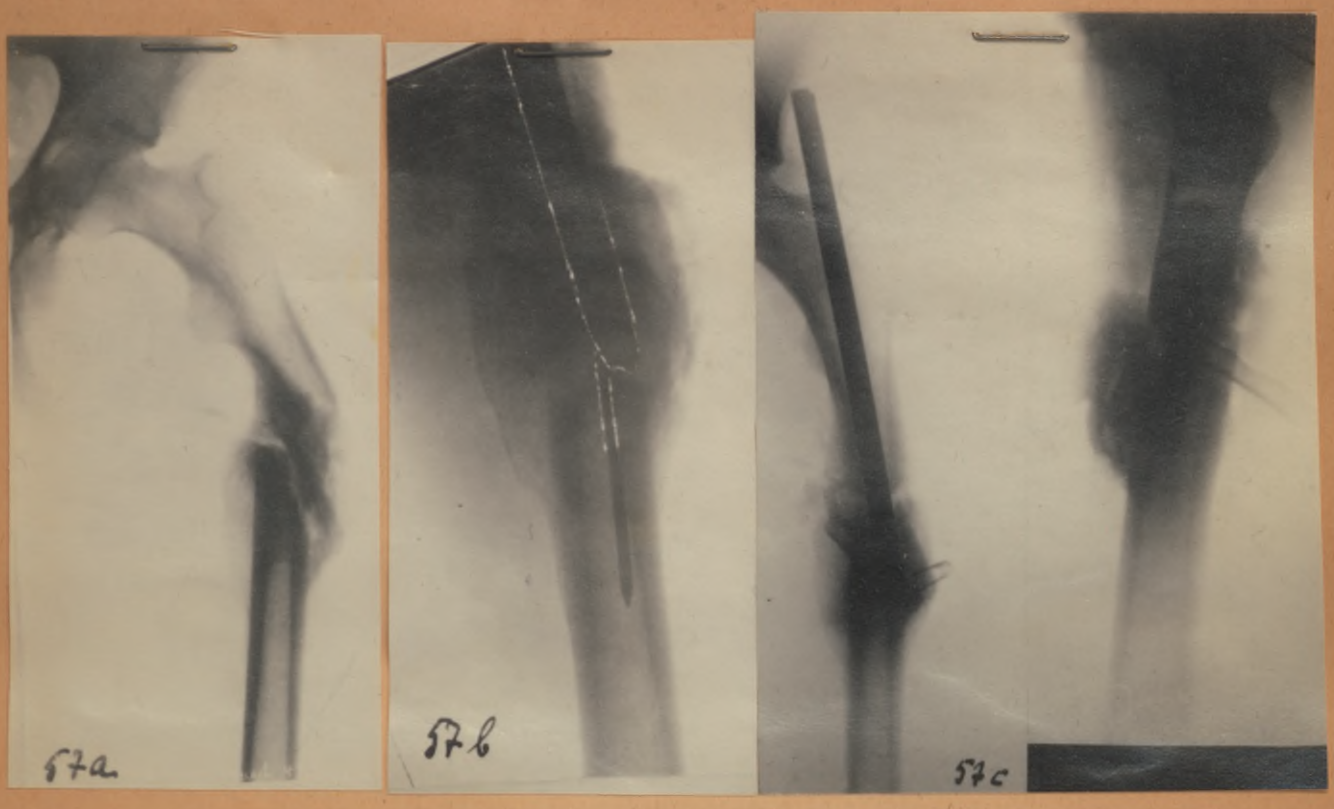
c

d

Illustration 56

c) Same fracture eight months after the operation. The nail had been removed 4 weeks previously. The patient had been sent to his unit for garrison duty 2 months p.op.

d) The patient the day of his release from the hospital. He is fit for service. The shortening amounts to 1 centimeter. From the clinical point of view a recurvation of the knee does not exist, the motion amounts to 180 - 60 degrees.



a b c

Illustration 57

a) Six month old closed thigh fracture which for a period of 4 weeks has been treated with a wire extension and plaster cast despite the fact that distraction existed. Three months after the injury another surgeon tried to nail the fracture. He did not however succeed in fixing the fragments. The shortening amounted to 2 centimeters, motion of the hip joint was considerably limited, the flexibility of the knee amounted to 180 - 160 degrees.

b) Osteotomy: It is relatively easy to open the fracture with a broad chisel. The distal marrow cavity was located under X-ray control by using KIRSCHNER wires. After that the canal was enlarged and the guide rod inserted which is fairly well seated in the distal marrow cavity. It was not observed that the guide rod was somewhat angulated. During the insertion of the nail it left the guide rod and entered the corticalis. In this case it would have been indicated to turn the nail 180 degrees with the opening pointing forwards and then insert it. Due to the fact that the nail could not be removed it was cut at the trochanter.

c) The same fracture after the nailing. The fragments are in good position, shortening does not exist and the fracture is absolutely stabil. Primary healing. The drain was removed two days later and the plaster splint was removed two weeks p.op. After that the patient started subjecting his limb to active exercises and to exercises after the manner of walking. Eight weeks after the operation the patient started subjecting his limb to weight bearing.

d e

Illustration 57

d) The same fracture 10 weeks p.op. Good formation of callus. Ball callus as well as rarefactions round the nail are not observed which proves that the nail is firmly seated.

e) The same fracture 5 months after the operation, 4 weeks after the extraction of the nail. The fracture is healed. The impediment of the hip joint is only slight, the knee joint impediment amounts to 180 - 80 degrees. The patient's gait is unhampered.

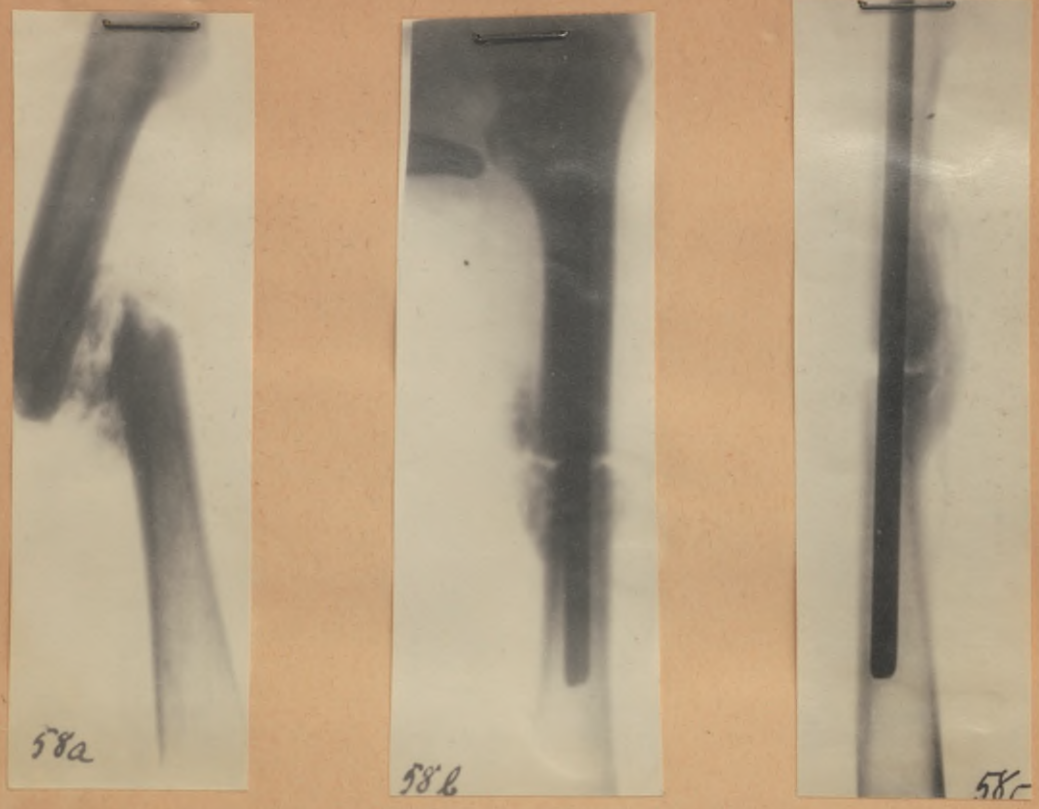
Any callus which does not interfere with the proper reduction of the fracture is left untouched and constitutes an important factor in the initiation of bone regenerations. We do not think it advisable, however, to reintroduce once removed pieces of callus into the wound, as is done according to VOELKER-LIFFLER in the operation of pseudarthroses, since the healing tendency is not disturbed. The detached pieces of callus are likely to decay and may form dangerous infection foci. Two cases treated in a military hospital in this manner resulted in severe infections.

We consider it an important point to conserve the periosteum as much as possible. The fact that it is admissible in marrow nailing to deviate from LANGENBECK's time honored principle of the subperiosteal osteotomy counts definitely to the credit of the method. In the nailing osteotomy the periosteum is in the first phase of the operation only incised at the site of the osteotomy. After the bone is cut with a chisel or GIGLI saw, the periosteum will be loosened only so far as will be necessary for the resection of certain parts of the bone.

The wide loosening of the periosteum was often held responsible for the delayed healing in old osteosyntheses. Whether this is true or not is difficult to say. The operation report relating to the fracture as illustrated under number 58 points out that: "the fracture ends were exposed with ample loosening of the periosteum" although the soft callus could be easily rended with a chisel. One year after the operation the fracture is only bridged over at the medial side, where the old remnants of callus were left untouched. The fracture cleft was still clearly visible in its total length. It must be admitted that the nail is rather short, the clarification next to its point indicates that it moved in the bone, but this does not, according to our experience, materially delay the healing of fresh thigh fractures. This is by the way the only osteotomy of the femur that healed so slow. In other cases where the osteosynthesis was also only "relatively stabile" the healing process took quite a normal course. It may, therefore, be safely said, that the wide loosening of the periosteum actually caused the delayed healing. How far this goes is demonstrated by the formation of the tiny callus spicules.

The wide loosening of the periosteum is especially hazardous if an infection sets in. The denuded bone is seriously jeopardized as to nourishment and extensive necroses may ensue, as in Ill. 54. The severity of the infection is certainly due to the fact that the osteosynthesis was very instabile and that the wound was not opened widely in due time.

Even if the nail is solidly engaged in the callus, as seen in Ill. 57, and the osteosynthesis is sure to become stabile, it is still better to drill the nail path from the very beginning in such a manner that a nail of sufficient size may be driven in. We had to make this experience lately in an obliquely healed fracture due to gunshot injury.



a b c

Illustration 58

a) Six months old closed thigh fracture treated with a 6 kilogram traction splint. Osteotomy because of a shortening amounting to 6 centimeters and marked angulation. Application of a traction bandage 8 weeks previously. Infection of the operation wound which is successfully overcome. Four weeks later the traction weights are diminished despite the fact that a shortening of 2 centimeters still exists. 14 days later the extension apparatus is removed and treatment with hot air, massage and electric stimulation started. After a lapse of 8 days another shortening of 4 centimeters and angulation is observed. The fracture seems to be stabil. Marrow nailing.

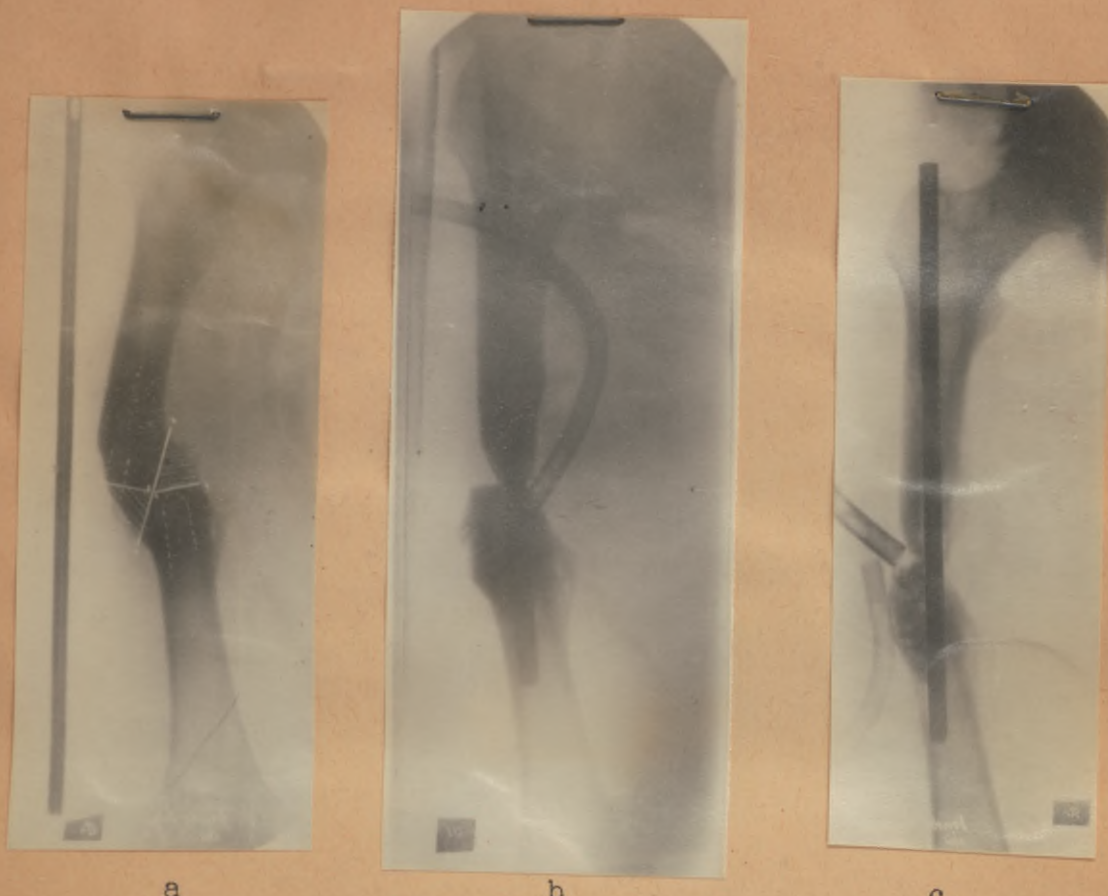
b) The same fracture after nailing. The nail is rather short. During the operation the ends of the fragments were "widely exposed subperiosteally in all directions". The fragments were resected until the marrow cavity was open. In this way a shortening of 2 centimeters occurred. Primary wound healing. The patient was able to get up 4 weeks later.

c) The same fracture 11 months after the nailing. The fracture cleft is still noticeable to its full extent. It is bridged over by callus only medially at the spot where the old callus is located. Around the nail tip we observe rarefactions with an accompanying irritation of the margins. The existing bridges of callus demonstrate how far the periosteum was separated. The nail was extracted 4 weeks later.

In the fracture due to gunshot injury represented in Ill. 59, 3 years old, healed with a shortening of 6 centimeters, wounds healed 1½ year ago, we started cutting the bone along the line 1 - 1. Then the proximal marrow cavity was opened along the line 2 - 2. The point of the distal fragment was cut off (line 3) and the marrow cavity was located by means of a drill. The correct position of the drilling canal was checked by X-ray and inserted tube. This canal was enlarged with ball trepan and chisel wide enough to make the introduction of a middle sized nail possible. With a view to determine the length of the nail required, we introduced a thin nail into the distal fragment. It was observed that the nail was lying at an angle and hit the corticalis if introduced by 9 centimeters. We did not attach too much attention to it and refrained from drilling a new canal. The bone ends were then brought into position and held with a LAMBOTTE's bone forceps and after checking by X-ray and securing the position clinically, a groove was chiseled into the bone to avoid axial displacement.* Now, a guide rod, was introduced into the distal marrow cavity to measure the distance (a) up to the trochanter. When the guide rod had pierced bone and skin at the trochanter, a medium size nail was driven in, the length of which had been determined as follows - a (= length of the proximal marrow cavity) plus 4 centimeters (= length that the nail may jut out at the trochanter) plus 9 centimeters (= length of the canal in the distal fragment). The nailing was uneventful and the fracture was absolutely stabile. The ends of the fragments joined only half of the periphery. (Ill. 59b). A drain was applied posteriorly. BRAUN's splint and plaster splint were used. Residual shortening 1.5 centimeters. The musculature did not reveal abnormal tension, the reduction was carried through without using undue force.

The operation was followed by two days of slightly raised temperature, on the third day the patient was free from fever. The drain was therefore removed on the fourth day. Then followed a sudden rise of temperature. The drain was reintroduced and a plaster cast was applied. The temperature returned promptly to normal. The drain is definitely removed on the 11th day and the plaster cast on the 12th day. The operation wounds had healed by that time. On the 21st day, after the operation a new rise of temperature up to 38° was observed. A collection of serum is palpable in the area of the fracture which is punctured. The temperature then returned to normal. (Cultures of straphylococcus were ascertained in the serum). The temperature remained normal and the patient began to move the limb on the 26th day after the operation. After two more days the patient was allowed to be ambulatory. After 35 days, the treatment could be continued on an outpatient basis. The patient could use the leg without any trouble and walk considerable distance if using a cane for support. 4 weeks later the patient could walk without a cane and the mobility of the knee which had previously been almost stiff had improved considerably. 3½ months after release from the hospital

*) distortion



a b c

Illustration 59

a) Three year old gunshot fracture. The wounds have been closed for 1½ years. The shortening amounts to 6 centimeters and the knee joint flexion to 45°. The lines in the picture show the separation of the bone, the hatched drawings indicate that part which had to be removed. The distal marrow cavity must not be opened. Attempts must be made to locate it by drilling in KIRSCHNER wires under X-ray control. After the insertion of a nail into the hole made with a chisel the nail touches the lateral corticalis 9 centimeters from the insertion spot because the canal did not run precisely in the axial direction.

b) The fracture after the nailing. Slight varus position. At the frontal aspect the nail projects 3 centimeters. The fracture is absolutely stabil. Long drainage tract to the rear. The shortening amounts to 1.5 centimeters. After the operation a rise of temperature was observed but the wounds came to a primary healing. After a lapse of 21 days another rise of temperature and the formation of serum at the fracture cleft were observed. After aspiration the temperature slowly decreased to normal. The patient was released for ambulatory treatment 35 days after the operation. Painless weight bearing. When walking the patient had to use a cane.

c) 3½ months later. For 14 days the patient has complained about increasing pains at the fracture site. Abscess at the operation wound. Rarefactions of the bone particularly of the distal callus. Rarefactions round the nail tip which penetrates the corticalis. Periosteal layer. The fracture is completely stabil. Wide incision of the abscess, drainage, and application of a cast with a window.

d e

Illustration 59

d) 4 weeks later. The nail tip has pierced through the corticalis. An increase of the periosteal layer is observed. Beginning formation of a ring sequestrum of the proximal fragment. Despite the fact that the nail holds the fragment firmly together and bony healing cannot be expected, it was removed in order to prevent a further piercing through of the nail. After the extraction of the nail a marked springiness of the fragments was observed. After that traction bandages and plaster casts were applied. Several sequestra had to be removed.

e) The same fracture 7 months after the operation, which is in satisfactory position and stabil. The shortening amounts to 2½ cms. and the motion of the knee amounts to 180 - 90 degrees. The wounds are closed.

It would have been better to resect the bone enough so that the distal marrow cavity would also have been opened and to perform a two-phase operation. In such a case the shortening would probably have also amounted to only 2½ centimeters and it would have been possible to shorten the sound leg later by means of a marrow nail. In doing so the operation would have been more simple and therefore an infection probably would have been prevented. The healing process would have been shorter.

the patient returned to the clinic with an abscess on the outer side of the thigh which had to be incised. The X-ray picture (Ill. 59c) reveals, apart from a loosening of the structure, a distinct neoformation of periosteum at the proximal fragment in the area of the point of the nail and below it a gradually increasing rarefaction of the corticalis was to be seen (Ill. 59d), so that we decided to withdraw the nail, although a solid bony fixation of the fracture could not yet be expected. A couple of abscesses had still ot be opened and a few sequestra to be removed when finally after 7 months following the operation the wounds had healed and a satisfactory fixation was achieved by the use of extension, bandages and plaster casts. Shortening 2 centimeters. Satisfactory axial position, knee joint movable between 180 and 90°.

If we have to deal with a torsion of the fracture site, as we could observe in four cases of thigh nailings, performed in other clinics, the osteotomy will be performed in the ideal portion of the bone, that is the middle third. The extent of the torsion is ascertained by determining the angle between the median line of the sole of the foot and the surface of the table at the utmost inward rotation of the hip joint. The difference between the sound and the affected sides constitutes the necessary correction. After exposure of the bone and loosening of the strict minimum of periosteum a longitudinal groove is chiseled into the bone which is then cut as far as possible with the nail lying in position. The nail is then drawn back as far as the fracture cleft and the remaining bridge of bone will be cut through. Then a guide rod is introduced into the nail and distal marrow cavity and the distal fragment is rotated to the extent of the necessary correction, so that the longitudinal groove is displaced by 3.5 millimeters per 10°. *By comparison with the sound leg at the utmost inward rotation of the hip joint, one makes sure that the position is correct and the nail is then driven in. It is not necessary to take a thicker nail. It is recommended, however, to drive the nail in 2-3 centimeters deeper which will always be practicable. (Ill. 60).

The results obtained:

In 23 nailing osteotomies which were uneventful the displacement* could be completely compensated for, except in one case (Ill. 61).

In 11 cases of shortenings up to 3 centimeters the compensation was a 100% successful. In 1 case a shortening of 1½ centimeter was left because the ends of the

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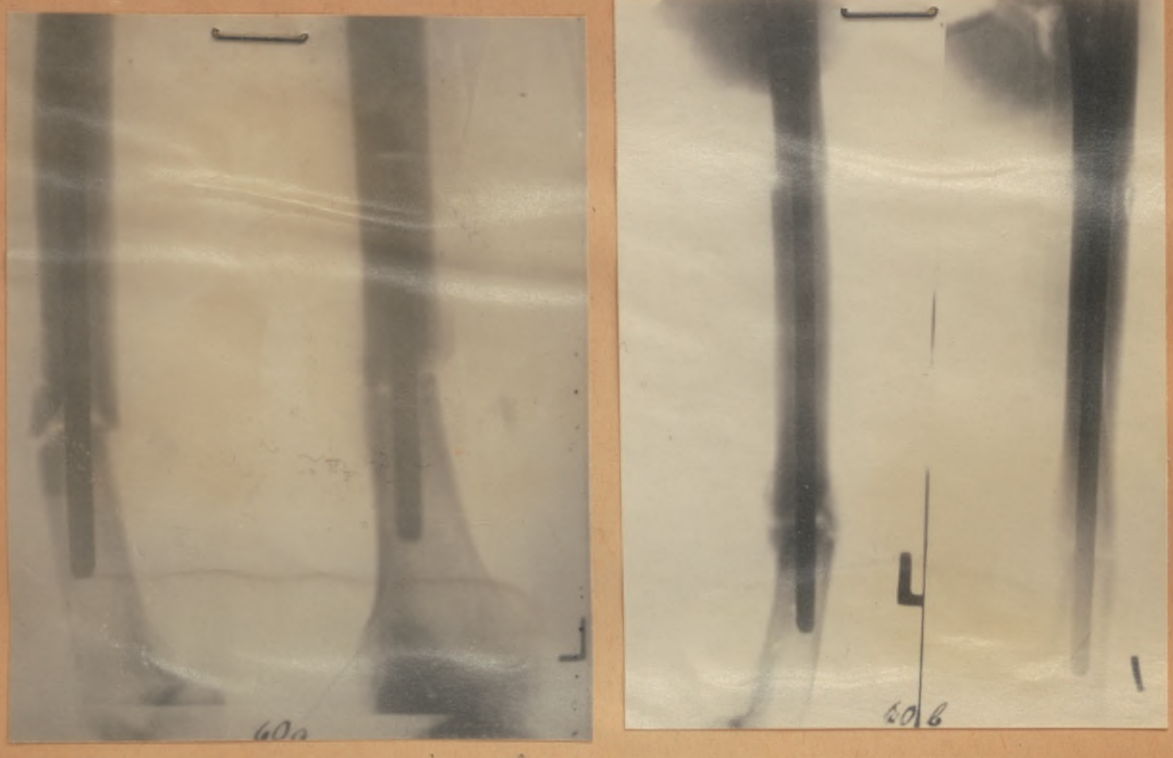
* The circumference of a circle over an angle of 10° is 10 arc $\frac{10r \cdot \pi}{180}$. With an average diameter of the thigh of 20 mm this will amount to $\frac{200 \cdot \pi}{180}$ = 3.46mm.

* distortion



a b

Illustration 60

a) Closed transverse fracture of the thigh 8 weeks after the nailing which was performed in another hospital. X-ray report: "Ideal position, very good formation of callus". The rotation of the nail to the exterior which amounted to 20 degrees could probably have been compensated inoperatively because the nail was too short, but it was not observed. The patient was brought to various hospitals and treated medico-mechanically, and with gymnastics. The impediment of his gait however did not subside. 4 months later, after he had been transferred to the special department of the hospital the fracture came to a bony healing.

Due to the fact that the nail was relatively short a rotation osteotomy was made at the junction of the upper and central thirds. In this way it was possible to use the old nail.

b) The same fracture 8 weeks after the osteotomy nailing. The patient is able to subject the limb to painless weight bearing. The osteotomy cleft is bridged over. The patient was released to his unit for garrison duty. The nail was removed two months later. Complete restoration.

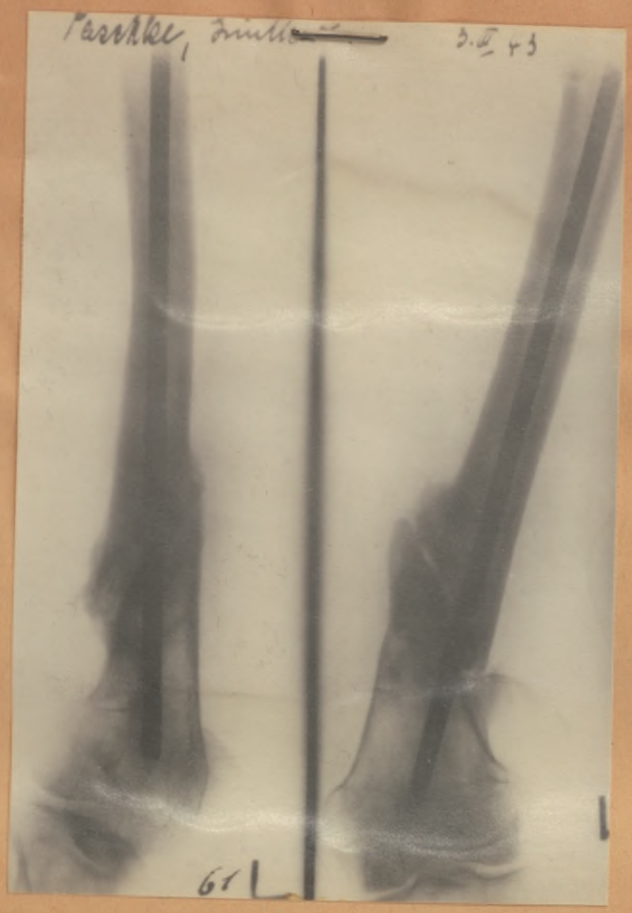


Illustration 61

Osteotomy nailing of the thigh performed in another hospital, 11 months old. The fracture is healed. Marked valgus position. The shortening amounts to 2 cms. The wounds have been closed for 10 months. 4 months after the operation the shortening amounted to 1 centimeter, the valgus position amounts to 15 degrees.

The nail was not inserted in the proper axial direction into the distal fragment. Fractures of this kind are not suitable for the nailing osteotomy. It is better to treat them according to the traction method after the osteotomy. Even a wire suture would not have been indicated in a fracture of this kind because it would not protect the fragments from slipping. A LANE's plate could at the best be applied but it would not give any advantage as compared to simple wire extension. Due to the fact that we have to deal with an old gunshot fracture the danger of infection might even increase.

fragments were resected, in another case the shortening left was 1 centimeter (see Ill. 61).

In 5 shortenings of 4 centimeters the leg remained 1 centimeter too short in one case. A shortening of 5 centimeterswas successfully compensated. In 3 shortenings of 6 centimeters the leg remained 1 centimeter too short in two of the cases.

Of special importance are the advantages with regard to the mobility of the joints. In all of the 23 cases under consideration the mobility of the knee joint and in 8 cases the mobility of the hip joint was limited, in some instances even to a considerable extent. In all fractures which were not older than 9 months the full mobility was restored. A considerable improvement was achieved in the older fractures. All the hip joints were movable and the flexion of the knees at least up to 90° was achieved in all operations.

It must be admitted that the limited mobility of the joints may also be successfully treated by osteotomy and wire extension. The fact that a stiff knee joint resulted in 4 cases where infections occurred weighs heavily on the method and the final compensation of the shortening means little if this price is to be paid.

b) Old and not yet fully healed thigh fractures in bad position and pseudarthroses

Under the impression of the relatively high incidence of infections in the open marrow nailing we were inclined to adopt the closed nailing in all cases of old fractures. In that case the patient enjoys all the advantages which were attributed to the marrow nailing of fresh fractures and all indications and contraindications apply to these cases.

The closed nailing will only be successful, however, if the fracture is thoroughly mobilized, even in case it appears to still be entirely free. When more than 3 weeks have elapsed there will always be certain fixations of the connective tissue of the fragments which make a correct reduction impossible. These fixations must be broken up forcibly.

In 20 thigh fractures which were from 4 to 10 weeks old we were always able to perform the closed nailing after a thorough mobilization, whereas in the military hospitals one was not successful in fractures which were only 4 weeks old because the mobilization was omitted and the exposure of the fracture site became necessary.

As a matter of fact, the surgeon who undertakes to nail old fractures must have experience with the nailing of fresh fractures, since the old fractures offer a considerable amount of additional difficulties. Although we have nailed 16 of the 20 fractures without the reduction apparatus, we have found that the use of this apparatus facilitates matters greatly and we recommend its use warmly.

If the shortening exceeds 5 centimeters it is recommended that a wire extension be used after the mobilization and to wait until the shortening is compensated for or even overcorrected. This is generally the case after 8 to 10 days and the operation is greatly facilitated by this measure.

Before the beginning of the nailing properly speaking, one must make sure that the fracture ends abut properly. If this is not the case one should not waste any time with renewed mobilizations and attempts of reduction but rather choose the open marrow nailing. The infection hazard, as we have seen is not so high in not yet healed thigh fractures.

Above all we warn against the closed nailing of fractures which are older than 5 weeks, especially so since we have experienced a fatal outcome due to fat embolism. The hazard that the marrow cavity be closed by more or less solid callus thus causing an overpressure when the nail is driven in is definitely higher in thigh fractures than the infection hazard in the open marrow nailing.

In 36 of our 44 cases of open nailed thigh fractures which were 4 to 40 weeks old we could observe the entire course of healing. The stay in the hospital lasted from 47 to 215 days, thus an average of 131 days. The unemployability lasted 86 to 240 days, with an average of 179 days.

We observed approximately the same values in 19 fractures which were treated by a closed nailing and which were 4 to 10 weeks old.

It is still more important to note that a shortening of 1 centimeter was observed only in one fracture which had been resected although it was only 4 weeks old. All the other fractures, including those which were more than 6 months old, healed without any shortening.

In one thigh fracture, 32 weeks old, in which the knee joint was already stiffened the nailing restored a 90° mobility. In all other cases the full mobility was restored although the knee joints were considerably hampered before the nailing.

There is no doubt that the greater part of old thigh fractures can be healed by bringing the fragments into contact by a bloodless mobilization and a sufficiently long period at rest. The old methods of osteosynthesis hardly

meant any progress over this conservative treatment. The advantage of the marrow nail, however, is that an additional bandage to secure the position at rest is no longer required and that the mobility of the joints is restored early. This advantage is so important that we give preference even to the open marrow nailing in case of old thigh fractures, under the condition, however, that at least a relatively stabile osteosynthesis can be achieved by the nail.

In deciding whether this is possible or not, one has to consider, apart from the location and form of the fracture, the condition of the bone, especially in subtrochanteric fractures. We have seen in the fresh fractures that a wandering of the nail may occur in the massive part of the trochanter which may lead to new angulations and loosenings of the osteosynthesis. The hazard of such wanderings is particularly high if the bone in case of an old fracture is atrophic and in such cases it may even happen that the nail is completely breaking out of the proximal fragment. In case of fractures below the middle, in which the nail must be driven in as far as the line of the epiphysis into the spongiosa, the nail may enter the knee joint in case of an atrophy of the bone.

<u>The presence of a bone atrophy, therefore, excludes the marrow nailing in thigh fractures.</u>

The hazard that these fractures will heal in a bad position is small. The atrophy is generally associated with a deficient callus formation and a bloodless reduction of the position will always be possible, at least to an extent that the usability of the leg will not be seriously hampered. If the fracture does not solidify in spite of satisfactory position, the nailing can be performed at a later date after the improvement of the calcareous contents of the bone. If the calcareous condition is normal, one should not hesitate to perform the nailing operation if the position of the fracture is not satisfactory. The more callus has developed and the more solid the fracture becomes in the faulty position, the more dangerous will the operation be and the greater will be the infection hazard. It is recommended again to perform a bloodless mobilization followed by the application of a wire extension in case that the shortening exceeds 4 centimeters. The nailing will be performed 8 to 10 days later when the shortening is compensated and the effects of the injury to the soft parts are overcome. We also wish to repeat that we introduce on principle a long drain posteriorly for 24 to 48 hours. Both measures reduce the infection hazard.

The old fractures in which the osteosynthesis becomes instable are not suitable for open nailing, that is all fractures which are less than 6 centimeters away from the tip of the trochanter and from the knee joint. If in these cases the faulty position cannot be compensated for with the conservative methods or if we have to deal with a pseudarthrosis, recourse must be made to the osteosynthesis with wire or LANE's plate, respectively to the bone graft or MATTI's operation. The use of the nail would not mean any

advantage, since an additional plaster cast or wire extension will be needed anyhow. If, however, an infection sets in, the nail would still increase the multiple hazards.

3. Fractures of the Lower Leg.

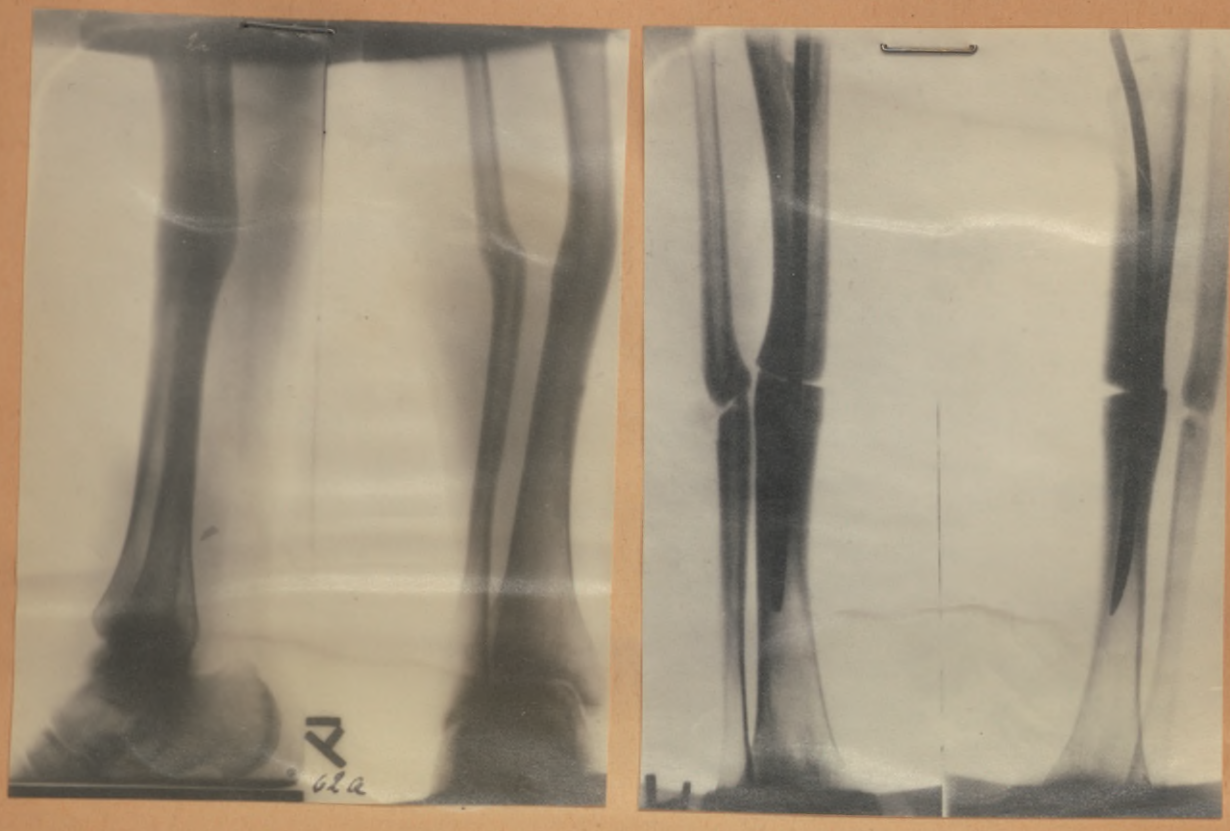
a) Nailing osteotomy of obliquely healed fractures

A really stabile osteosynthesis in obliquely healed fractures of the tibia is still more rarely obtained by osteotomy than in the fresh fracture, because the nail will only be firmly engaged in the hour-glass shaped marrow cavity if the fracture is located in the middle of the bone. The smooth resection areas will not afford any hold if pressed together and one will only very rarely succeed in obtaining a firm hold for the nail in the callus which closes the fracture ends. If the cuts are applied transversely to avoid a slipping off, it will always be necessary to resect a large piece of bone. This will make a shortening unavoidable. The smooth transverse fractures of the tibia have a tendency to a delayed callus formation. If no resection was performed to avoid the shortening and if a gap is left between the abutments of the fracture, as seen in Ill. 62, there will be a still greater hazard of a delayed healing in spite of the osteosynthesis being stabile in the beginning. The nail will gradually loosen in the bone, the fibula will heal early and a shearing movement of the smooth cuts is likely to develop which seriously interferes with the healing process. It is of little use to fill the gap with pieces of the resected bone (Ill. 63) not to mention the increase of the infection hazard.

If the cut is applied at a slant it will become necessary to use a wire suture and a plaster cast to avoid slipping and shortenings. Thus the nail does not bring any advantages.

Only by cutting the bone in the shape of a staircase will one obtain a wide contact of the fracture ends and avoid all longitudinal displacement. This procedure may appear relatively simple in the copies of the X-ray picture. In reality, however, it is a very complicated and tedious procedure and if a satisfactory result is striven for, the operation will imply many hazards of breaking asepsis.

It is by far easier to perform an oblique osteotomy and to unite the fracture ends by wire suture after the removal of a corresponding wedge. This method will serve to compensate the angulation and the shortening at the same time (Ill. 64). (Authors Note: It is not quite easy for the inexperienced surgeon to establish the proper form of the wedge after the X-ray copies in two planes. To facilitate the determination of the bone wedge it is recommended to prepare a Plastilin model according to the (possibly stereoscopic) X-ray pictures and to perform the resection on this model). The plaster cast required in this method will not constitute an important inconvenience. It



a b

Illustration 62

a) One year old open leg fracture. Valgus-position and recurvation; the shortening amounts to 1 centimeter.

b) The same fracture 4 weeks after osteotomy and nailing. The nail is too short and the osteotomy planes are in contact less than 50 %. It would have been better to resect the fibula at some distance from the osteotomy site.

Four months later no formation of callus to be observed. Therefore the fibula was resected.

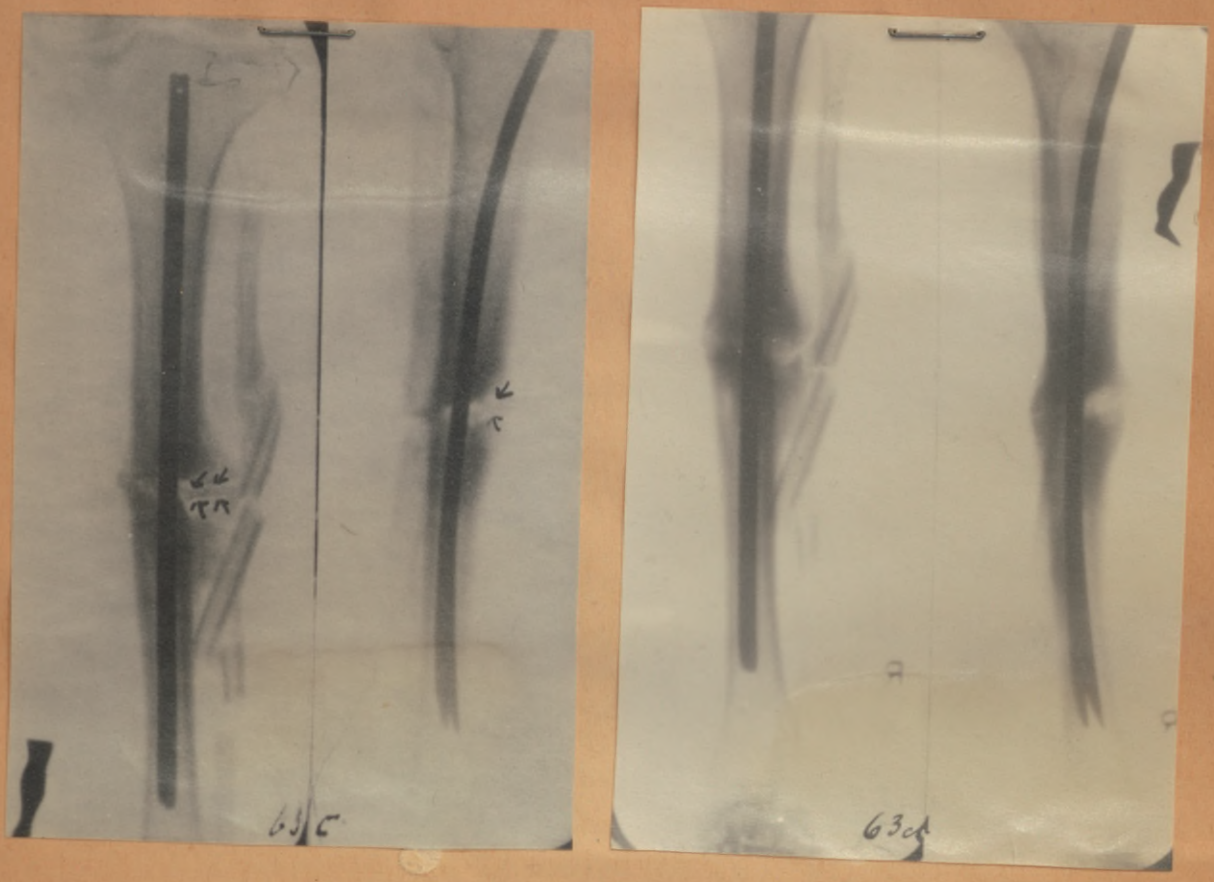
Six months after the operation the fracture cleft was still gaping, some symptoms indicating a formation of console callus were observed. Marked rarefactions around the nail tip (pictures were lost). Removal of the nail, BECK's drilling, application of a plaster cast. Eight weeks later the fracture was stabil.

a b

Illustration 63

a) Fracture of the leg which was nailed 2 months before in another hospital. Due to the fact that the simple nail was too short an angulation of the fracture occurred which was in good position in the beginning. The limb was subjected to weight bearing too early, and was not well enough observed.

b) The same fracture 7 months after the nailing after the patient had been brought to the special department of the hospital. The nails have been removed. After resection of the fibula an attempt was made to correct the angulation by use of the osteoclast but this failed. Therefore, eight days later osteotomy with marrow nails was performed.



c d

Illustration 63

c) The same fracture after the osteotomy. The fracture cleft which is gaping in front and medially was filled with resected parts of the bone (I). The fragments are in good position. It would have been better to use longer nails.

d) The same fracture 4 months after the operation. The fracture cleft is not yet healed but only filled with cloudy callus. It is stabil from the clinical point of view and the patient does not complain about pains during weight bearing. Four weeks later the nail was removed. Pains and swellings were observed which subsided 5 weeks later.

will also be required in most of the cases where a marrow nail is being used and besides this, the hazard of a stiffening of the joint is less imminent in fractures of the tibia. The hazard of damage due to infection appears to be increased by the use of the marrow nail.

Guided by these considerations I did not use the marrow nail for the correction of obliquely healed fractures of the tibia.

In the Military Hospitals the marrow nail was used 5 times for this purpose. Infections did not occur.

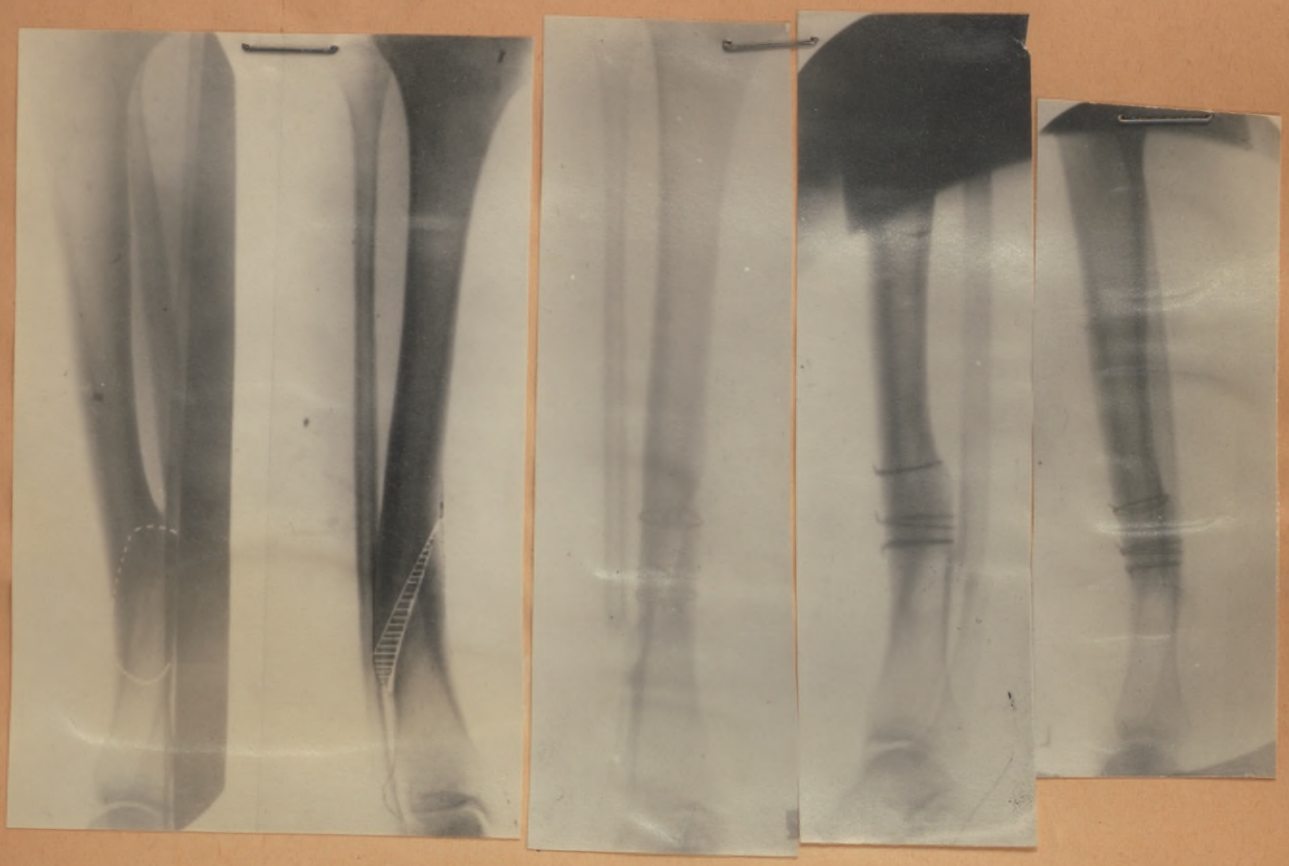
Two patients could not be observed until final healing. The fracture of Ill. 62 did not reveal any formation of callus in spite of a completely healed fibula for this reason a resection was performed. Eight weeks later the fracture was still springy and it could be seen in the X-ray picture (unfortunately now lost) that the fracture cleft was still open. There was a slight indication of spicules of callus and rarefactions next to the point of the nail could be observed. The nail was, therefore, withdrawn. BECK's drilling and a plaster cast were used. After eight more weeks the fracture finally solidified.

In case of the fracture of Ill. 63, the additional plaster cast could also be removed only after 3 months. Four months after the operation the fracture cleft is still clearly visible (63b) and when the nail was removed 5 months after the operation, the fracture was clinically solid but swellings occurred and pain was felt when putting stress on the fracture and the patient could be discharged only 6½ months after the operation.

The fifth patient also required 6 months for the healing. The fracture treated with nailing osteotomy was located at the limit between the median and distal third. A plaster cast was necessary for 4 months. A shortening of 1 centimeter occurred.

The fracture of Ill. 64, however, with osteotomy and wire suture was healed after 8 weeks to an extent that the patient could be discharged with an UNNA's bandage. The shortening was completely compensated for and the joints were perfectly movable. In 6 other osteotomies of the tibia treated in the same way the stay in the hospital varied between 36 to 98 days, an average of 56 days. The unemployability lasted for 81 days on the average. A permanent involvement of the joints was not observed in these cases. A shortening of 1 centimeter occured in one case.

It may, therefore, be concluded that the marrow nailing after the osteotomy of obliquely healed fractures of the tibia does not promise any advantage whatsoever. In consideration of the hazards due to the marrow nail in case of an infection, preference should be given to the old osteosynthesis methods.



a b c

Illustration 64

a) 15 months old closed leg fracture. Recurvation, Varus-position, the shortening amounts to 2 cms. Plotting of the osteotomy line and removal of the hatched part of the bone.

b) The same fracture after an oblique osteotomy of the fibula and resection of a wedge out of the tibia. The fragments are held in place by means of wire sutures. Shortening was compensated. The varus position as well as the recurvation were eliminated.

c) The same fracture 8 weeks after the operation. Healing was obtained and all joints are freely movable. Shortening was not observed. Very slight recurvation which is negligible from the clinical point of view.

b) Old but not yet healed Fractures and Pseudarthroses

Apart from the old fractures with faulty position, those tibia fractures with deficient callus formation and pseudarthroses are the ones which necessitate surgical intervention. The poor healing tendency is in the majority of cases with the exception of infections due to disturbed mechanical conditions, including inadequate fixation. If these mechanical disturbances are eliminated, one will as a rule be successful in obtaining bony healing in old fractures of the tibia.

In case of genuine pseudarthroses in which the ends of the bones are covered with a newly formed fibrous cartilage, and in defect pseudarthroses it will always be necessary to expose the fracture site. In case of the fracture without healing, that is the connective tissue pseudarthrosis, it is sufficient to resect the obstructing fibula and to assure a perfect abutment of the fragments (with or without BECK's drilling)and adequate position at rest. The healing will take place without exposure of the fracture site.

According to our experience it will not always be possible to distinguish with certainty between a genuine pseudarthrosis and a fracture without healing. The time that has elapsed since the accident does not furnish any clues. The X-ray picture is not conclusive either in most of the cases.

I would like to mention an example from my experience as assistant.

An osteosynthesis with LANE's plate had been performed on tibia fractures as per illustration 65a two years previously. As no bony healing occurred, the patient was given a brace. When the patient was admitted to our hospital, the fracture was distinctly springy. The brace was too wide and I requested in my report the modification of the apparatus. One year later the patient came back for a final check up. The apparatus had not been changed. The fracture had healed clinically and reontgenologically (Ill. 65b) without resection of the fibula, without BECK's drilling and without a bone graft solely through the brace which prevented lateral movements and since the brace was too short, allowed for a pushing together in an axial direction. The healing was possible only because we had to deal with a connective tissue pseudarthrosis and consequently the bone ends were not covered with fibrous cartilage.

a

b

Illustration 65

a) Pseudarthrosis of the tibia, two years after osteosynthesis by means of a LANE's plate. Probably the fibula was not severed and therefore the osteotomy is gaping. The plate is loose, because the screws were fixed in only one side of the corticalis. The marrow cavities seem to be entirely covered. We have to deal with a typical pseudarthrosis. The patient uses a brace which is too loose.

b) The same fracture one year later. Bony healing, without any additional operation. Consequently there was not a true pseudarthrosis in question but only a "fractura non sanata".

According to our experience a bony healing may still be expected in tibia fractures which are up to 5 months old if the fracture ends are well adapted (with or without BECK's drilling) and if a sufficient position at rest by a walking-cast is assured. It is, however, necessary and this is often omitted - to resect the obstructing fibula. (Authors Note: The resection of a piece of bone about 1 centimeter long is preferable to a simple oblique osteotomy. The latter heals so early that the bone will obstruct again.

If the closed nailing can be used in such fractures in the place of the plaster cast and if at least a relatively stabile osteosynthesis can be achieved, the patient enjoys all the advantages which are indisputably established in the marrow nailing of fresh tibia fractures. In this case it is not important, whether the bony healing will take 6 or 16 weeks, inasmuch as the patient has the full use of the limb with the nail in position and the employability is only slightly reduced. The main hazard, namely the infection is completely eliminated in the closely marrow nailing.

In 16 fractures of the tibia which were 4 to 23 weeks old, we have carried through the closed marrow nailing and all have healed without shortening and with free mobility of the joints, although there were already considerable restrictions in the mobility of the ankle joint in nearly all fractures more than 14 weeks old. The stay in the hospital varied between 18 and 80 days, the average was 43 days. The unemployability lasted from 85 to 170 days, that is 125 days on the average. Similar results cannot be obtained without using the marrow nail.

We are, therefore, of the opinion that the attempt is indicated to nail all old tibia fractures, as far as they are suitable for nailing, without exposure of the fracture site. And this should be done the earlier, the better. All the contraindications which exist in case of fresh fractures must be considered very carefully.

The resection of the (already healed or intact) fibula will become necessary in all cases. The fracture must be throughly mobilized. If there is no considerable shortening or lateral displacement, the nailing will be performed in one session together with the resection of the fibula. In case of a considerable lateral displacement or shortening, however, and in case of very old fractures, a wire extension will be applied after the resection of the fibula and the nailing will be postponed until the faulty position and particularly the shortening are compensated for and until the injury to the soft parts due to the mobilization of the fracture has subsided.

In case of old compound or infected fractures, the extension bandage must be left in position until one can be sure that the infection will not suddenly flare-up.

In deciding the question whether it is advisable to perform the nailing of an old compound fracture of the tibia in case that the closed nailing is not possible, it must be considered if the nailing offers important advantages over other methods. This decision will always be possible in case of pseudarthroses and fractures which are older than 20 weeks.

An abnormal variation in the time of necessary treatment could not be observed in our patient material. Even in those 26 primarily healed cases, the average stay in the hospital after the operation was 123 days and the period of unemployability lasted 178 on the average. These results can also be obtained with other methods.

The average will still be worse if the infections are taken into account. Only 10 of the infected cases could be observed until their final healing. The average stay in the hospital of the 36 patients then is raised to 245 days, the unemployability to 273 days.

17 of the aseptically healed fractures (49%) did not show any shortening or impediment of the joints. 2 cases resulted in a slight impediment of the ankle joint. 4 patients had a permanent impediment in the mobility of the ankle or knee joint and 3 pseudarthroses did not come to bony healing. All the fractures complicated by infections healed with stiffened ankle joints and a more or less pronounced impediment of the knee joint.

It must, therefore, be admitted that the results of the open nailing of the old tibia fractures, even in case of aseptic healing, did not show a result which could be called appreciably superior to other methods. The hazard of infection is ever present in this method and the nail means additional hazard in that case.

Two of these infected cases turned out fatally.

In a transverse fracture in the middle of the tibia, the site had been exposed after several unsuccessful attempts to perform a closed nailing (the mobilization had been omitted). The osteosynthesis was stabile. An elevation of temperature was already observed one day after the operation. On the fifth day an abscess at the entrance wound of the nail had to be opened. The wound at the fracture healed primarily.

As the fever did not subside and in consideration of the poor general condition of the patient, a blood transfusion of 500cc. was carried through on the 12th day after the operation. 4 hours later the patient was seized by a chill with high temperatures, apparently the onset of an acute sepsis, which caused the death of the patient the next day. The postmortem findings revealed:a streptococcic sepsis with chronic tumors of the spleen, liver and myocardium were damaged; fresh septic infarcts of the lungs as metastases from foci in the tonsils. The patient had suffered from an acute angina in the previous hospital, a fact which he had not mentioned. He already

had a slight fever before the nailing and this had been overlooked afterwards as the attention was concentrated on the fracture. Although the blood transfusion can be considered as the directly releasing factor of the fatal septic action, there is no doubt that the nailing also contributed to mobilize the latent sepsis. This outcome is the more regrettable since the position of the fracture was not too bad and could have been healed conservatively.

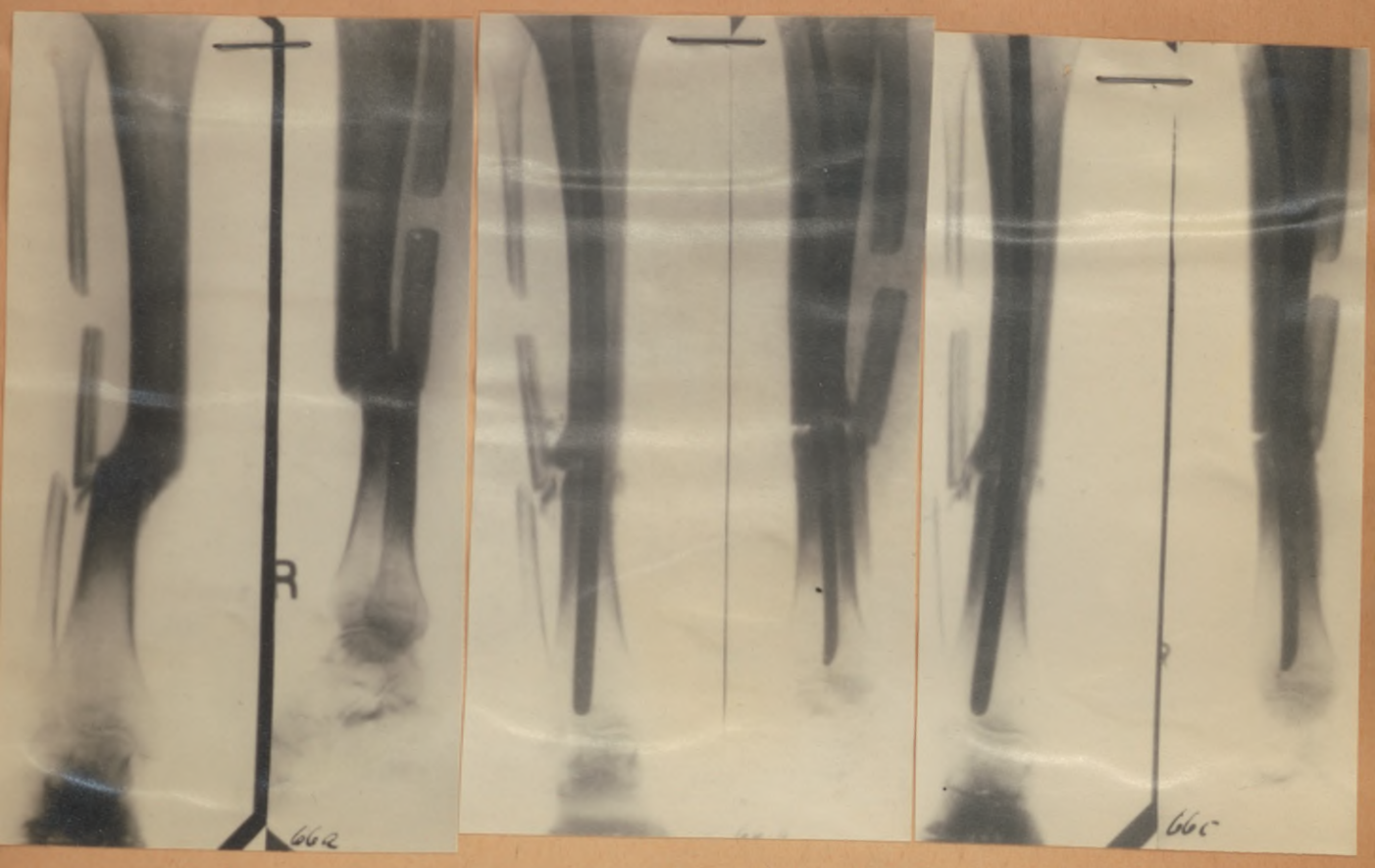
It results from the foregoing that the surgeon must ascertain the general condition of the patient very carefully before a nailing operation is performed.

In the second fatal case, the nailing is also only indirectly responsible for the outcome.

In the ten months old tibia fracture of Ill. 66a an open marrow nailing was performed, because the fracture was still movable two months after the severance of the fibula. A necrosis of the skin developed (lobular incision) which turned into an erysipelas and the fracture became infected. The osteosynthesis was not stabile because only one nail, the thin one, had been used (Ill. 66b), so a slight valgus position developed (in spite of a splint). When the fracture was clinically fixed 12 weeks after the operation (Ill. 66c) and the fistula showed only a very little secretion, the nail was removed. With the view of obtaining a better hold on the nail, the intensely stiffened knee joint was mobilized (!) and now an empyema of the knee joint developed which was drained by resection of the condyles. A new abscess developed at the fracture site which lead to sepsis with fatal outcome, because it was omitted to amputate in due time. In the autopsy still another empyema was found in the ankle joint, which had spread by way of the nail path. This wandering took place after the removal of the nail and was due to the fact that the nail had been driven in too far beyond the line of growth, almost to the cartilage of the ankle.

In this case too the position of the fracture was not bad at all and a healing would certainly have been obtained without the use of the nail with adequate immobilization. Once again the rules of general surgery were disregarded, since it is strictly prohibited to forcibly mobilize a stiffened joint if it is in a purulent state as this means a serious hazard of infection to the joint.

As has been mentioned before, there was no stabile osteosynthesis in almost all the infected cases and the results are different if viewed from this angle (Table V).



a b c

Illustration 66

a) 10 months old leg fracture, 2 months after the resection of the fibula. Open marrow nailing indicated because the fracture is not yet stabil from the clinical point of view.

b) The same fracture after the nailing. According to the records the fragments were properly separated and the marrow cavities were opened by drilling. Only too thin a nail was used. An erysipelas and infection of the fracture occurred which were developed from a skin necrosis in the lobe shaped incision.

c) The same fracture 3 months later. Slight structural loosening at the fracture cleft. Laterally the fracture is somewhat angulated. A small fistula was observed at the level of the fracture with only slight secretion. The nail was removed because the fracture was stabil from the clinical point of view, and bridged over by callus at least in the rear. It was hoped that in this way the suppuration would subside. During this operation the knee was mobilized with the patient under anesthesia.

Subsequently a knee joint empyema was observed and shortly after that a lethal sepsis occurred.

T a b l e V

Open marrow nailing in aspetic old tibia fractures and pseudarthroses

	Number of cases	Average stay in the hospital	Average unemployability in days	Infection	Result I	II	III	IV*
Osteosynthesis stabile	14 (+ 1)	53 (31-96)	108 (85-193)	1 (+ 1 see text)	13	1	-	-
Osteosynthesis relatively stabile or instabile	21 (* 10 not observ. until final healg.	221 (136-368)	248 (136-380)	10 (+9) =61%	prim. 4	1	healed 4	2
					infected 2	1	7	-
					6	2	11	2

It becomes evident that the infection hazard is very low in case of a really stabile osteosynthesis and that the results in that case are better than could possibly be achieved by other methods of osteosynthesis. The stay in the hospital is generally shorter and impediments of the joints are avoided and existing ones ameliorated or compensated, because the patients may begin quite soon after the operation with adequate movement exercises.

In case of an insufficient stability, however, the infection rate is very high (61%!), the treatment is very long and the results must be called very poor.

To a large extent the infection can be held responsible for the poor results. The fracture must remain for a rather long time in the plaster cast because of the pus secretion and considerable stiffenings of the foot and sometimes of the knee joint are the consequence. Intense angulations or shortenings could be avoided in the infected cases because the fractures were not put under stress too early.

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* I. Healing without shortening, angulation or impediment of the joints
II. Slight angulation, shortening or impediment of the joints EM 20%
III. Marked shortening, angulation or impediment of the joints EM 25%
IV. Pseudarthroses

* The open, previously infected fractures, the wounds of which had healed more than 8 weeks before are included in the "aseptic" fractures, Old fractures due to gunshot injuries are not included.

The cases grouped under III of the table of the aseptically healed fractures refer to marked angulations, which were either present after the nailing and were not noticed (Ill. 67) or were due to the fact that the patient was allowed to use the fractured limb too early without paying attention to the gradually increasing angulation.

The stability gains special importance in pseudar. - throses, which according to our usage will include all fractures which are older than 6 months, regardless if we have to deal with a genuine connective tissue pseudarthrosis or with a fracture without healing.

We would like to give a few examples in this connection:

A 24 weeks old tibia fracture located at the limit of the distal third was treated with closed nailing and simultaneous resection of the fibula. The osteosynthesis is stabile and a bony healing is achieved so that the nail can be withdrawn after 5 months.

In the 26 weeks old fracture of Ill. 68a, however, the resection of the fibula was omitted and only one nail, the thin one was introduced from the distal side without opening the fracture (Ill. 68b). No healing was observed after 11 months (Ill. 68c), because the thin nail had no grip and could not prevent the undesirable lateral and tilting movements and because the fibula had not been resected. The nail was then removed, an osteotomy of the fibula was performed and a shifting of the bone graft at the pseudarthrosis was carried through (Ill. 68d).

It is very likely that healing would have occurred in this case without the nail if the obstructing fibula had been resected.

In the 10 weeks old pseudarthrosis of Ill. 69, in which the marrow cavities were closed by hard eburnised bone and the fracture cleft was filled with connective tissue, the marrow cavities were only opened wide enough to allow the nail to enter. The osteosynthesis was stabile (Ill. 69b) and the patient could walk freely without a cane 4 weeks after the operation. Five months after the operation the fracture was completely healed and the patient was discharged from the hospital.

In the 7 years old pseudarthrosis of Ill. 70, however, the scar tissue that filled the fracture cleft was removed only at the anterior part and the marrow cavities were opened wide enough to introduce the nail. The gap thus left at the anterior side was filled with previously detached bone chips. The patient could use the leg 4 weeks after the operation and was drafted for the Labor Service 8 weeks after the operation. Three months after the operation the patient could not walk any longer and the fracture site was painful to palpation or use. After 4 weeks confinement to bed the troubles were apparently overcome, but a callus formation could not be observed 4 months after the operation (Ill. 70b). The lateral X-ray picture revealed slight rarefactions which indicated that the

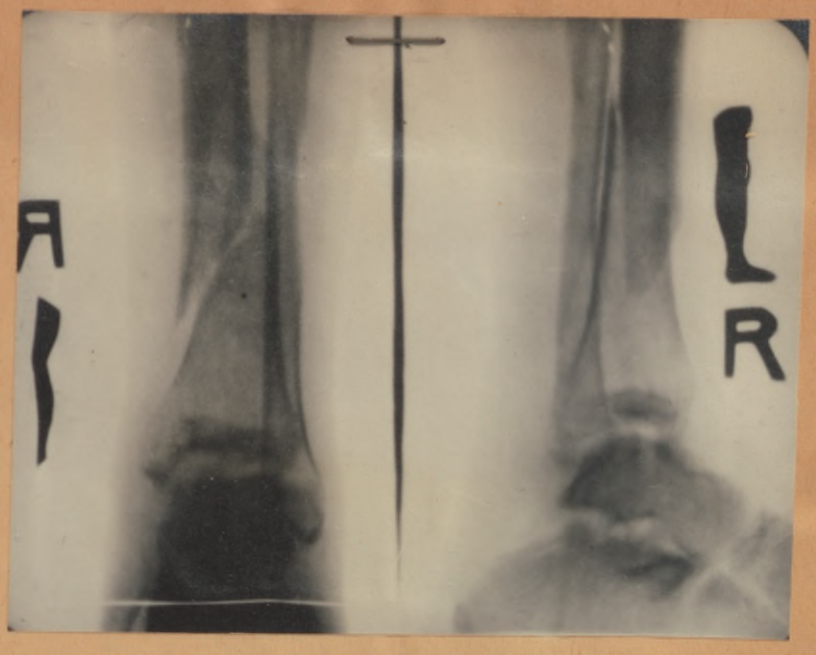


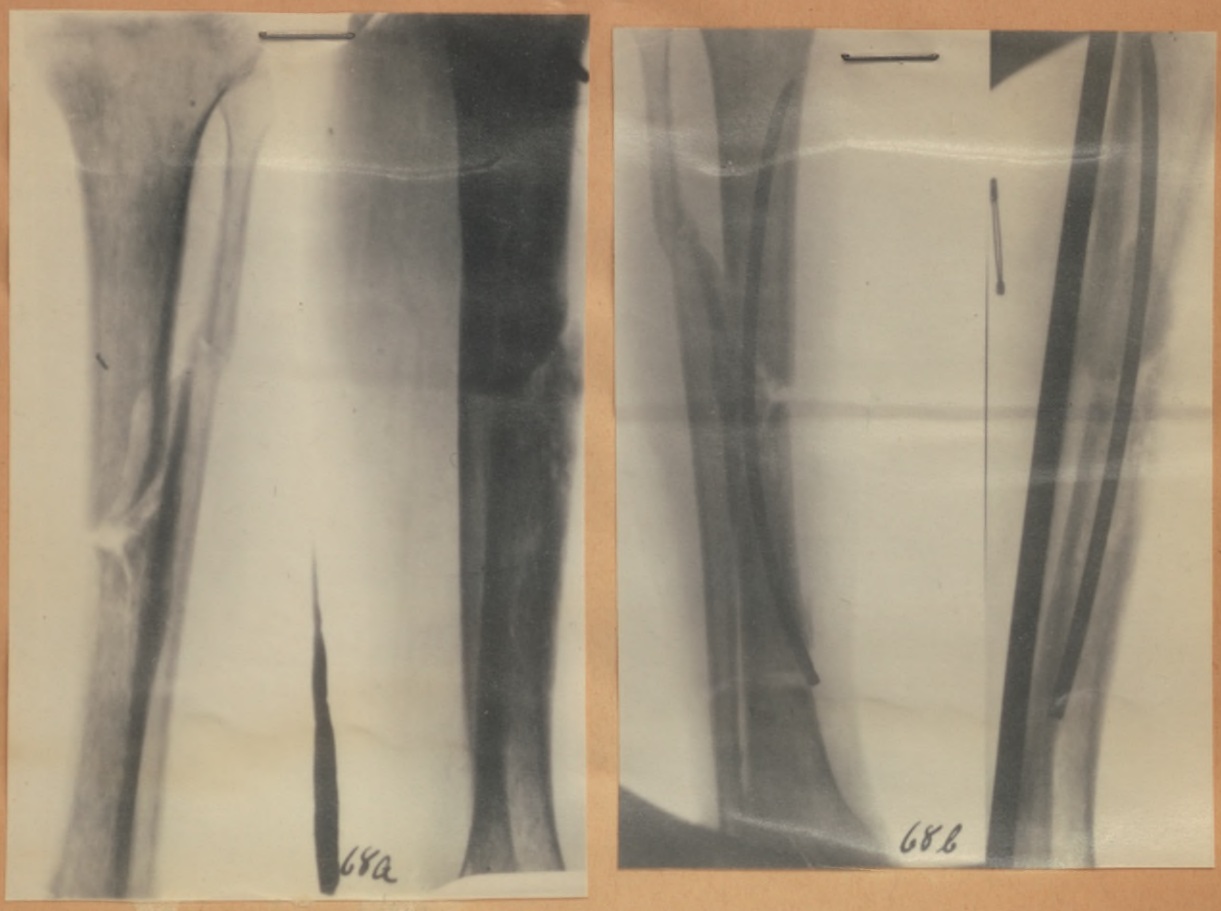
Illustration 67 a
Four month old oblique fracture of the leg in the lower third. The fibula is healed.

b Illustration 67 c

b) The same fracture after open nailing had been performed in another hospital. The nail does not find sufficient hold in the distal fragment. The fibula was only severed. Application of a plaster cast. Four weeks later the patient started subjecting the limb to weight bearing with the cast in place. Two months after the operation the plaster cast was removed, because the fracture was thought to be stabil (X-ray missing).

c) The same fracture 3½ months after the nailing. It was healed in a recurvation and typical varus position.

If one had decided to only resect the fibula and to apply a walking cast the fracture would have healed in better position and more quickly. Old fractures of this kind are not suitable for nailing. If an osteosynthesis is really necessary, the only suitable method is the use of a wire suture.



a b

Illustration 68

a) Six month old leg fracture without any formation of callus. The fibula is healed.

b) The same fracture after the closed nailing. Due to the fact that it was impossible to insert the nail into the distal marrow cavity from above it was inserted from the distal side. Only a thin nail was used which did not find sufficient hold in the proximal marrow cavity. The osteosynthesis was instabil. The healing was hindered by constant waddling movements which were due to the fact that the fibula had not been resected.

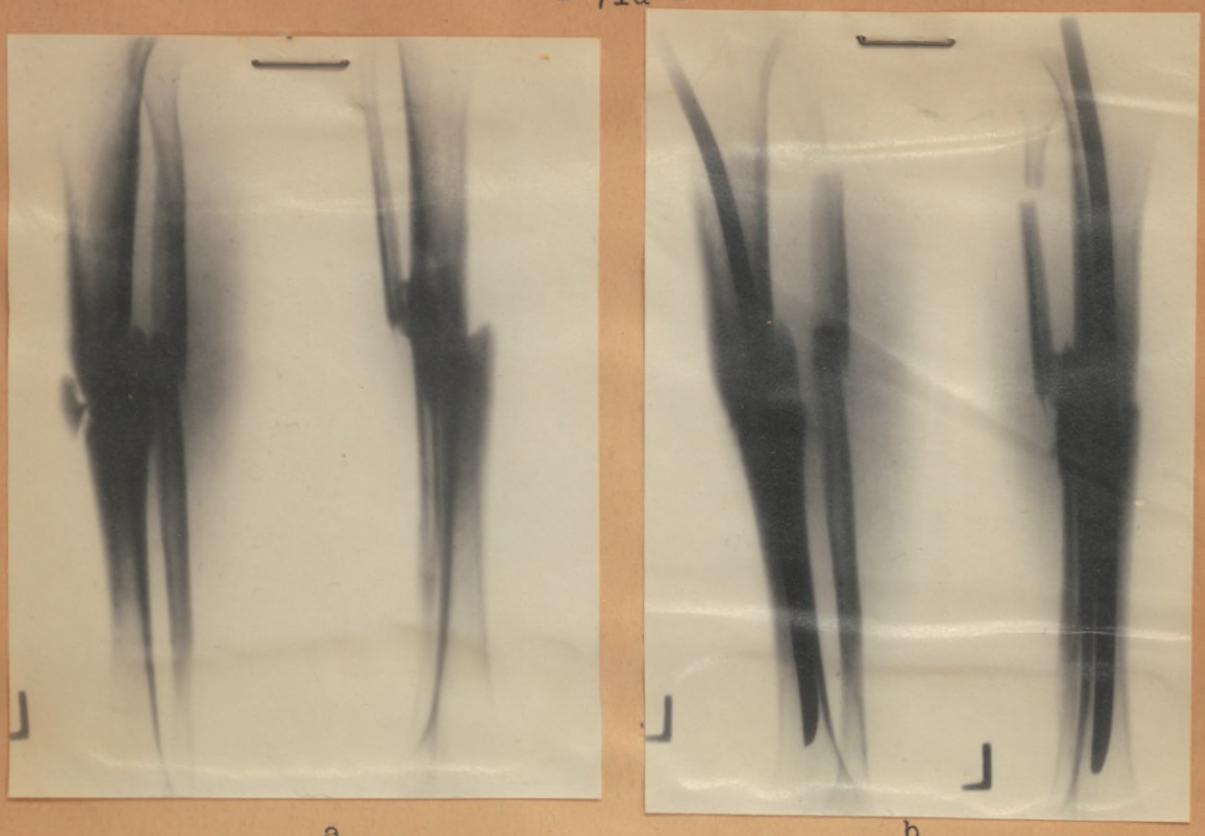
c d

Illustration 68

c) The same fracture 11 months after the operation. Pseudarthrosis of the proximal fracture cleft.

d) Removal of the nail, supramalleolar osteotomy of the fibula. Displacement of the graft in the pseudarthrosis site. Healing obtained 8 weeks later.

Also in this case a simple resection of the fibula without nailing would probably have been more simple and healing would have been obtained more quickly.



a b

Illustration 69

a) 10 week old leg fracture without formation of callus. The fibula is healed.

b) The same fracture after the resection of the fibula and open marrow nailing. The nail finds a good hold in the distal marrow cavity and the osteosynthesis is stabil. The patient was able to walk freely and therefore he could be released to his unit after a period of eight weeks.

Illustration 69c

The same fracture 5 months after the nailing. Bony healing. All joints are freely movable.

a b

Illustration 70

a) Seven year old pseudarthrosis of the leg after the resection of the fibula and open nailing. The connective tissue which filled the cleft of the pseudarthrosis was removed only in front. After that the marrow cavity was opened enough so that the nail could be inserted. Bone splinters were inserted into the cleft, where the connective tissue had been removed. The nail found sufficient hold in the spongiosa so that 4 weeks later the patient was able to subject the limb to weight bearing and 8 weeks later he was drafted to the Labor Service.

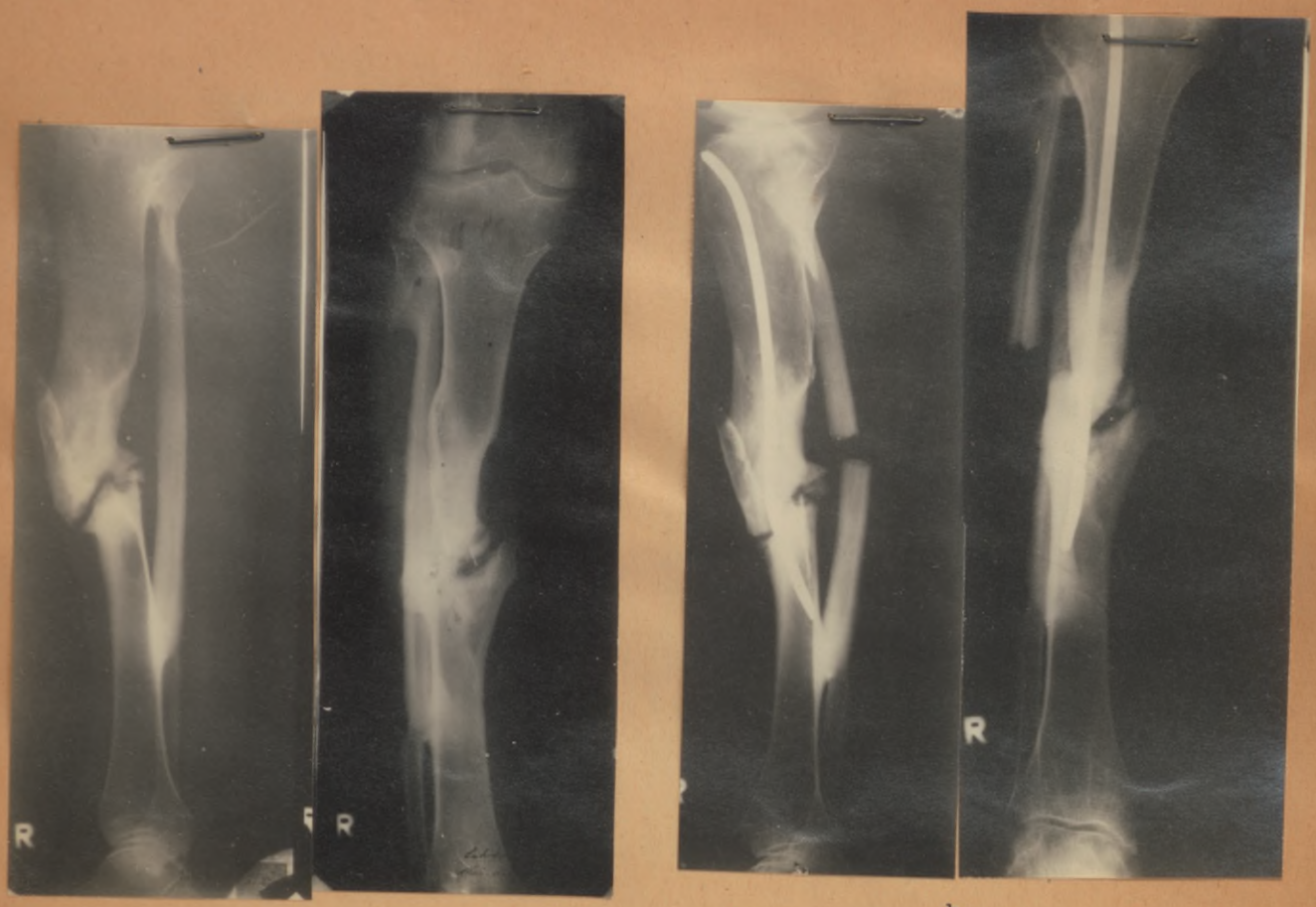
b) The same fracture 4 months later. No noteworthy formation of callus to be observed. The fracture cleft has not yet healed at any place. Slight rarefactions round the nail tip indicate that the nail is "working". Four weeks before the patient had suffered such terrible pains that he was not able to walk any longer. He felt better after confinement to bed. The nail was removed in the hope that in the vicinity of the nail canal a new stimulation of callus would develop. After three months treatment with the walking cast the fracture was healed (X-rays destroyed).

nail could work. The nail was withdrawn with the expectation that the callus formation would be stimulated at the path of the nail. The fracture was still springy (Result IV). After 3 months with a walking cast it finally solidified.

The withdrawal of the nail would not have been necessary. The fracture would have solidified in the same way if only an additional plaster cast had been used. The insufficient stability is probably responsible to a certain extent for the delayed callus formation. Besides it would have been indicated in such an old pseudarthrosis to remove all the scar tissue or the gap should have been filled with the spongiosa in the sense of MATTI's operation. It cannot be expected that the removal of the nail might have a stimulating effect on the callus formation comparable to BECK's drilling since no new bone wounds are thus created.

Ill. 71 shows that a several years old pseudarthrosis with absolutely stabile osteosynthesis will heal without any grafting of spongiosa if the faulty tissue is carefully removed.

In the following we describe a 3 year old pseudarthrosis following a complicated fracture of the tibia with a shortening of 3 centimeters. The ends of the fractured bone which were connected by a sturdy connective tissue callus were exposed. Part of the fragments were covered with fibrous cartilage. In order to prevent a further shortening, the faulty tissue was carefully removed from the ends of the fractured bones until fresh bone was exposed throughout. The marrow cavities were not opened. They were difficult to trace by means of KIRSCHNER wires and X-ray control and a canal for the nail was then pierced through the hard callus. The driving in of the nail presented considerable difficulties. The fracture had at first to be fixed in a strong recurvation and then bent into position. The nail became S-shaped by these manipulations and soon touched the posterior corticalis, to which it finally became so firmly engaged that the nail could not be driven in any farther and had to be cut. The fracture was absolutely fixed after the operation (Ill. 71b). As only the thin nail had been used, we applied a light plaster cast for the following 8 weeks and although the X-ray picture (Ill. 71c) revealed a distinct callus formation, the patient had to wear a hinged brace apparatus for another 3 months. After this he could walk long distances without any trouble. (Ill. 71d). He was then drafted for military service and came back only 6 months ago, that is 4 years after the nailing operation to have the nail withdrawn. The fracture showed a good bony healing (Ill. 71e). The removal of the nail was not possible, because of its S-shape it could not pass through the small canal in the callus. The blood picture did not reveal any changes whatsoever and the patient had no trouble. The shortening was still 3 centimeters. Rotation of the ankle joint was reduced to $\frac{1}{4}$ of the normal. Flexion and extension were normal. Since the patient was only 28 years old we proposed to shorten the sound leg in the femur by 3 centimeters by use of the marrow nail. This operation is going to take place in the near future.



a b

Illustration 71

a) Three year old pseudarthrosis of the tibia after a compound leg fracture. Two years before the fibula had been resected and an unsuccessful BECK's drilling had been made. The shortening amounted to 3 cms. and the patient used a splint (Stuetzapparat).

b) The same fracture after the nailing and resection of the fibula. The bones were partly covered with cartilaginous fibres. They were united by thick sclecrotic connective tissue. Diseased tissue was carefully removed until finally fresh bone was exposed everywhere. Through the hard callus which covers the bones a canal was drilled for the insertion of the nail. This operation proved to be very difficult. The inner nail jammed in the distal fragment so much that it was impossible to drive it in any farther. Therefore it had to be cut. The outer nail could not be inserted at all. After the operation the fracture was stabil. A walking cast was applied because the thin nail did not guarantee a stabil osteosynthesis.

c

d

Illustration 71

c) The same fracture 8 weeks later. The fragments were pressed together because of the weight bearing. Beginning formation of callus. The patient was able to subject the limb to painless weight bearing. He must however use a splint in order to prevent angulation.

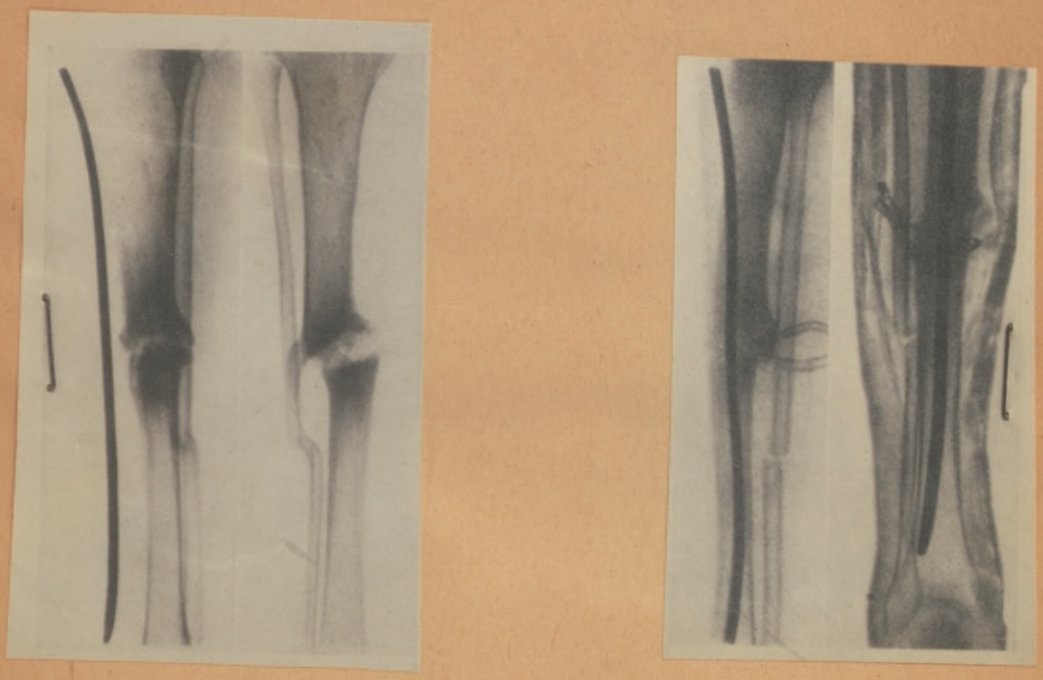
d) The same fracture 5 months after the nailing. It is widely bridged over by callus. The patient was able to walk without a splint even for long distances and does not suffer from pains any more. Rarefactions round the nail tip cannot be observed which proves that the nail has wandered somewhat higher. The patient was drafted two months later.

Illustration 71e

The same fracture 4 years after the operation. Bony healing. The extraction of the nail was unsuccessful, it is held in the callus by the curvature. In the proximal fragment reactive formation of bone can be seen around the nail. In order to compensate the shortening of 3 cms. it was intended to shorten the sound thigh by using a marrow nail.

The operation of the 3 year old pseudarthrosis as per Ill. 72 presented similar difficulties. The fracture cleft was filled with connective tissue but a transformation into fibrous cartilage could not be observed. Although double nails had been used, the fracture was still readily movable. The nails were too short, they should have been driven into the spongiosa as far as the line of growth. A U-shaped splint was at first applied for two weeks. The fracture could then be stressed and the patient was discharged. He continued wearing his hinged brace apparatus for some time. After 6 months when the nail was removed, the fixation of the fracture was complete. In the X-ray picture, however, the fracture cleft was still clearly visible (Ill. 72c). 3 months after the removal of the nail the patient came back and complained about pain and swelling at the fracture site. Clinically we observed a slight springiness of the fracture and we proposed the resection of the fibula to which the patient did not consent. When the patient came back again 4 years after the operation, we observed a persistent slight elasticity of the fracture and the X-ray picture, (Ill 72d) still shows the entire fracture cleft. There is again a tight, apparently connective tissue pseudarthrosis. The reason for this faulty healing is the obstructing fibula, which we had (this was a fault) only osteomized and not resected as is necessary. Judging from the X-ray picture it can be expected with certainty that the resection of the fibula will bring final healing. The patient refused again because his pseudarthrosis which saved him at the time from military service will now save him from undesired work.

These faulty healings were due to technical errors (premature removal of the nail, omission of the fibula resection) and could have been avoided. If the surgeon tries to avoid an extensive resection of the bone and thus a shortening, then the location of the marrow canal and the provision of the path for the nail in the hard callus will present considerable difficulties and makes tedious manipulations necessary. This means an increased infection hazard. One is never sure whether or not an absolutely stabile osteosynthesis will be achieved by the use of a simple marrow nail. The use of a spread nail, will, however, render the operation still more complicated. We, therefore, no longer nail routinely when the conditions are adverse. We rather perform the bone graft operation in addition to a resection of the fibula. The disadvantage of a long plaster cast is certainly more than compensated for by the greater security of healing and if a light plaster walking cast is used, the hazard of a stiffening of the joints will be small.



a b

Illustration 72

a) Three year old pseudarthrosis of the tibia after a compound fracture. Resection of the fibula. A nailing operation after the removal of the connective tissue callosities between the ends of the fragments was technically very difficult without resecting the bone.

b) The same fracture after the nailing. The nails should have been longer. The fracture was still somewhat movable and therefore a U-splint was applied for 2 weeks. The patient was able to subject the limb to painless weight bearing. Later on the patient wore a hinged brace.

c d

Illustration 72

c) The same fracture 6 months after the operation, which, after removal of the nail is absolutely stabil from the clinical point of view. The greater part of the fracture cleft is still visible. Three months later the patient complained about pains and swellings after excessive walking. The fracture is slightly springy. The X-ray (unfortunately lost) revealed that the fibula was healed and in the tibia the same findings were observed as in Illustration 72 d. The patient refused a proposed resection of the fibula.

d) The same fracture 4 years after the operation. The fibula is healed and the entire fracture cleft in the tibia is readily noticeable. The fracture is slightly springy. We have to deal with a connective tissue pseudarthrosis. The patient uses a splint and refuses a resection of the fibula once again, which probably would have brought a bony healing.

4. Upper Arm.

a) Osteotomy Nailing of obliquely healed Fractures.

Fractures of the upper arm very infrequently heal in such a bad position that the function of the arm is seriously hampered. In most of the cases the patients come for expert treatment before a bony fixation has developed.

So we count only three osteotomy nailings in our case material which became necessary because of a marked angulation of the axis. Our records of former times include 4 osteotomies which were provided twice with LANE's plates and twice with wire suture.

As far as these few cases allow a comparison, it can be said that the marrow nail does not essentially further the bony healing.

The marrow nailing should still be given preference in all cases where it secures a stabile osteosynthesis, that is in all fractures located at a distance of more than 7 centimeters from the joints. The nail facilitates the treatment greatly because the plaster cast, if required at all, will not be necessary for more than 2 to 3 weeks and the patients can move the joints early. The same as in fresh fractures, the stay in the hospital and the unemployability are considerably shortened.

Since a shortening of the upper arm is of no consequence with regard to the function of the arm, it is indicated to resect the fracture ends far enough to open the marrow cavity and to freshen the fragments in the shape of a staircase to secure large abutments.

An additional wire suture is, in our opinion, not necessary. As a rule there is already a shortening and the muscles have shrunk accordingly so that there is still enough tension after the freshening of the bone ends to hold the fragments together. We did not observe in any of the three cases that this tension was insufficient.

b) Old Fractures and Pseudarthroses

Whereas in peacetime surgery we rarely had to deal with fractures of the upper arm which were in such a bad position that a bony healing was not secured, the same as with pseudarthroses, we have seen even in civilian practice during wartime a surprisingly great number of such fractures. The reason for these conditions was in most of the cases a faulty treatment due to the circumstances (inexact reduction, inadequate fixation).

A closed marrow nailing of old fractures of the upper arm in faulty position may be performed up to 6 weeks after the accident if the fracture is previously well mobilized and if a wire extension is used for 8 days in case of a considerable shortening. If this is done the marrow nailing will have all the advantages which it has in the case of fresh fractures.

14 fractures so treated healed uneventfully and without any impediment of the joints and with an average stay in the hospital of 32 days and an average unemployability of 73 days.

In fractures more than 6 weeks old we did not attempt to perform a closed nailing, inasmuch as the infection hazard is very small in the upper arm and the operation is greatly facilitated by the exposure.

Among the 55 cases of old fractures of the upper arm which we nailed with exposure, there was only one case of a (5 years old) genuine pseudarthrosis which is shown in Ill. 1. In all other cases the fracture ends were covered by callus connective tissue. The reason for the disturbed healing was the same in all cases, namely an inexact reduction, that is a distraction of the fragments.

Five patients with 8 to 12 weeks old fractures could only be observed about 3 to 4 weeks after the operation, so that nothing can be said about the final healing result.

Eight more patients whose fractures were 2½ to 4 months old, were treated on an outpatient basis after their discharge. A distinct callus formation could be distinguished after 6 to 10 weeks. A bony healing can be expected in these cases, although the final healing result could not be checked.

37 of the remaining 42 cases showed a bony healing with full mobility of the joints. The stay in the hospital lasted 21 to 89 days, that is an average of 47 days. The unemployability lasted 74 to 168 days, that is an average of 108 days.

Five of the cases, including the above mentioned pseudarthrosis did not show a bony healing and it is desirable to discover the reasons.

In case of the genuine pseudarthrosis, that is the formation of a new cartilage surface of the joint, the removal of this cartilage together with fixation is apparently not sufficient to achieve the healing. This seems rather surprising at first if we think of an arthrodesis of a joint in which we also remove the cartilage and furthermore we have seen in many connective tissue pseudarthroses that a stabile osteosynthesis without resection of the bone assures a full success. I had this fact in my mind when I abstained from performing a resection in the genuine pseudarthrosis of the upper

arm shown in Ill. 1. The nervus radialis was imbedded in the new joint capsule and passed proximally through the callus in which remnants of the former wire suture still lay. I intended to perform the operation as simply as possible so as to create the smallest possible hazard to the nerve.

And still there is a distinct difference between the genuine joint and the pseudarthrosis on the one hand, and between a genuine and connective tissue pseudarthrosis on the other hand. Below the thin intermediate lamella of the genuine joint (which will always be removed), lies sound spongious bone with blood and cell containing marrow which is just able to initiate the regeneration of bone as the marrow of the flat bone in case of a fracture. Below the cartilage of the pseudarthrosis, however, we find a rather thick layer of eburnised bone which is poor in vessels and free of marrow and which cannot give rise, therefore, to a noteworthy regeneration which could take place only in case of a decomposition of this bone. Such a decomposition is observed in almost any bone fracture healing and this is the only source for the minerals required for the calcification of the bone. It can take place in the presence of a local acidity (increase of the H-ions). It develops in the first phase of a reparative inflammation of the wound and fracture healing but will subside in a relatively short period of time in an aseptic course. This will be sufficient if we have to deal with a thin bone which is easily diffused by the tissue juice to dissolve the precipitated salts. It will, however, not be enough in case of the almost impermeable eburnised bone.

In case of a fracture without healing, a connective tissue pseudarthrosis, the fragments are also not infrequently covered by such eburnised bone. In this case, however, the periosteum is separated from the bone and will initiate the callus formation. The decomposition necessary for the calcification takes place at the subperiosteal parts of the bone which are easily diffused and rich in blood cells, and not at the eburnised ends of the bone. It appears on the X-ray picture (see Ill. 71e) that the marrow cavities are still closed after two years. It must also be borne in mind that the scar tissue is readily dissolved and thus prepared for a deposit of minerals. The histologic picture of this tissue changes into a fresh connective tissue, which is liable to a metaplastic bone formation. If, in case of a genuine pseudarthrosis, the cartilage will be resected within the capsule without separating the periosteum, a periosteal neoformation of bone cannot take place.

In the genuine pseudarthrosis too it is, therefore, necessary to resect the fracture ends far enough so that sound bone tissue is exposed and that the sound periosteum can assume the formation of callus.

In the other four fractures the faulty healing was due to a lack of stability of the osteosynthesis, similar to what was observed in tibia fractures. Whereas in the latter type of fractures it was the healed fibula which favored lateral movements, in the fractures of the upper arm we observe a distraction caused by the weight of the

arm, a hazard which we already observed in compound fractures. This hazard is particularly great if the muscles have become atrophic due an extensive immobilization.

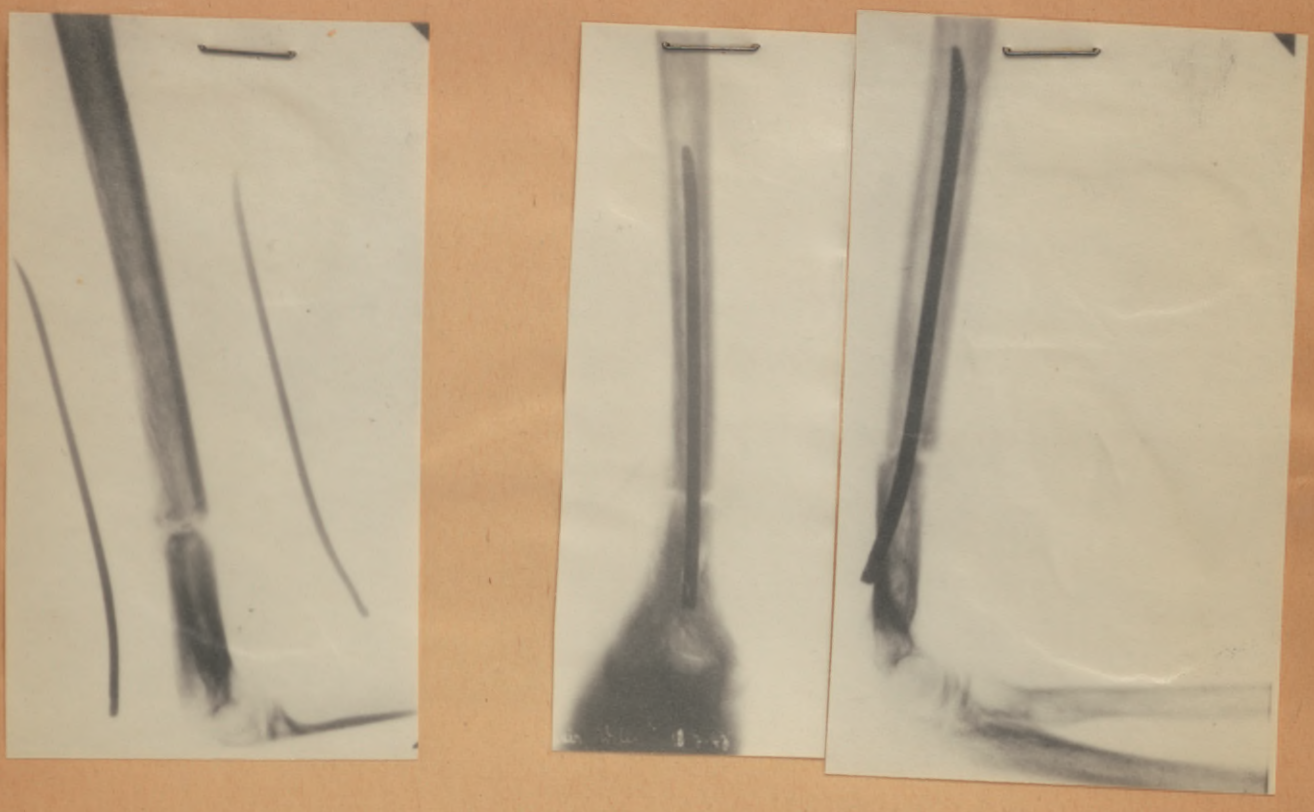
In the fracture shown in Ill. 73, 8 weeks old, only the thin nail had been used and it was much too short. It can be seen distinctly in Ill. 73b that the nail has considerable play in the proximal marrow cavity. Four weeks after the operation the patient made his first movement exercises and he complained continually about pains. 3 months after the operation, it was noticed that the fracture was somewhat movable and a plaster cast was applied for " a short while". It is overlooked that the fracture was distracted (the nail had slipped out of the proximal marrow cavity (Ill. 73c)). It was omitted to push the fracture together and a plaster cast up to the shoulder was applied instead of a thorax-arm-abduction cast. Eight weeks later the nail broke off at the fracture cleft due to the reinstitution of exercises. The marrow cavities were gradually covered by bone caps and a pseudarthrosis developed due to the permanent lateral movements at the fracture cleft (Ill. 73d) which fully developed within the following 3 months (Ill. 73e). It was bridged over by a tibia graft and now a thorax abduction cast was applied for 8 weeks which leads to final healing.

According to our experiences with a similar fracture (Ill. 74) the pseudarthrosis could have been avoided, if double nails of sufficient length had been used. It could probably still have been avoided if the distraction had been noticed, that is to say if the arm had been pushed together and put at rest in an abduction plaster cast. (See: Infected fractures due to gunshot injuries.)

Similar conditions prevailed in the two other 5 to 6 month old fractures which had also been treated outside our clinic. In these cases too only one short nail was used, the distraction was not observed and the immobilization was omitted, although the patients complained about pains when the exercises were instituted.

The nail in position seems to have a suggestive influence. All the interest centers around the nail and the callus formation and distractions, changes of the position and distorsions are overlooked. Guided by the desire to take advantage of the possibility of an early movement of the joints due to a stabile osteosynthesis, the principles of bone surgery are completely disregarded, namely that the fracture must be absolutely put at rest and that such movements are permissible which do not cause pains.

That we also fell prey to this suggestion is shown in the following case of our special ward. A short greenstick fracture of the upper arm slightly below the middle was treated for 10 months with a plaster cast and abduction splint. A final healing could not be achieved because of continuous dislocation of the fragments.

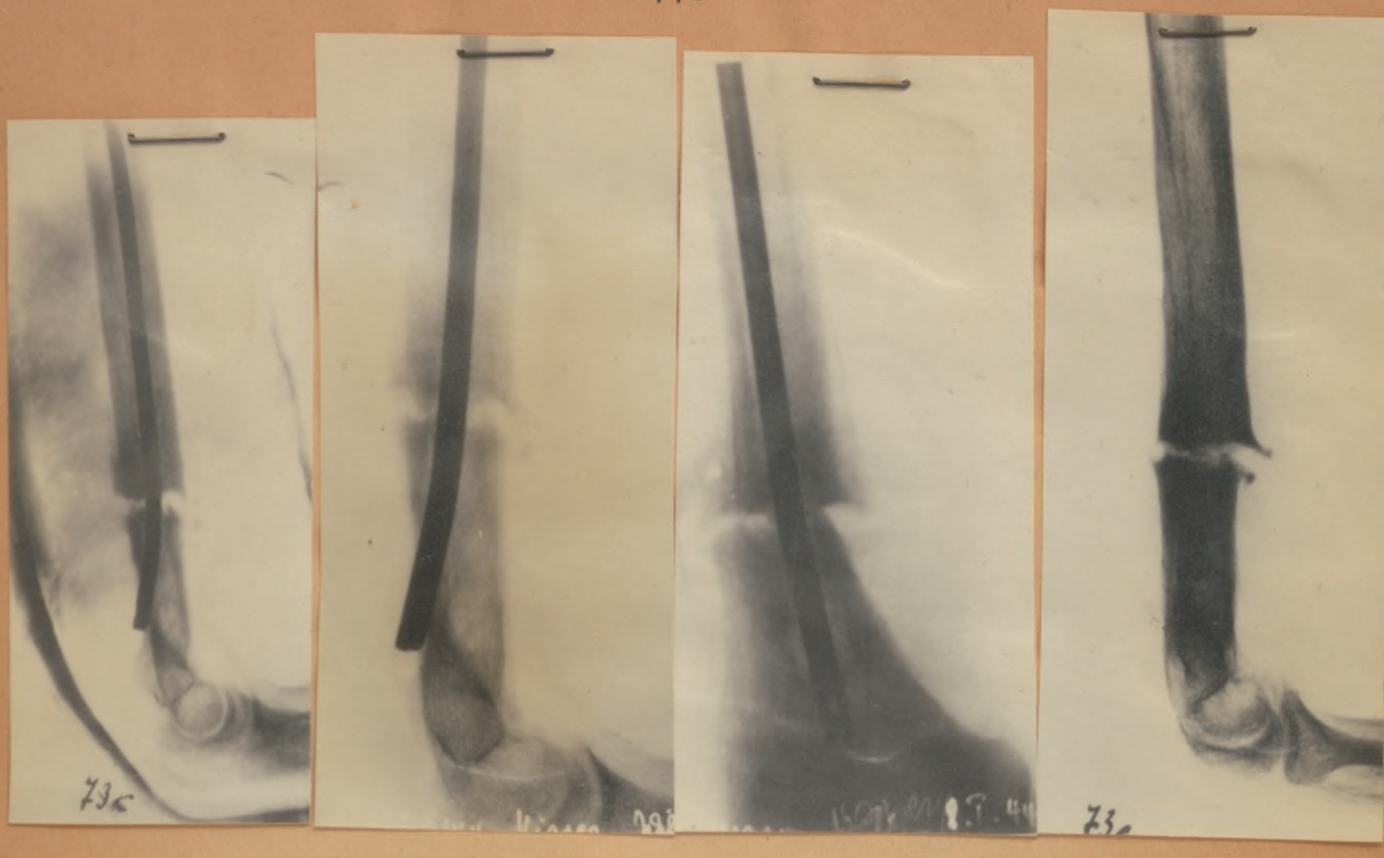


a b

Illustration 73

a) Eight week old "fractura non sanata" of the arm above the elbow. Only an inner nail which was much too short was erroneously applied on each side.

b) Despite the fact that according to Illustration 73 a the thicker nail would find sufficient space in the marrow cavity only the inner nail was used. It is much too short and everywhere in the proximal marrow cavity it is loose. It should be driven into the spongiosa of the head. Instabil osteosynthesis. In spite of this, 4 weeks after the operation the patient began subjecting his limb to exercises which were painful.



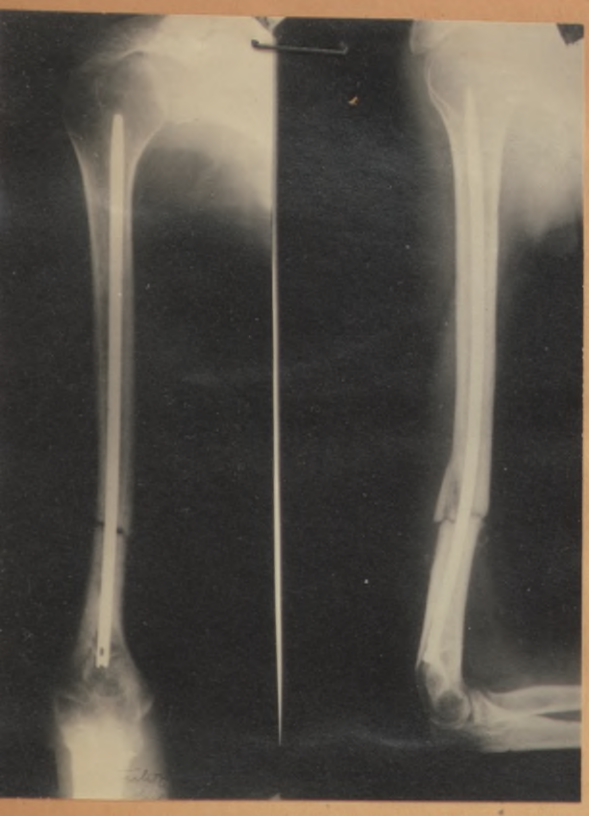
c d e

Illustration 73

c) Three months after the operation. Finally it was observed that the fracture was somewhat loose and consequently it was decided to apply a simple cast to the arm "for a short period of time." The fracture is distracted because of the weight of the arm and the nail had slipped out of the proximal marrow cavity. This however had not been observed and consequently the fragments were not pressed together in the cast.

d) Five months after the operation. Due to the exercises to which the patient had again subjected his arm for 6 weeks the nail is angulated in the fracture cleft. The fracture is still distracted and the marrow cavities have begun to form covers. Beginning pseudarthrosis. In spite of this the patient continues subjecting the limb to exercises.

e) Eight months after the operation, after the removal of the nail a pseudarthrosis was observed. A graft from the tibia was applied. Application of an abduction cast. The fracture was healed 8 weeks later. If from the very beginning the fracture had been immobilized by an abduction cast or, after the distraction had been observed, the fragments had been pressed together again, a faulty healing would have been prevented.



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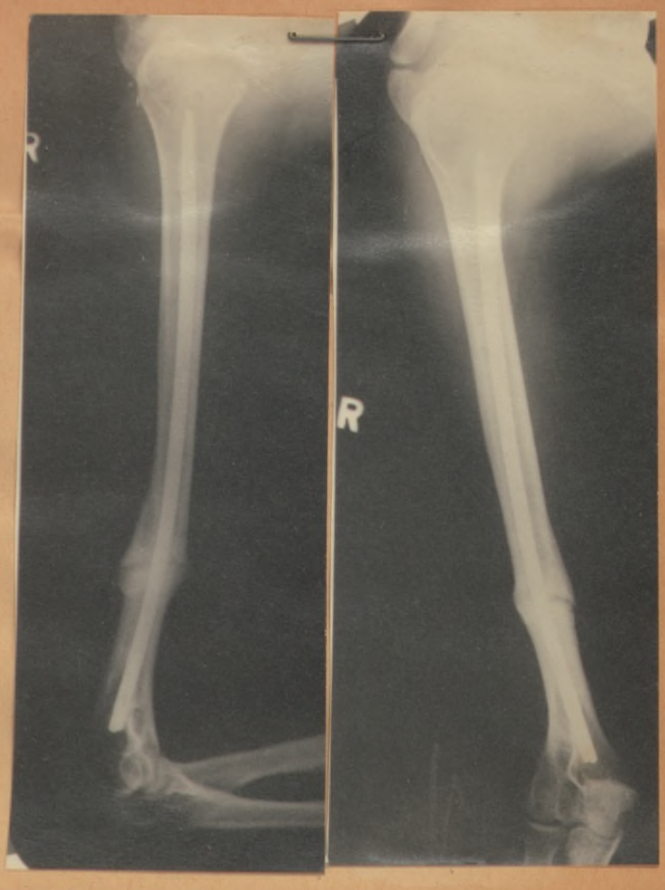


b

Illustration 74

a) Ten week old similar "fractura non sanata" of the arm above the elbow, after the nailing. Marked atrophy of the bone due to previous immobilization of the limb with a plaster cast. The displacement amounted to 1½ times the width of the shaft and the fracture was angulated. This immobilization had been made in another hospital. Also in this case only the inner nail could be used because the marrow cavity was very narrow. The nail was driven into the spongiosa of the head. In this way the osteosynthesis was stabil. 14 days later the patient started subjecting the limb to exercises which were not painful. Three weeks after the operation the patient was released from the hospital for ambulatory treatment. He was able to resume working 6 weeks after the operation.

b) The same fracture 6 months after the operation. A bony healing was obtained. All joints are freely movable. Extraction of the nail.

The fracture was then nailed outside our clinic (Ill. 75a). The nail was too short and did not find sufficient hold in the proximal marrow cavity. A distraction of the fragments which were not pushed together could be observed. The plaster cast was removed 8 weeks after the operation and the limb was moved in the abduction splint. Three months later a distinct valgus position and crepitation was observed at another military hospital (Ill. 75b). In spite of these findings the movement exercises were continued. Again two months later (5 months after the operation) the patient felt slipping at the fracture site and the X-ray picture revealed an increased angulation of the fracture and of the nail (Ill. 75c). The fracture was then reduced under anaesthesia and a thoracic plaster cast applied and left in position for four weeks. Then again the patient began with movement exercises in the abduction splint. X-ray pictures were not made. The fracture was still movable 9 months after the operation when the patient was admitted to the special ward. The X-ray picture revealed a pseudarthrosis and breaking of the nail. I removed the pieces of the broken nail and freshened the ends of the fracture conservatively (a dorsal callus spicule was intentionally left in position) and two longer nails were introduced distally. I overlooked that the marrow cavity in the proximal fragment was very wide. The nail should have been driven still farther into the spongiosa of the head (Ill. 75e). The fracture was apparently fixed after the nailing, therefore, only a U-shaped splint and sling were applied. The patient began two weeks after the second operation with exercises of the shoulder and elbow joints. The U-splint was removed six weeks after the operation and an X-ray picture was made. The deputy chief surgeon who was in charge was under the impression that a callus bridge had developed at the posterior and inner sides (Ill. 75f) so the movements were made without any bandage.

It passed unnoticed that the fracture was distinctly distracted and that the alleged bridge did not represent a new callus formation but was the bone spicule which I had left in position. Within 8 days the patient complained of pains and a thoracic abduction cast was applied, the pushing together of the fracture, was, however, omitted. I saw the patient only two months later when the plaster cast was removed and I proposed to bridge the pseudarthrosis by a graft with the nail left in position. The bone ends were freshened, the fragments were pushed together and the tibia graft was fastened with wire loops (Ill. 75g). In spite of a thoracic abduction cast, distraction of the fragments developed again in that the distal wire loop slipped off the slightly tapering bone end. I overlooked this when the patient was presented to me 3 months after the operation (Ill. 75h) and I instituted exercises. Five months after the operation the fracture though resistant to bending permitted distinct rotary movements and the X-ray picture revealed that the bone graft was connected only to the proximal fragment, that the fracture had again distracted and that again a pseudarthrosis existed. The patient had to be discharged from the hospital due to the course of the war. He has reported that the nail broke again despite the hinged brace apparatus. The nail was removed and a new bone graft was performed which again proved unsuccessful.

a b

Illustration 75

a) Ten month old pseudarthrosis of the arm above the elbow after an open nailing which was made in another hospital. Application of only one nail which however, was too short and which did not find sufficient hold in the proximal marrow cavity. The fragments are not pressed together. The fracture cleft is gaping. The osteosynthesis is not stabil. A nailing from the proximal side would have been better. Application of a plaster cast for eight weeks. After that: exercises with the limb in the abduction splint despite the fact that "the fracture is still somewhat movable."

b) The same fracture three months later (after the patient had been brought to another hospital).

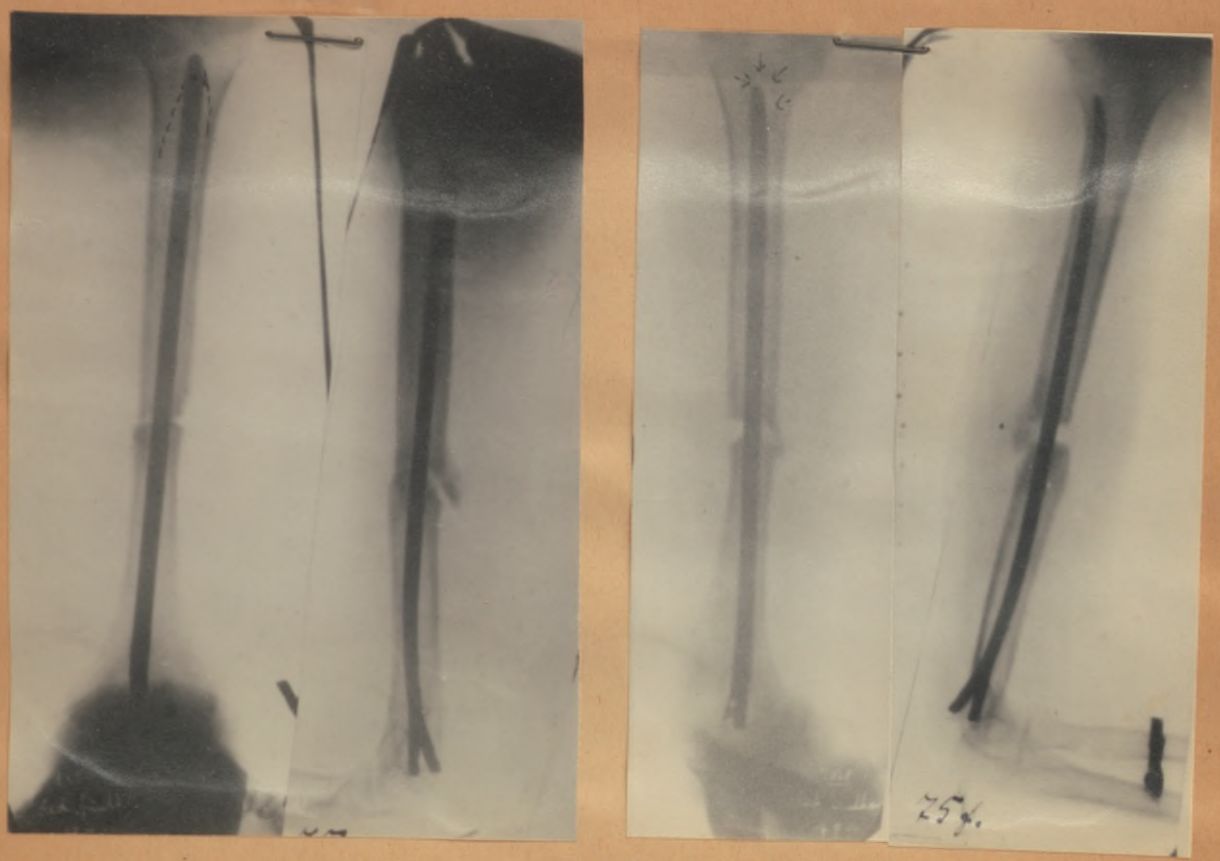
Marked valgus position. Clinically marked crepitation is observed. In spite of this the patient continued subjecting the limb to exercises.

c d

Illustration 75

c) Five months after the operation. During his exercises the patient suddenly felt a crack in the limb. Probably a callus jag had broken. The bending of the fracture and of the nail is more marked. Straightening with the patient under anesthesia and application of an abduction cast for 4 weeks. Once again the patient begins with exercises. No X-ray control!!

d) 9 months after the operation, after the patient was brought to the special department of the hospital; pseudarthrosis and fracture of the nail.

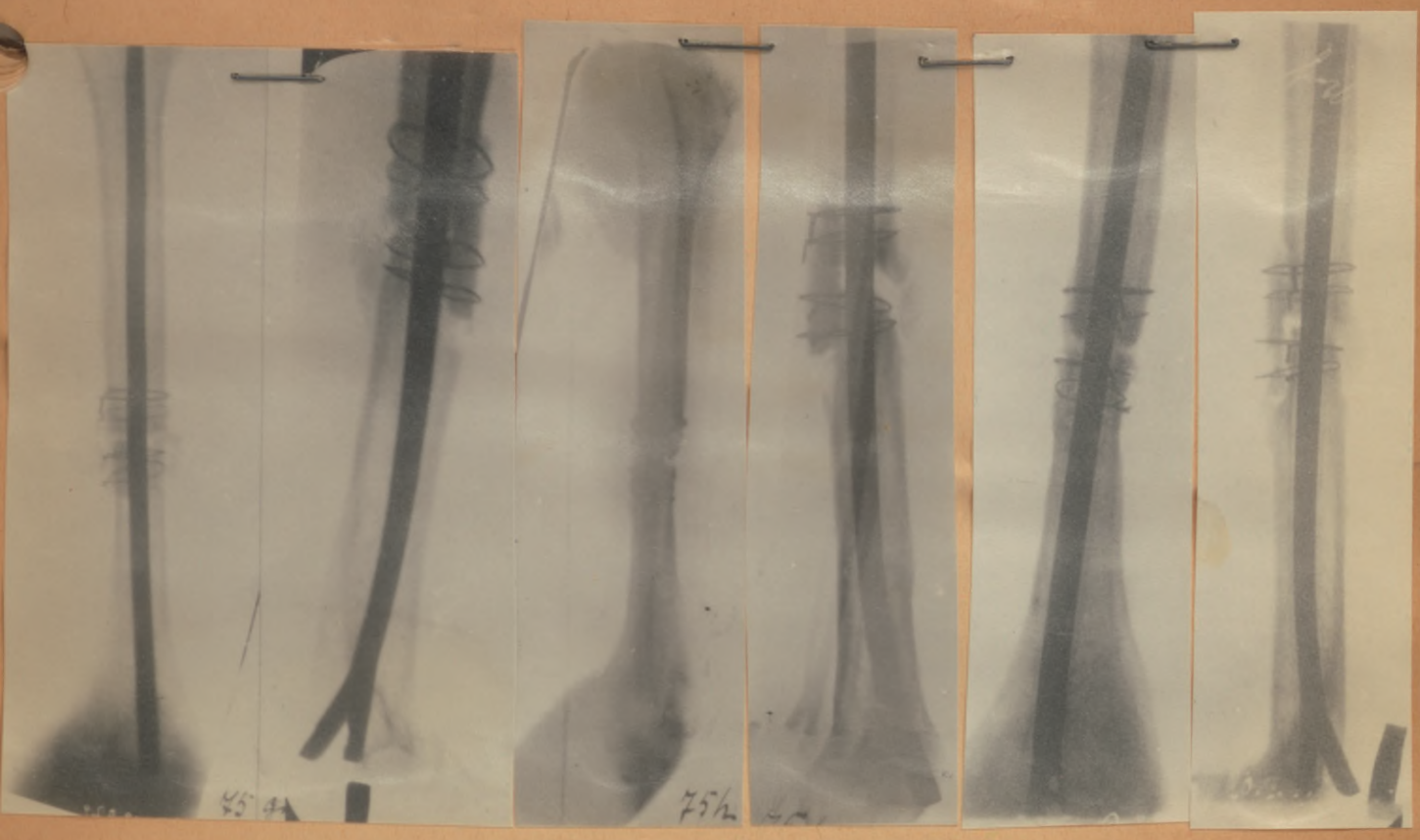


e f

Illustration 75

e) After the second operation: Conservative refreshening of the ends of the fragments. Removal of the broken nail, insertion of a longer double nail which however is also too short. Its tip just touches the spongiosa of the epiphysis. After the nailing the fracture is stabil. Therefore only a plaster cast U-splint was used with which the patient subjects the limb to exercises 3 weeks later.

f) Six weeks after the second operation. "Narrow callus bridges" are thought to be observed in the dorsal direction and therefore it was decided to remove the splint. It was not observed however that it was not newly formed bone in question, but only the remnants of the old callus bridge. Moreover, the distraction of the fracture was not noted. The nail had slipped from the spongiosa of the head. The old nail bed may be recognized at its bone margins (!). Due to the fact that once again the patient suffers from pains 8 days later another abduction cast was applied. The fragments however were not pressed together.



g h i

Illustration 75

g) 2 months later, after another operation: Pressing together of the fragments, graft plastic with the nail in place. The wires for the graft were only led around the bone and were not pierced through it.

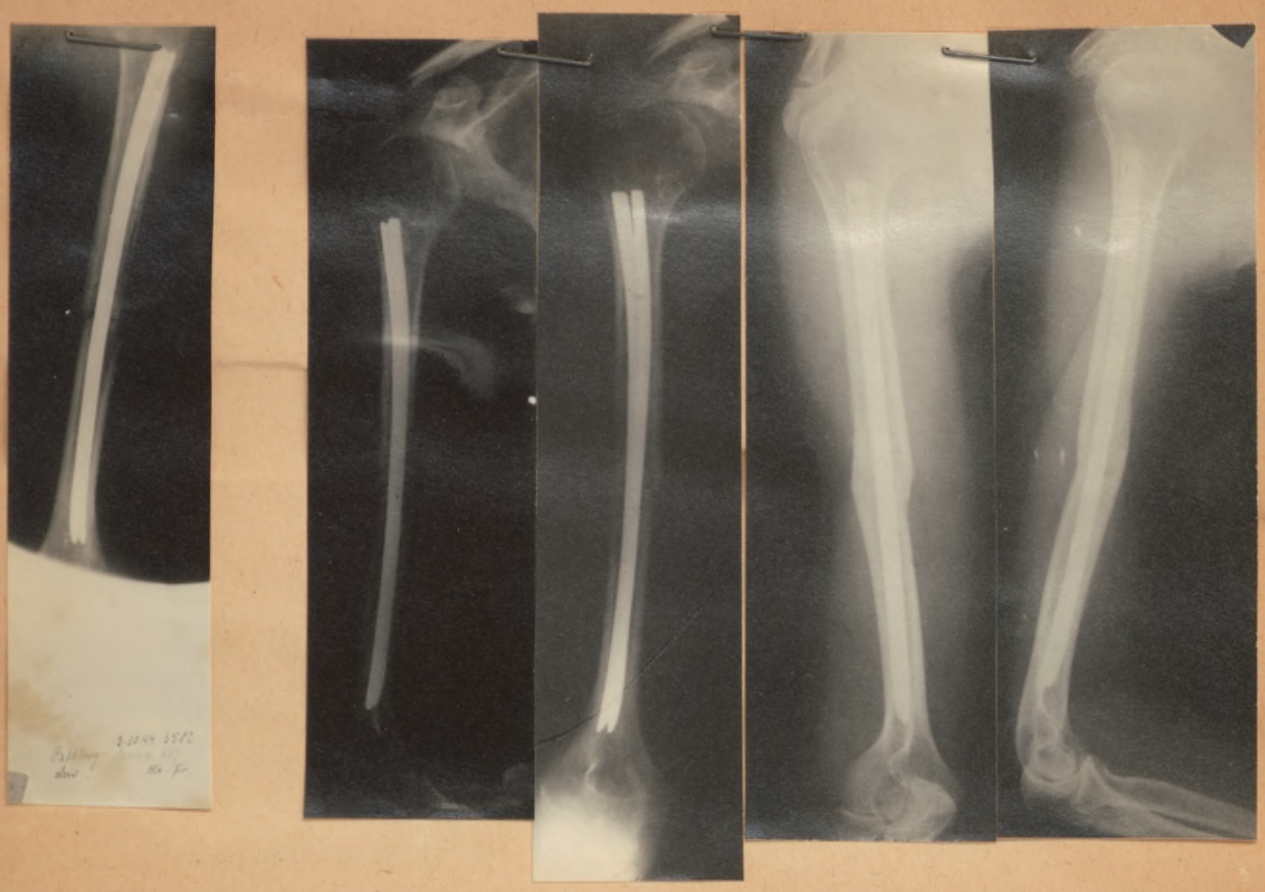
h) Thus, 3 months after the third operation the wires had slipped from the conically shaped end of the distal fragment and the fracture is somewhat distracted again. This, however, was not observed and because the fracture seemed to be clinically healed the patient was subjected to exercises again.

i) Five months after the third operation; Further distraction of the fragments, further slipping of the wire loop at the distal end. Rotation pseudarthrosis between the distal fragment and the graft. According to his own report the patient has later used a hinged splint in which however another nail fracture occurred. Removal of the nail and another bone graft was without success.

There is no doubt that several technical mistakes were made in the case of this patient. First of all it would have been necessary to use in the very beginning a double nail which should have been chosen long enough to have a good grip in the spongiosa of the head. Considering the wide proximal marrow canal it was indicated to nail the fracture from above. I had an opportunity to correct this mistake on the occasion of the second operation but this possibility was unfortunately not present in my mind and I saw on the spur of the moment only the possibility of introducing a new nail along the old one which was then still too short. And if I had finally fixed the fracture ends by a wire suture a new distraction would have been prevented. During the bone graft the nail should have been replaced by a longer one and above all the nails should have been lead through the bone to prevent the slipping off.

BOEHLER postulates for an additional longitudinal wire suture in all old fractures of the upper arm to prevent distraction. One objection was raised against this suggestion, namely the undesirable effect of the wire suture in case of an atrophy of the bone, which according to our experience is observed very frequently in fractures of the upper arm. In this case the wire suture may cut the bone and present a hazard. We consider the wire suture suitable only in exceptional cases, such as very old pseudarthroses. The bone atrophy in itself does in our opinion not constitute a definite contraindication to marrow nailing unless it is not too advanced (in contrast to thigh fractures). The breaking out of the nail is hardly to be expected in the upper arm, because the lateral stress is not so strong as in the thigh. In case of an atrophic bone the fracture of the upper arm can be nailed from above and the nail can be driven very deep into the distal epiphysis so as to firmly engage and to make a distraction impossible (Ill. 76).

Ill. 77 confirms that also very old connective tissue pseudarthroses of the upper arm with a positively stabile osteosynthesis will finally come to a fixation by solely using the nail without any additional wire suture. It is very important in these cases to leave the abduction cast on long enough in case of such old fractures with atrophic bone and musculature and that the arm is carried above the horizontal in this plaster cast (this requirement is often disregarded). After 3 to 4 weeks the part of the cast next to the forearm may be removed and the elbow may be moved freely. The rest of the cast is left in position for at least 8 weeks and will be removed only if the movements are free from pain and if the X-ray picture reveals a distinct callus formation. If one is not overenthusiastic about the nail and if the hazard of a distraction is always borne in mind, especially if the nail was introduced from below, there will hardly be any disappointment.



a b c

Illustration 76

a) $4\frac{1}{2}$ month old fracture in the arm above the elbow (which had been treated in another hospital). A formation of callus had not been obtained. A marked proximal bone atrophy was observed after the open nailing operation. The nails forge a stabil union with the distal spongiosa. The patient started subjecting the limb to exercises ten days later. He was released from the hospital after a lapse of 18 days. Ambulatory treatment.

b) Six weeks after the operation. The patient uses his arm fully and no distraction can be observed. Beginning formation of callus. Due to the conditions of war the patient did not show up for a late examination.

c) $2\frac{1}{2}$ years after the operation. The fracture is completely healed and the joint is freely movable. The nail was then removed.

a b c

Illustration 77

a) 1½ year old (connective tissue) pseudarthrosis of the arm above the elbow after a compound fracture which had been treated primarily with a wire suture and which became infected. The wounds have been healed for 8 weeks. Marked atrophy, particularly of the proximal fragment. During the nailing operation only the connective tissue callosities were removed. The bone was so soft that it could be cut and the marrow cavities are easily located.

b) The same fracture after the nailing. Abduction cast with which the patient subjects the elbow to exercises. After a lapse of 8 weeks he starts subjecting the arm above the elbow to exercises with the abduction plaster cast in place. The cast was removed after a lapse of 12 weeks.

c) After the removal of the nail four months after the operation. Healing was obtained.

Finally we want to show by one more example that the stabile fixation of the fracture constitutes the most important factor for the final healing. This case is particularly interesting because the healing was achieved with too small a nail. The fracture complicated by a small skin wound in the distal third was provided with too thin and much too short a nail (ulna nail). The wounds healed primarily, but a healing was not achieved after 8 months of treatment with a plaster cast (Ill. 78a). I suggested therefore, exposing the fracture, freshening the fracture ends and using a properly dimensioned nail. I did not foresee, however, that the nailing was again performed with an ulna nail. Nevetheless, the nail got a good hold because it bent right in the beginning of its introduction and came at a slant into the proximal narrow cavity, where it finally stuck. The patient was able to move the arm freely 5 weeks after the operation and when he was admitted to our special ward 6 months after the second nailing, the fracture was healed well enough so that we could withdraw the nail, (Ill. 78b).

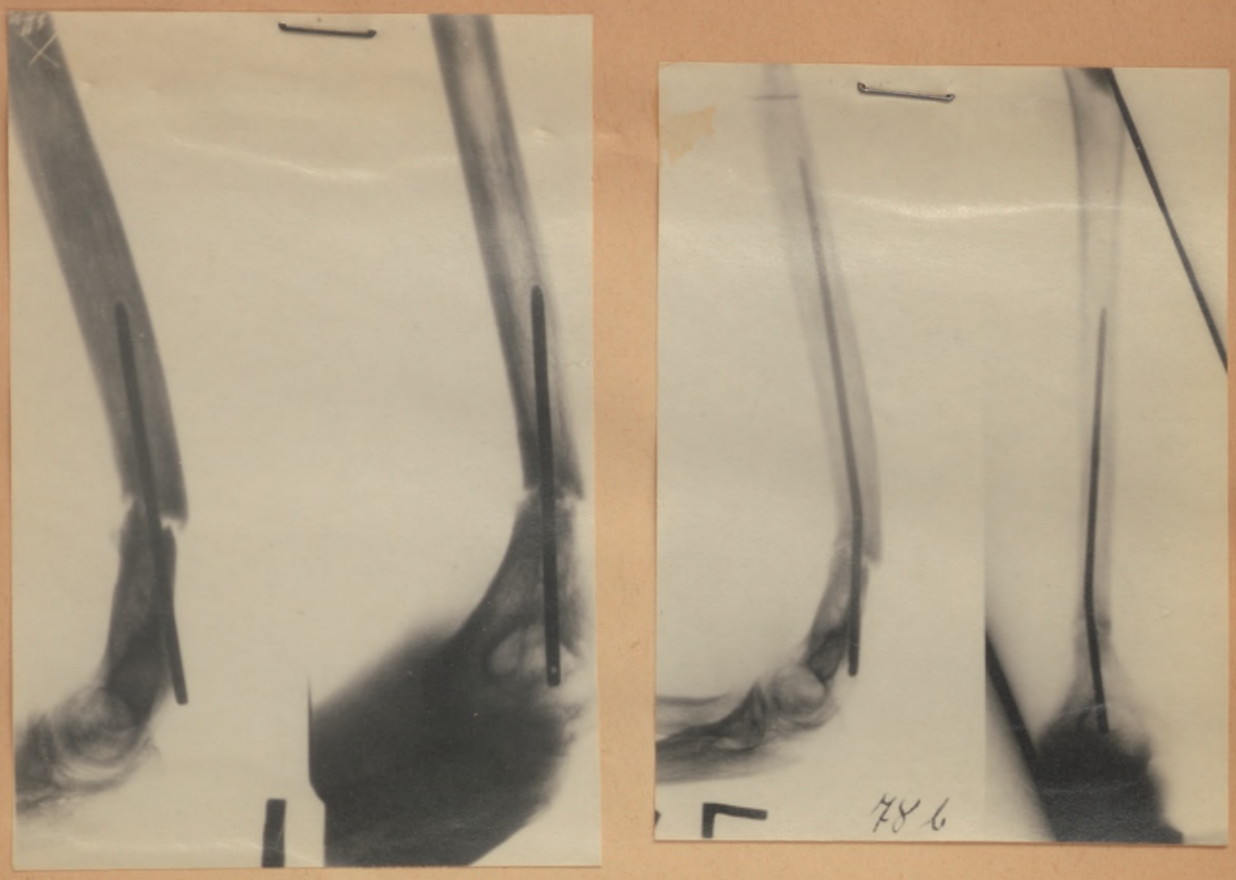
On the strength of these results (and despite the accidents which were due to technical faults), we feel that we cannot share the negative attitude of BOEHLER and are of the opinion that the treatment of old fractures and pseudarthroses of the upper arm are best treated with the marrow nail under the condition , however, that a positively stabile osteosynthesis is achieved.

IV.

Fractures of the Forearm.

A. Osteotomy-Nailing of fractures healed with Angulation

If a fracture of the two bones of the forearm heals in a faulty position, the rotary movement will be impeded and thus reduce the use of the hand to a considerable extent. The old osteotomy methods did not prove quite satisfactory in this type of fracture. The bones are not thick enough for the proper use of LANE's plate which may, in case of an inadequate technique, have an obstructive effect and delay the healing. The cut must be performed at a very acute angle to allow the use of several wire sutures. If only one suture is applied in case of short cuts (which as a matter of course must be drilled through the bone) there will be a considerable hazard, that new displacements will occur. It could thus be expected that the marrow nail would bring special advantages.



a b

Illustration 78

a) Compound fracture of the arm above the elbow (treated in another hospital) with a small pierced wound. An ulna nail was used which was too short and too thin. In spite of the application of several plaster casts the entire fracture cleft is gaping. No formation of callus to be observed.

b) The same fracture 6 months after the second nailing. The ends of the fragments indicate that only the scar tissue has been removed and the bone was not resected. Once again an ulna nail was used. This nail jammed in the proximal marrow cavity because it angulated at the fracture cleft. In this way the osteosynthesis became stabil despite the fact that the nail was too short and too thin. Plaster cast for 10 weeks. The fracture healed.

We have used the marrow nail in 6 osteotomies of the two bones of the forearm in which, as a matter of principle, both bones were nailed.

It is again necessary that the fractures are located far enough away from the ends of the joints, so that a stabile osteosynthesis can be achieved. Special attention must be paid to the fact that an atrophic bone should not be nailed because of the hazard of a perforation by the nail. The marrow cavities must be wide enough to offer at least enough space for the thin nail (1).

With regard to the appropriate technique, it may be said that the two bones should be severed, to begin with, and if possible at the old fracture line. Next, the bone ends of the ulna will be freshened (always at a slant or staircase-shaped) until they can be brought to a good abutment. Then follows a fixation with LAMBOTT's bone forceps and the radius is put in the proper position. The result is checked by X-ray. (Attention to a possible luxation of the ulna in the distal radio-ulna joint.) The necessary corrections can now be performed easily and no sooner than a perfect position is achieved, the bone ends will be brought together and the nailing will take place, preferably the ulna at first, because the nail may be driven in by approach from the fracture cleft, through the olecranon with its eye anteriorly. At the radius, however, one must proceed much as in simple fractures. If one proceeds with the nailing without making sure that the cuts abut properly, conditions may arise similar to those shown in Ill. 79a.

After the performance of an osteotomy, we nailed the ulna first and the position was satisfactory. When nailing the radius, however, it was discovered that there was again a gap in the ulna. So we had to withdraw the nail and resect the bone. After that, we still had a slight gap, the cuts not being fully congruent. This is not very important in itself. If, however, the nail is too short, as was the case in this instance (a longer nail was not at hand) obstructing effects may develop and tilting movements of the fracture cleft which might interfere with the healing process. The nail then works in the bone and may break through the corticalis (Ill. 79b). A periosteal deposit of new bone will take place in case of an aseptic healing which will not cause any serious trouble, but the nail will have to be removed early. (Ill. 79c).

Infections did not occur in these 6 osteotomies. a plaster splint was used in all of the cases and the patient began to move the limb in this splint after 8 days. The splint was removed after 2 to 4 weeks. After 4 to 5 weeks the patients were able to make full use of their arms and to perform their duties as usual. The advantage over the old osteosynthesis methods is quite obvious.

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(1) We are definitely against the "inner splinting" using KIRSCHNER wires on the basis of our experiences gained in the treatment of fresh fractures. The simple wire is too elastic to prevent the undesirable lateral movements which cause a faulty healing.

a b

Illustration 79

a) Fracture of both forearm bones which had healed in bad position. After the resection of both bones first the ulna and then the radius was nailed. The bones had not been put together before by means of LAMBOTTE's pincers. Due to the existence of a bone jag the fracture planes cannot come to a broad contact. Both bones should have been resected more thoroughly. The ulna nail is too short and the osteosynthesis is not absolutely stabil. Primary healing of the wound. The fracture is healed from the clinical point of view. The patient was released from the hospital for ambulatory treatment.

b) The same fracture 7½ months after the operation. For 4 weeks after the operation the patient was able to use his arm without any impediment and to do all kinds of work with it. The radius bridged over by bone. At the ulna the greater part of the fracture is clearly noticeable. Round the tip of the ulna nail, which has penetrated the corticalis, marked rarefactions and periosteal layer can be observed.
The nail will be removed.

c d

Illustration 79

c) The same fracture after the removal of the nail. The nail canal and the cavity in the ulna are clearly noticeable.

d) The same fracture three years after the operation.

B. Old Fractures and Pseudarthroses

It appears doubtful whether or not fractures of the forearm which are older than 1 week may still be treated with the closed nailing method. We had no such cases in our clinic.

15 of the 23 fractures nailed with exposure of the fracture site were up to 3 months old, that is in a condition in which a healing was still perfectly possible by using the old conservative methods. They all resulted in a bony healing with the nail.

Isolated fractures of the shaft of the ulna were not among our cases. We had only one isolated fracture of the shaft, of the radius in which the nail could be removed after 2½ months.

An infection occurred in 4 of the 14 fractures of both bones.

An infection of the entrance site of the ulna nail, which had been pinched off because it could not be driven in far enough, occurred in one of the cases. It was omitted to smooth the sharp edge with a file and an inflammation developed. When a callus formation became clearly visible at the fracture after 5 weeks, the nail was removed and an abscess developed at the fracture site 8 days later. It had been omitted to keep the arm in an elevated position after the removal of the nail. Eighteen days after draining the abscess a small sequestrum was ejected, hereupon the wounds closed and the fracture healed with full function of the limb.

In this fracture the osteosynthesis was stabile. In the following instance the fixation was only incomplete.

In the fracture of Ill. 80 only the ulna was nailed and the nail had been driven in hardly more than 2 centimeters. The point entered the corticalis (same as in Ill. 79b) and when the nail was removed 3 months after the operation, a marginal sequestrum was ejected, whereupon the wound healed. Since the fracture was in good shape after the marrow nailing and thanks to the plaster cast which was left in position long enough, the full use of the limb was finally restored.

The result was, however, bad in the two other fractures, because the nailing did not come up to the technical requirements.

In the 8 weeks old fracture of Ill. 81, only the radius is nailed (incorrectly by approach from the head). The fracture ends were resected, it was omitted, however, to resect the ulna fracture at the same time, which apparently had already solidified to a considerable extent. Thus a defect of about 5 millimeters developed in the radius. (Ill. 81a). The operation lasted for 1½ hour, so it is no wonder that an infection ensued. The wound being opened widely in proper time and the limb put at rest, an infection

Illustration 80

Six week old closed forearm fracture two months after nailing. Only the ulna was nailed. Infection of the wound. The nail, which is much too short, has perforated the corticalis of the distal fragment.

a b

Illustration 81

a) Eight week old forearm fracture after the nailing which was made in another hospital. Only the radius was nailed (erroneously from near the head). The fracture planes had been resected. Due to the fact that the ulna was already stabil a distraction of 5 mm occurred. After the development of a wound infection it was immediately widely opened and a plaster cast was applied. In this way an infection of the bone was avoided.

b) The same fracture 6 months after the operation. Luxation in the distal radio-ulnar joint. In this way the fragments of the radius were pressed together and healed. Pronation stiffening of the arm and impediment of the wrist extensors.

of the bone was avoided. But a luxation of the distal radio-ulna joint developed and the final result, (as shown in Ill. 81b) is a pronation position of the arm with considerable impediment of the outward rotary movement and of the flexion of the wrist joint. But for the distal luxation which caused the radius fragments to come in contact, the radius would not have healed at all.

In case of the fracture of Ill. 82a, the first mistake was made in the determination of the length of the nail according to the X-ray picture and secondly in that the nail was applied in the wrong way and that a radius nail was used for the ulna. The surgeon was apparently entirely indifferent about the X-ray picture, otherwise it could hardly have escaped his notice that the nail was too narrow for the proximal marrow cavity of the radius. The marrow cavity was split when the nail was forced into it and it was not noticed that the nail no longer was in the bone. For fear that the same might happen at the ulna, the latter was "nailed" with KIRSCHNER wires, (Ill. 82b) although a nailing would have been easily possible with a thin ulna nail. In this case, therefore practically nothing was achieved with the nailing, the fracture shifted repeatedly in the plaster cast and had to be corrected several times. Severe swelling and blebs developed in the plaster cast, due to the insufficient reduction and fixation of the fracture. When the patient was admitted to the special ward, five months after the operation, the wounds as well as the fracture had healed. The fracture revealed a displacement of about the width of the shaft and a slight angulation (Ill. 82c). The result was a complete impediment of the rotary movement, limitation of mobility of the hand joint by about 50% and of flexion in the elbow by 90°.

One must admit that both fractures would have healed more quickly and presumably with a better result if they had been treated by the conservative methods. But in these cases the marrow nailing method cannot be blamed for the failure but rather the faulty technique. If suitable nails were not available, the operation should not have been performed.

If the fractures are less than 3 months old, nothing should be resected off the bones, because the best abutment of the two bone ends is guaranteed if they are not resected. The marrow cavities are easily found. Nevertheless it is recommended to proceed in the same manner as in the osteotomy, that is to reduce both bones with LAMBOTTE's bone forceps before the nails are driven in. We have once seen a defect of several millimeters sustained at the radius, although nothing had been resected. In such cases it will be necessary to shorten the second bone accordingly in order to secure a wide abutment. A faulty healing is imminent if a wide abutment is not obtained.

a b c

Illustration 82

a) Nine week old fracture of the forearm. This picture was taken to determine the correct nails. Mistakes: A radius nail was placed along the ulna and the nail along the radius is not placed the right way. The marrow cavity of the proximal fragment is quite noticeable. It is much too narrow for the nail.

b) The same fracture after the nailing which was made in another hospital. The nail of the radius is lying beside the proximal fragment. A KIRSCHNER wire had been used for the ulna, the marrow cavity of which would certainly have been broad enough for the insertion of an ulna nail. Infection of the wound.

c) Five months later. The displacement of the fragments is equal to the width of the shaft. They are somewhat angulated and healed. Rotary movements are no longer possible and the function of the wrist amounts to only 50 %.

If the appropriate technique is applied the result of the nailing of old double fractures of the forearm will be good. The 10 remaining fractures healed in a good position without any impediment whatsoever. The average stay in the hospital was 56 days and the unemployability was 115 days on the average.

It may safely be said that the nailing of the old forearm fractures brings definite advantages. It is indispensable, however, that a really stabile osteosynthesis is achieved and this is possible only if both bones are nailed. In due consideration of the increased infection hazard, the operation will be performed only if one does not succeed in obtaining a satisfactory reduction by using conservative means or if no callus formation is observed after 3 months.

Special attention must be attached to an accurate adaptation and fixation of the bone in those fractures which are older than 4 months, that is to say if we have to deal with a pseudarthrosis or if the development of a pseudarthrosis is imminent. In these cases it will regularly be necessary to freshen the fracture ends.

The most favorable conditions prevail if there is no healing of the two bones. In this case the ends of the fracture can be brought together in such a way that a wide abutment is achieved and if sufficiently long nails are used a stabile osteosynthesis is guaranteed. The technique in this case is the same as usually applied in osteotomies. In three cases of (connective tissue) pseudarthrosis, 7 to 12 months old, a complete recovery was achieved (Ill. 83).

If a pseudarthrosis exists in only one bone a wide and positive abutment of the bonescan be achieved only in case of oblique fractures.

If the fracture site is sparingly freshened obliquely, a positive abutment can be achieved under certain circumstances, especially if the nail used is long enough. We were successful in two radius operation of a 5 and 7 months old (connective tissue) pseudarthrosis. Both cases resulted in good bony healing. (Ill. 84).

If the fracture ends do not firmly abut, as was the case in the above mentioned ulna pseudarthrosis (HAEBLER, a.a.O. Ill. 88) and if in addition the nail is too short, or if even only a KIRSCHNER wire is used for the "nailing" as was done in the 1 year old ulna-pseudarthrosis, a faulty healing will be unavoidable.

The hazard is great, that a defect develops as a result of the necessary resection of one bone in case of a pseudarthrosis and that the second sound bone will have an obstructive effect and thus jeopardize the healing process. The solution imposes itself of resecting the other bone and using a marrow nail.

a b

Illustration 83

a) Five month old fracture of the forearm. Three weeks after the accident radius and ulna were exposed and the ulna was fixed by means of a wire loop. After the removal of the plaster cast 4 weeks later, that loop had slipped and therefore the entire fracture was not stabil.

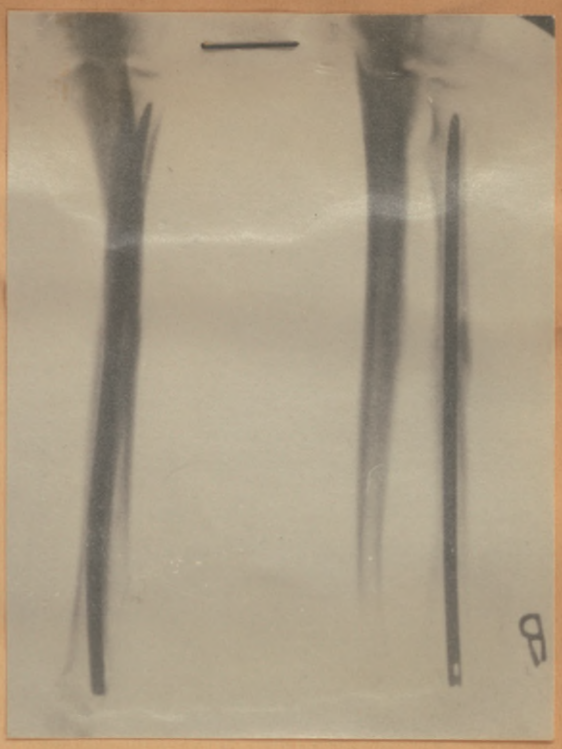
b) The same fracture after the open nailing of both bones. Stabil osteosynthesis. The patient was released to his unit 4 weeks after the operation.

c d

Illustration 83

c) The same fracture 8 months after the operation. The fragments are healed and rarefactions around the nails cannot be observed.

d) After the removal of the nails.



a b

Illustration 84

a) Five month old oblique pseudarthrosis of the radius. Only the scar tissue located between the ends of the bones was removed.

b) Ten weeks after the operation most of the fracture cleft is bridged over. The nail was removed 4 weeks later.

We proceed that way in all cases (except in old fractures due to gunshot) and we would like to describe the course of a 1½ year old pseudarthrosis of the radius (Ill. 85).

In this case, a bone graft had been performed 9 months previously, which due to infection lead to the ejection of the bone graft and resulted in a faulty healing. The marrow cavity was so narrow that only an ulna nail could be used. This nail became so firmly engaged in the cavity that a shorter nail had to be chosen. A relatively short nail had also to be used for the ulna, because of the age of the fracture. As a consequence the fracture remained movable in an axial direction after the nailing and the osteosynthesis was instabile. (Ill. 85b) An infection associated with a formation of sequestra which developed at the fracture cleft of the radius lead to a fresh luxation in the distal radio-ulna joint and to a wandering of the radius nail (Ill. 85c). The final result was a defect pseudarthrosis with luxation at the distal radio-ulna joint, that is a condition which was worse than before the operation.

It must be admitted that we had to deal with an increased infection hazard and that the instabile osteosynthesis was responsible for the bad result. On the other hand, we have made similar experiences in isolated pseudarthroses following fractures due to gunshot and we refrained from making further experiments. The hazard of an infection and the complications which ensue in such cases by the use of the marrow nail in the exposed nailing of old fractures of the forearm must be given serious consideration.

For the same reason we do not see our way clear to adopt the recently renewed suggestion of resecting a corresponding piece of bone off the second bone for the purpose of inserting it into the defect with the marrow nail. On the strength of the results observed in patients nailed outside our clinic, we deem this method even more hazardous than a bone graft.

In due consideration of these facts we have refrained from nailing isolated pseudarthroses of a bone of the forearm if it could not be expected or if the operation revealed that a proper abutment of the fracture could not be achieved. In these cases we rather grafted a tibia strip and have always achieved (7 cases) a bony healing.

Summary

The hazard of an infection of the fracture cleft is considerably higher in the open than in the closed marrow nailing. The indication must therefore be checked very carefully.

a b c

Illustration 85

a) 1½ year old pseudarthrosis of the radius. 9 months ago a bone graft was done and it became infected. (The nails had been laid alongside in the wrong way). The marrow cavity of the distal fragment of the radius is too narrow for a radius nail.

b) After the nailing. In the radius only a thin ulna nail was used which however jammed so much in the proximal marrow cavity that it was impossible to insert it any farther. Also only a short nail was driven into the resected ulna because of the old fracture. Consequently the osteosynthesis was not stabil. Infection of the wound. Several sequestra were cast off from the radius.

c) Four months after the operation. The ulna is healed. Luxation of the distal radio-ulnar joint. Defect pseudarthrosis in the radius out of which the nail has slipped distally.

Long duration of the operation, improper technique and especially an incompletely stabile osteosynthesis are the main causes of infection.

In those cases, where a stabile osteosynthesis cannot be expected from the very beginning it is better not to nail and to have recourse to the old methods of osteosynthesis. The nail constitutes in these cases a far greater hazard than the wire suture or plate.

As a rule a (long) drain is to be inserted at the physically proper place in all cases of open marrow nailing and the limb will be put at rest in a plaster cast until the infection hazard has definitely been overcome.

In case of a relatively stabile osteosynthesis (tibia) there is a particular proneness to late abscesses if the limb is used too early. It is therefore recommended to use additional means of fixation such as a walking cast until the fracture has positively healed. At any rate, the fixation has to be instituted right away if the patient complains about swellings or pains.

If an infection occurs (fever) it will be necessary to open the wound widely to prevent the infection spreading into the marrow .

The infection hazard is especially great in the osteotomy of fractures of the thigh healed with angulation. Particularly so if the fracture has healed a long time before the operation when it will be very difficult to restore the accurate anatomic conditions. In these cases one should rather put up with a shortening and shorten the sound leg with the nail.

The nailing osteotomy should as a rule be performed as early as possible in femur fractures, healed with angulation.

Those fractures in which a stabile osteosynthesis cannot be achieved are not suitable for nailing.

In case of a considerable shortening or displacement the operation should be performed in two sessions. The first session includes osteotomy and wire extension and when the shortening is compensated for by this treatment, the "open" nailing will follow.

If we have only to deal with a peripheral dislocation, the nailing osteotomy will be performed remote from the fracture at the "site of choice".

The results of the correctly performed nailing osteotomies of femur fractures healed with angulation, are superior to those of all other methods hitherto known.

Old thigh fractures which are not older than 5 weeks may be treated with the closed nailing method and will then benefit by all the advantages which the nailing offers in the treatment of fresh fractures.

An important conditions is, that the fractures are thoroughly mobilized even though they may still appear quite movable. A reduction apparatus facilitates this operation greatly.

In case of a considerable shortening one must wait after the mobilization of the fracture until this shortening is compensated for or overcorrected.

Femur fractures which are older than 5 weeks should not be treated by the closed nailing method because of the increased hazard of fat embolism.

The (connective tissue) thigh pseudarthrosis does not call for a resection of the bone.

Atrophy of the bone excludes treatment by open marrow nailing of old femur fractures. All fractures which are located less than 6 centimeters away from the tip of the trochanter and from the knee joint are not suitable for nailing because the osteosynthesis has little chance to become stabile.

If the osteosynthesis is good, the results of the marrow nailing method are definitely superior to all other methods and the infection hazard is low.

In the osteotomy of tibia fractures healed with angulation the marrow nail does not constitute any advantage over the old methods. In case of an infection the nail means an additional hazard. Therefore, the old methods of osteosynthesis should be given preference in this type of fracture.

Old tibia fractures with a delayed formation of callus may be treated up to 20 weeks after the accident by closed marrow nailing if the fibula is resected and if the fracture is thoroughly mobilized. If these points are observed, the indications and advantages will be the same as in fresh fractures.

In cases of a considerable shortening and in very old or previously compound or infected fractures, a wire extension is applied for a period of 8 to 15 days following the fibula resection and mobilization.

In the open nailing of old tibia fractures there is a serious infection hazard which threatens the limb and sometimes the life of the patient, if the osteosynthesis is not absolutely stabile. Utmost care is therefore necessary.

If a positively stabile osteosynthesis is achieved and if the appropriate technique is applied, good results may be expected and the nailing proves superior to all other methods.

If the fracture is, however, older than 6 months, the marrow nail will not bring substantial advantages, regardless of whether we are dealing with an unhealed fracture or a genuine pseudarthrosis. In these cases we can hardly expect a stabile osteosynthesis and a shortening cannot be avoided by the use of the marrow nail. If an infection occu

this means complications which weigh more heavily than in other methods.

The marrow nail is indicated in the osteotomy of fractures of the upper arm healed with angulation, if a stabile osteosynthesis can be achieved. It fits the purpose to resect the fracture ends (staircase shape) far enough, to open the marrow cavities. An additional wire suture is not considered necessary.

Old fractures of the humerus may be treated by a closed nailing up to 6 weeks after the accident, on the conditions that they are thoroughly mobilized prior to the operation. The results then will be comparable to those obtained in fresh fractures.

The infection hazard is insignificant in the nailing of old fractures of the humerus with exposure of the site.

The staircase shaped resection is imperative in the genuine pseudarthrosis which must be performed wide enough that sound bone is exposed. This resection is not necessary if we have to deal with an unhealed fracture.

A faulty healing is often caused by distraction due to the weight of the arm if the osteosynthesis is not stabile. A longitudinal suture will avoid this distraction, but it is of no use if the bone is atrophic.

Atrophy of the bone is not a contraindication to the nailing of old fractures of the upper arm. The nails used in this case must be long enough so that they may be driven in as far as into the spongiosa of the epiphysis. An abduction cast in which the arm must be elevated above the horizontal will be necessary until the musculature is again strong enough.

The marrow nail is superior to all other methods for obtaining a stabile osteosynthesis in the fractures of both bones of the forearm healed with angulation.

As a rule both bones have to be nailed. The nails will only be driven in if the bones are properly resected an brought in position.

The closed nailing will generally not be possible in old fractures of the forearm.

The infection hazard is rather great in the nailing with exposure of the site, so that the indication must be thoroughly checked and the operation should be restricted to those cases in which a satisfactory reduction cannot be achieved by the conservative methods.

In case of pseudarthroses of the bone it will be possible only very rarely(in transverse fractures) to secure a wide abutment and accurate fixation of the fracture ends. The attempt to obtain better conditions by resection and nailing of the second bone, seems to be more hazardous than a bone graft.

The marrow nailing brings about excellent results in case of a pseudarthrosis of the two bones if a stabile osteosynthesis is achieved.

A KIRSCHNER wire will in no case be a substitute for a marrow nail.

Infected fractures due to gunshot injuries

Up to now the surgeons were guided by the rule that an osteosynthesis by use of a foreign body in infected fractures could take place no earlier than 9 months after an uneventful healing of the wounds.

FRITZ KOENIG has, however, even before 1931, performed osteosyntheses using foreign bodies in infected fractures of the tibia. He considered this procedure as an emergency measure and the progressive development of the conservative treatment (wire extension) reduced the number of these emergency cases to a minimum. The remembrance of these cases and the many osteosyntheses of fresh compound fractures which I saw during my time as his assistant at Wuerzburg and in my own practice convinced me that a stabile osteosynthesis with the marrow nail should be possible before that period of time and even in still fistulating wounds, since the complete fixation assists the struggle of the body to overcome the infection and the nail will not have the slightest ill effect if in proper position, as has been shown by the course of the infection in case of open marrow nailings.

Already in 1941, I have successfully nailed a still purulent thigh fracture with concomitant performance of the necessary sequestrotomy. Also in the military hospital under my jurisdiction as a military consultant we nailed old fractures due to gunshot injuries with the wounds still in the fistulating stage. The majority of these operations were performed by younger colleagues who were enthusiastic about the method and liberal with regard to its indication. We, therefore, had very serious complications besides good results. The complications were particularly serious in cases without a stabile osteosynthesis. I finally had to assume the responsibility as to the indications and carried out most of the operations myself. For this purpose the patients were transferred to my special ward and with growing experience the results improved. The indication was checked with an increasing accuracy.

As is quite logical in military hospitals in the homeland, we had only very few cases of fresh fractures due to gunshot injuries. We dispose, however, of the history of 126 cases of old fractures due to gunshot injuries treated by the marrow nailing method, at a time, when the wounds had just healed or in many instances were still fistulating or purulent. These cases included 51 femur fractures, 28 tibia fractures, 39 fractures of the humerus, 8 fractures of the forearm. One femur fracture and three tibia fractures could not be observed until final healing.

T A B l e VII

Marrow nailing of old fistulating fractures of the tibia

Nr.	Time between injury and operation	Type and site of the fracture	Condition of the wounds	Nailing O-Open C-Closed	Osteo-synthesis S-Stabile R-Relat. stabile I-Instabile	Addition. fixation BS-Braun's Splint P-Plaster VS-Volkmann Splint	Treatmt. of Wounds D-Drainage S-Skin suture A-Approx. suture C-Wound left open	COURSE OF HEALING: the wound VS-Suppurat. of wound GA-Gravity abscess Ph.-Phlegmons	Sequestrum	Osteomyelitis	Stay in hospital after the nailing operation	Healing of the fracture	FINAL RESULTS: Position	Shortening	Joints K-Knee joint A-Ankle joint	Remarks
1	5 days	Short comminuted fracture in the middle, position satisfactory	torn up strongly purulent	O	R	P	D/O	tedious suppuration GA	**	-	11 months	bony	good	3 cm.	A-stiffened K-½	See III.99
2	4 weeks	Transverse Fracture just below the middle, slightly splintered, Position satisfactory	Granulating Fistulating Prox.fragment lies free in the wound	O	R	BS	D/O	per gran. moderate suppuration	after removal of the nail	-	9½ months	delayed bony after resection of fibula	good	½ cm.	A= 1/5 K= 180-90°	See III.100
3	6 weeks	Short oblique fract. in the middle, slightly splintered, slight valgus and recurvation sequestra	Fistulating Removal of sequestra necessary	O	S	BS	D/O	r gran. derate uppuration	-	-	7 months	bony	good	—	free	
4	8 weeks	Short comminuted fracture in the middle, Sequestra, Recurvation	Fistulating Removal of sequestra necessary	O	S	P	D/O	od supp.per ran.	*	-	8½ months	bony	good	2 cm.	A= 1/3 K= 180-90°	
5	10 weeks	Greenstick fracture just below the middle with broken out bending wedge, sequestra, slight valgus and recurvation	Fistulating Removal of sequestra necessary	O	R only one nail	BS	D/A	l. and GA edious supp. rysipel	-	-	14 months	bony	good	1 cm.	A= 2/3 K= 180-100°	Due to the defect of the bendg. wedge, the nail penetrates repeatedly into the soft parts at the distal fragment.
6	11 weeks	Oblique fracture slightly below middle sequestra, positions satisfactory	Fistulating Removal of sequestra necessary	O	R	P	D/A	ong supp.	-	-	9 months	bony after resection of fibula	good	2½ cm.	A= 1/3 K= 180-80°	
7	4½ weeks	Isolated short comminuted fracture of the tibia, middle, position good	Granulating slight secretion	C	R	BS and later P	D/A	edious supp. of the fract. nd entrance ound	** repeatedly	-	10 months	bony	good	-	A= ¼ K= 180-80°	See III.101
8	5 weeks	Isolated tibia fracture, middle, small bone splinter broke out which sequestrates, slight recurvation	Fistulating Sequestrum can be removed by enlarging opening of fistula	C	S	P	D/O	losed after weeks	-	-	3 months	bony	good	-	free	
9	6 weeks	Isol. transverse fract. of the tibia, slightly below middle, sequestr., slight recurvation.	Fistulating Removal of Sequestra necessary	O	R	P	D/O	tedious suppuration	**	-	11 months	delayed solid aft. resect. of fibula	good	½ cm	A -¼ K- free	
10	7 weeks	Isol. oblique fracture of the tibia, middle small sequestrum, position good	Fistulating Sequestrum removed by enlarging the wound	C by appr. from the dist. side	S	BS later walk. cast	D/O S at entrance wound	closed after 6 weeks	-	-	3½ months	bony	good	-	free	
11	7½ weeks	Isol. short oblique fracture of the tibia with sequestrum position good	Fistulating Sequestrotomy by enlarging the wound	C	S	P	D/O	healed after 14 weeks, aft. ejection of sequestra	*	-	6 months	bony	good	½ cm	A-¼ K-free	
12	5 months	Isol. short oblique fracture., middle, defect of 0.5cm., lateral displacement by width of shaft, fibula solid	Fistulating	O Fib. not resect.	S	BS	O	Per granulationem	-	-	8½ months	delayed, bony after resection of fibula	good	1 cm	free	
13	7 months	Transverse fracture just above the middle line, lateral displ. more than width of shaft, fractured cleft covered, articulus talocruralis stiffened	Fistulating Sequestrum palpable	O Fib. not resect.	S	P	D/A	Per granulationem	-	-	9 months	Nail removed aft. 3 months, fract.sprgy. becomes solid with walking cast	good	1 cm	A-stiff (alread. bef.oper.) K-100-180°	See.Ill. 103
14	10 months	Transverse comminuted fracture, middle, Displ. by 3/4 of width of shaft, recurvation, hardly any formation of callus, gap at fracture cleft, fibula solid sequestrum, ankle joint stiffened, knee 180 - 160° movable	Fistulating	O Fib. resect.	S	P	D/O	Per granulationem	-	-	7 months	bony	good	1 cm	A-stiff K-180 - 100°	
15	18 months	Defect fracture, located at the line defining the median and lower third, position good, sequestrum ejected 14 days previously, fibula solid	Fistulating	C Fibula Osteot.	S	BS weight-bearing after 14 days	Entrance Wound of the nail sutured	Abscess at the entr. wound of the nail GA	* also after heal. of the fract.	-	10 months	bony	good	2 cm	A-½ K-free	Re-operat. because of Verhaltung. in the nail canal. Nail corroded w. begin. fract. of the nail. S.Ill.102