THE

TECHNIQUE

OF

INTRAMEDULLARY NAILING

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With 135 Illustrations

GEORG THIEME PUBLISHERS LEIPZIG
Foreword – Küntscher, a path of clinical innovation

This text provides rare insight into the initial development of one of the most significant contributions to orthopaedic surgery and trauma care in the history of medicine.

First consider that this development occurred during World War II in the time period from 1939 to 1942 in Germany, while Germany was at war with Europe and the British Empire. Maatz was on board a German Hospital Ship in the Mediterranean Sea and Küntscher was deployed in Kemi, Finland as a Chief Medical Officer for the German Army. The availability of materials, implants, and instruments was limited by war and author communication was erratic. Yet, from their initial efforts in Kiel, Germany and use of nailing in the military hospitals, over 500 cases were followed and documented during these 4 years. There is an extensive bibliography showing the rapid acceptance of the technique in the German countries. Equally astounding is that the United States, Great Britain and its allies were shocked to learn of these techniques at the end of WWII in 1945, 3 years later. Dr. Hugh Smith, one of my mentors at the Campbell Clinic told me of the amazement of the surgeons on the first interviews with captured allied prisoners who sustained femur fractures and had received intramedullary nails and healed with a more rapid mobilization then considered possible at the time. Sir Watson-Jones, the chief Medical officer for the British Forces, Dr. Smith and others worked to retrieve these nail devices and explore the ramifications of Küntscher’s invention. At the end of the war, Küntscher himself was taken to the United States to work with the Armed Forces to report and describe his technique; Professor Philip Procter only recently rediscovered this document after declassification of the book by the United States Military. This book is now available for surgeons from the Stryker Company and must be read to understand how far ahead of his time Küntscher really was.

The contents of this text are required reading for any student of intramedullary nailing. I seriously believe if this text and Kuntscher’s military book had been available to my generation, many of our errors would have been prevented. The section on the early experience of the estimating potential for stability of the construct, with regards to the cortical thickness, medullary canal space and nail diameter as demonstrated in Figure 49 would have avoided many misadventures reported in the literature today. The importance of radiographic control of the surgery and the importance of protection of the surgical team from the dangers of radiographic techniques is another reason for the rapid acceptance of this technique in Germany and the hesitancy of its acceptance in the United States and England. The mention in the text of Pohl’s development of the adjustable X-ray, which was the precursor of C-arms, is revealing. Küntscher and the group at Kiel developed close ties after the war with Pohl and his company, which led to numerous inventions and improvements in intramedullary nailing including the compression hip screw plate and the Y-Nail. Stryker, now owns Pohl’s company through a previous acquisition by Howmedica, responsible for the Grosse-Kempf and Gamma nails, continuing the heritage of nail improvements. The sections on reconstructive nailing are particularly insightful and reflective of what has now become standard practice for pathologic fractures and deformity treatment.
The third aspect of this text is the underlying theme of surgeons and manufacturers striving to improve nail design, instrumentation and techniques. The resources and technology of their day limited these surgical pioneers. I believe most of the advances in interlocking nailing we now enjoy have resulted from company interactions with the capabilities for computer-assisted design and manufacturing, innovations permitting better tolerancing of implants, closed section designs, improvements in image intensifier C-arm technology and better education and training of surgeons, but all of these developments have their origin from Küntscher’s synergistic integration of biocompatible implants (Germany made the best steel in the world in 1940), innovative design ideas which were converted into surgically efficient, radiographic directed instrumentation and the biological concept of remote implant placement through a minimally invasive technique.

This is an exciting and stimulating glimpse into our collective surgical history.

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Foreword – Küntscher from clinical controversy to clinical impact

Intramedullary nailing of long bone fractures has to be regarded as the most significant achievement in orthopaedic traumatology of the last 100 years, and some might reasonably argue that it compares with other major advancements in orthopedics, including the development of joint arthroplasty and arthroscopic surgical techniques. Interestingly, although IM nailing is now the standard of care for long bone fractures of the leg, it has a relatively short history in North America; short enough that many still-practicing surgeons remember its controversial introduction into North American surgical practice. Since its introduction as a treatment for femoral and tibial shaft fractures, indications for use of intramedullary nailing has expanded to fractures of the humerus and forearm, as well as metaphyseal and peri-articular fractures, and for reconstructive techniques such as osteotomies, arthrodeses, treatment of some bone tumors, and fracture nonunion.

The history of the development of IM nailing is fascinating, but due to quirks of history is still largely hidden. Only now is the development of IM nailing as we now know it beginning to be understood. The modern technique of intramedullary nailing was largely developed and perfected by the dedicated work of the German surgeons Gerhard Küntscher and his student, Richard Maatz. Since Professor Küntscher and his team were working within Germany during World War II, their work remained largely unknown to the rest of the world. This English translation of the earliest known work of Prof. Küntscher is a treasure. Anyone who reads this tome will immediately see that Prof. Küntscher’s work extended well beyond the nailing of femoral shaft fractures, and includes “modern” concepts of positioning, imaging, a surprisingly advanced understanding of the pulmonary consequences of intramedullary instrumentation, and the adaptation of techniques of intramedullary nailing to other fractures, including those of the upper extremity. One of the pioneers of intramedullary nailing in North America, Dr. Robert Winquist, would often say in his lectures that “There is nothing new in nailing since Küntscher”, and this manuscript proves the truth of Dr. Winquist’s comments.

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Foreword: the Technik der Marknagel translation project and its discoveries

The English translation of Technik der Marknagelung is a project that I have wanted to do for many years. In 1986 I started to work as a product manager in Howmedica Europe for Eddy Van Den Branden. Eddy had developed all of the marketing, training and education programs for the Grosse and Kempf (G & K) Locking Nail. At G & K Locking Nailing courses and clinical meetings, time and time again, clinical presenters acknowledged the “Technik der Marknagelung” book alongside a picture of the hero of intramedullary nailing Professor Gerhard Küntscher. I read this book and realised that it was a defining moment in the history of the technique. My first major project in Howmedica Europe was the development of the Gamma Locking Nail for proximal femoral fractures. The Küntscher Y nail was one of the major inspirations for the Gamma Locking nail. As this was first described in the Technik der Marknagelung it became my ambition to create an English translation to enable access of non-German speaking surgeons to this classic work.

For the translation project I engaged Mrs Karin Band, a professional translator with exceptional experience in the translation of medical texts from German into English. In 2006 we had completed the first draft when through an internet search I made the astonishing discovery that a complete translation already existed. The translation was located in the Otis Historical archives of the National Museum of Health and Medicine in Washington DC USA. I contacted the museum and obtained a copy of the translation for the princely sum of 20 USD. When it arrived at my office in Geneva I read it straight away. The foreword to the translation, written by a Commander Harry Alvis, of the US Navy, contained a revelation that I could hardly believe.

“Although KUENTSCHER is listed as senior author there is good reason to believe that he had little to do with the writing of this work “

When I later visited the National Museum archive in person I discovered a further unknown manuscript that was authored by Küntscher at the request of Commander Alvis. The manuscript was entitled The Marrow Nailing Method and was a complete and thorough account of the technique that Küntscher had developed. Both Küntscher and Alvis intended this to be published and to reach US surgeons. For many reasons the manuscript never made it into print and 13 copies of the manuscript remained unrecognised in archive locations in US until I came across the copy lodged in the National Museum. With the support of the Stryker Corporation the manuscript was made into a book that was printed in 2007. I presented this book and my discovery story at the OTA in Boston in 2007. In Küntscher’s foreword to The Marrow Nailing Method I found the same assertion that he was not an author of the Technik der Marknagelung.

“During the war the author of this book was not in a position to write a book of his own about this subject, and the publication by KUENTSCHER and MAATZ mentions only his name. In reality this book was exclusively written by MAATZ “

It is difficult to reconcile this statement with the view of history that Küntscher and Maatz co-authored this first and most important book in the development of Intramedullary Nailing. I had no doubt that Küntscher was connected with the Technik der Marknagelung at least in authorship and the writing of an original manuscript. After all he and Maatz had worked very closely together in developing the application of the technique. So what possible explanations could there be for distancing himself from the first work that carries his name? My speculation as to why this happened is as follows. In an archived note by Commander Alvis it is stated that the original manuscript was destroyed in bombing raids on Leipzig. All materials for printing the book were lost so reconstructing this and getting copies of original X-Rays would have been next to impossible under wartime conditions.

“Küntscher, with Richard Maatz as co-author, also had a manuscript “Technik der Marknagelung” with illustrations ready for print in 1942, but this was unfortunately destroyed in the raids on Leipzig, and the book could only be published after much delay in 1945.”

From late 1942 until September 1944 Küntscher was stationed in Kemi in Finland close to the Russian front. Over the same period Maatz ends up stationed on a hospital ship in the Mediterranean from where he writes the foreword to Technik der Marknagelung. Communication on the subject of a clinical book under their respective wartime circumstances is difficult to imagine. So we can be fairly certain that they were unable to communicate on this project once they had gone to their respective postings. According to Commander Alvis, in his foreword to the US Navy translation of Technik der Marknagelung, Küntscher and Maatz were quite opposite in character which might account for Maatz acting on his own.

“The personality of two people could not have been more opposite in nature. MAATZ the tense, alert, extrovert with rapid fire reactions – KUENTSCHER the shy scholarly introvert, self depreciating and carefully thinking things through. One cannot escape the thought that the Surgical Clinic at the University of Kiel must have been an interesting place when these two people were having a debate.”

So it could have been that Maatz decided to act on his own initiative to secure their place as originators of the technique. The pressure to do so was probably mounting since other surgeons such as Böhler and Häbler were already publishing ahead of them on the Küntscher technique. So I speculate that Maatz, enthusiastic for their work in Kiel to be recognised, authored the text himself reconstructing what he can from the original manuscript and adds Küntscher as first author. He writes the foreword on his own and adds a foreword from Professor AW Fischer who was their chief at the hospital in Kiel. Fischer was an appropriate choice as it was he alone who supported Küntscher when he first presented the very first series of 11 femoral nails at the congress of the German Surgical Society in March of 1940. With the Küntscher technique being adopted by many other European surgeons Fischer would also have welcomed recognition as the first centre to develop the method and might even have encouraged Maatz to go ahead with reconstructing the book on his own. Accor-
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Foreword

The idea that a healing fracture may be held in correct alignment by the introduction of a foreign body into the medullary cavity is not new. Metal wires and pins, and even ivory pegs, have been used for this purpose. However, the insertion of these devices required the exposure of the fracture fragments, and thus carried a risk of infection.

The essential feature of the Küntscher technique is the introduction of the foreign body through a portal that is remote from the fracture site. In this it differs essentially from all other methods of operative fracture treatment used in the past. The basic principle consists in the use of a specially shaped, very stable nail-like splint, which fits itself elastically against the walls of the medullary cavity; the device is intended to provide maximum fracture site stabilization, and to dispense with the need for supplementary support by a plaster cast or traction apparatus. This stabilization also serves to avoid the detrimental results of prolonged immobility of the limbs.

The technique of femoral neck nailing originally developed by Smith-Petersen has been expanded by Küntscher into a technique for the nailing of long-bone shafts. When first presented by Küntscher to the Surgical Congress in Berlin, the technique met with disapproval by the majority of his colleagues. This is understandable, and shows that these German surgeons were responsible people, who were concerned, first and foremost, about the harm that could be caused to their patients by the introduction into the medullary cavity of so large a foreign body. This was also my concern when Mr. Küntscher first expounded his idea to me; even though, in the light of the animal studies, this “instinctive” worry was unlikely to be justified. Indeed, when the technique came to be used in humans, there were no adverse effects in the medullary cavity or elsewhere.

The method has now been adopted in numerous civilian and military hospitals. It is being continually improved. Surgeons at many centres, including our own at Kiel, are working to design reduction instruments, to improve the radiation protection of the surgeons, and to perfect the nail patterns. In addition to these technical matters, the indications of the technique are being studied. We are beginning to establish which fractures are suitable, which are borderline, and which are entirely unsuitable for nailing; which fracture patterns will still required casting after nailing; and which fractures will allow early weight-bearing after nailing, as opposed to those where weight-bearing will have to be delayed. This is an on-going exercise.
It is hoped that this treatise will be an aid to surgeons who are practising, or intending to practise, intramedullary nailing. Its purpose is to describe the state of the art, as well as the pitfalls of the technique.

As pointed out elsewhere, it is imperative that the technique should be used only by those who are properly skilled in this form of fracture management, and who have the complete armamentarium required. Intramedullary nailing requires supreme technical skill.

To my way of thinking, the Küntscher technique constitutes the greatest progress in fracture management since the invention of skeletal wire traction by Rudolf Klapp. I am convinced that it will be adopted worldwide.

I bid this book good-speed, and am sure that it will have the success it so amply deserves.

A. W. Fischer, Kiel

Preface

By December 1942, we had completed the manuscript of this treatise describing our technique of intramedullary nailing. However, permission to publish was not forthcoming. When, one year later, these difficulties had been overcome, almost all the illustrations were destroyed during an enemy air raid on Leipzig. I was then posted to a hospital ship, which has made it very difficult to remain in contact with my publisher and with my co-author. This is why the publication of this work has been repeatedly delayed. Unfortunately, we are also not in a position to print the intended annex to this treatise, with a short summary of our results to date – we have, by now, followed up more than 500 nailing operations, of which just under 400 were done at the Kiel centre, and the rest in forward or in base military hospitals.

In the meantime, all surgeons have learned to make do with less and less. Wartime restrictions on the manufacture of surgical equipment have made it impossible currently to obtain all the hardware specified in this book. Nevertheless, intramedullary nailing remains an ethically defensible technique, providing that the operating surgeons have X-ray apparatus, nails, nail guides, awls, slotted hammers, and block and tackle in their theatres. For all the other items, makeshift solutions can be found for the time being; they are not a must.

Surgeons who are new to the technique are strongly advised to confine themselves, initially, to the fracture patterns that are “very suitable”, i.e. to patients in whom intramedullary nailing is an absolute indication. This is the best way to learn to appreciate the benefits of this excellent technique. As the surgeon’s experience increases, the range of indications will be widened. The guiding principle in all cases should be the need for stable apposition of the fracture fragments by nailing. Where this condition has not been met, any adverse outcomes will be the fault, not of the technique, but of the operating surgeon.

On board a hospital ship
in the Mediterranean August 1944

Maatz
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1. Introduction

Any surgeon wishing to embark upon intramedullary nailing will need to familiarize himself with the principles upon which this technique is based. Only when he has grasped these fundamental concepts will he be able to make full use of what this modern technique can provide. The main point to remember is that this is a true nailing procedure. Just as a carpenter’s nail unites two pieces of wood with elastic forces, the intramedullary nail is intended to unite two fragments of broken bone. The nail is driven in with hammer blows, to wedge itself in the two fragments in such a way as to make it impossible for the fragments to displace. This pattern has to be achieved for the intramedullary nailing procedure to be considered a success, and for the superior potential of this procedure to be fully exploited.

Once the fracture fragments have been stabilized in this way, no further measures such as splinting, casting, or traction will be required. The patient will be allowed to freely move the limb, and even to weight-bear. The risk of muscle wasting or circulatory problems will, at worst, be very minor. There should not be a problem with joint stiffening, since the joints are not immobilized. The fracture will be exposed to an optimal stress pattern, with compressive stress only, and no exposure to tensile or shear stresses. As a result, bony union will be obtained within a very short time.

The nail is held by friction against the rough inner wall of the bone-shaft cylinder. Since the internal diameter of the shaft varies, the nail must have maximum cross-sectional compressibility. It is for this reason that a U-shaped cross-section has been chosen for the device. After successful nailing, friction between the nail and the bone may be so great that the construct can withstand a pull-out force of several hundred kilograms. However, not all long-bone fractures are equally suitable for management with this technique. The shape of the bone, the pattern and site of the fracture, and the possibilities of introducing the nail into the bony cylinder, are important factors to bear in mind. For patient selection, for the nailing technique, and, above all, for the aftercare of the patient, it is vital to know the forces that will be acting on the construct.

The fundamental object of the technique – obtaining adequate friction of the nail in both fracture fragments – cannot be attained in each and every case; however, it may still be possible to use the technique successfully in such cases, providing that one understands the deficiencies of the method sufficiently well to compensate for them.

The mechanical conditions are simple and straightforward.
A bone with a fairly uniform diameter of its medullary cavity will present the most favourable conditions (Fig. 1). The fracture pattern and site will be of no concern, provided that the two fragments are long enough for the nail to obtain a sufficient purchase. It should, however, be borne in mind that in fractures involving a bone defect, the nail will need to cope with all the bending stresses at the fracture site; whereas, in a smooth transverse fracture, the nail will be firmly constrained by the bone and largely guarded against any bending stresses acting at the site. Fig. 1 Optimal mechanical conditions: uniform medullary-cavity diameter, and straight nail.

Where there is insufficient friction between the nail and the bone, the nail will act as a simple peg (Fig. 2). While it will prevent angulation and lateral displacement, it will not secure against rotation. In such cases, the actual fracture pattern is of the utmost importance. A comminuted fracture will telescope, a spiral fracture will twist, a smooth transverse fracture would not be protected against rotation, while an oblique fracture would usually show little rotation, but go on shortening until the nail (acting as a peg) will have wedged in the bone (Fig. 3). Fracture fragments with markedly jagged ends may be protected against displacement, since the ends may mesh like the teeth of what, in engineering, is known as a Hirth-type face gear. Muscle pressure will make the serrations mesh, to protect against rotation.

Conditions are less favourable where the medullary cavity diameter varies widely. If the fracture site coincides with the narrowest part of the medullary cavity, sound nailing may still be achieved, thanks to the cross-sectional compressibility of the device (Fig. 4). Over a distance of a few centimetres along the medullary cavity wall of the fracture fragments, the nail will achieve sufficient friction. If there is little friction, the nail will act as a peg, and its effect will be limited to the prevention of lateral displacement. If the fracture is a transverse one, the correctly apposed fracture fragments, which are protected against lateral displacement by the nail, will be pressed together by the muscles, and angulation will be prevented; at the same time, the fracture will be protected against rotational displacement by the interlocking of the jagged fracture ends. If the fracture pattern involves a bone defect, the two fragments cannot be apposed in correct alignment, and angulation will occur (Fig. 5). If the fracture site does not coincide with the narrowest part of the medullary cavity, the displacement that can be prevented by the nail will depend upon the extent of the mismatch between the cavity diameter and the diameter of the nail. In the most unfavourable case, the fragments can displace laterally by the thickness of the shaft cortex.

In this case, lateral displacement, shortening, angulation, and rotation may occur – in other words, any displacement that can occur may occur to affect the construct (Fig. 6). The situation is more complex if the nail has to be introduced from the side rather than from the end of the bone. While, in the fragment that contains the nail entry portal, rotation between the nail and the bone cannot occur, the goal of strong friction between the nail and the fracture fragments will, as a rule, be unobtainable, since the nail diameter must be less than that of the medullary cavity (Fig. 7). If the fracture is in the narrow part of a tapering medullary cavity, the nail–cavity diameter mismatch, which is required for the insertion of

Fig. 1 Optimal mechanical conditions: uniform medullary-cavity diameter, and straight nail.

Fig. 2 Nail acting as a peg, and (left) the principle of interdigitation (Hirth-type face gear).

Fig. 3 An oblique fracture managed with a peg-type nail will shorten insignificantly, and thereafter be secured against all forms of displacement.
Friction also occurs between the nail and the cancellous bone in the ends of the long bones. While, in the majority of cases, the stability of the nail in these parts of the bone is irrelevant to the stabilization of a fracture, it may be of special significance in some cases, and consideration must be given to the level of stress that this softer bone tissue can be expected to withstand. One example we have seen was the grafting of a piece of the radius onto the ulna, near the elbow joint. In this case, bony union had not been obtained by five months post-nailing (infection, distracting action of the nail). The joint had been virtually fused. Motion was possible over a range of 20 degrees; however, this was not due to the springiness of the nail, but to the fact, documented by the superimposed roentgenograms, that the nail had worked a slot in the cancellous bone, in which the nail end could sweep over a distance of 12 mm (Fig. 8). If bone tis-
sue is cyclically or constantly subjected to excessive compressive stress, it will resorb at the point of stress. While, in the diaphyseal part of a long bone, nail pressure and the resultant resorption of bone on the inside wall will be associated with vigorous bone formation on the periosteal aspect preventing nail break-out, this reaction is not seen in cancellous bone. The nail will create a bed for itself, and eventually break out through the cortex (Fig. 9). This is why early weight-bearing is not allowed after subtrochanteric fractures; this is why the head of the nail used in the management of fractures close to the elbow is particularly broad; and this is why it would be useless to advance a tibial nail to the level where its tip is in the distal cancellous bone:

Fig. 8 Loosening of the nail in the cancellous bone of the ulna.

any purchase obtained there would be negligible and unreliable.

It follows that the object to be attained is the nailing of the fracture. This may not always be feasible. Where it is not, pegging may still be an option, and has several advantages. If secure pegging cannot be guaranteed either, the fracture should be considered unsuitable for this new technique. However, this is not a hard-and-fast rule, and, in special cases, the surgeon may consider nailing, especially where there is little prospect of early and sound healing with conventional techniques. The illustrations provided (Figs. 10 and 11) are examples of mechanically far-from-ideal multi-fragment and segmental fractures, in which intramedullary nailing produced an excellent outcome.

In practice, the situation will often be very complex. Thus, it is very difficult to analyze the forces that keep a tibial fracture managed with a spreading nail in correct alignment, and it may be impossible to decide whether it is nailing, pegging, the interdigitation of jagged fracture ends, or other factors that are mainly responsible for securing the construct. The only important thing is for the surgeon to get a “feel”, early on, for the amount of stress a construct may be expected to withstand. In a written text, only general guidelines can be given. Mastery of this subject can come only from personal experience.

From what has been said above, it should be clear that there is no such thing as “an indication” for intramedullary nailing. One must distinguish between “absolute” and “extended” indications. The former group comprises fractures described below as “very suitable”, i.e. fractures in which nailing is far superior to any of the other techniques; the latter group comprises fractures listed below as “suitable” and “borderline”, i.e. fractures in which nailing should not be expected to produce the full benefit inherently associated with this technique.

Those at the bottom of the learning curve should concentrate on the “absolute” indications. With increasing proficiency, they will undoubtedly be able to extend the range of indications.

While the nail is in the bone, there will be certain changes which must be taken into account. The nail may loosen inside the bone, as early as the first few weeks. Where the nail presses against the inside of the shaft, bone will be resorbed. This

Fig. 9 Lateral break-out of nail from the trochanter mass.

Fig. 10 Multi-fragment tibial fracture.

Fig. 11 Segmental humeral fracture.
reduces the friction between the nail and the bone. However, since bone loss is confined to the sites of maximum pressure, grooves will form in the medullary cavity, which will allow the fragments to slide longitudinally, whilst preventing rotation. Rotational displacement is also prevented by the central callus filling the fracture ends. This creates favourable conditions for the knitting of the fracture, since the nail will act as central rail that will allow the fracture site to be subjected to compressive stresses only.

Obviously, nail loosening during the first few weeks can be detrimental in certain fracture patterns and at certain fracture sites; this fact will need to be duly taken into account.

Any distracting effect of the nail will be immaterial, providing that the construct is stable enough and that the fracture fragments are properly fixed. The gap will be bridged in a surprisingly short time (Fig. 12).

If, however, there is insufficient stability of the nail and insufficient friction between the nail and the bone, distraction caused by the nail may lead to delayed fracture healing (Fig. 13).

Where the nail acts as a peg, the nail tip will progressively gouge a bed in the shorter fragment; sideways break-out of the nail will, however, be prevented by periosteal new bone formation in response to compressive stressing. The fragments cannot settle down and knit; and the extent of the distracting effect of the nail is demonstrated by the fact that, under the conditions described above, nails have been known to start migrating and to work their way out of the bone.

Nail migration is always evidence of insufficient stabilization of the fracture by the nail; and for as long as a nail can be forced out of the construct, a fracture will not have united.

Even an apparently well-seated nail, used in the management of an inherently favourable fracture pattern, may slow down healing and lead to greatly delayed callus formation if but a single mistake has been made. Thus, if a smooth transverse mid-shaft fracture of the tibia is managed with an unduly thin nail, there may, especially in this fracture pattern, be shear movement at the fracture site, which will prevent, or at least greatly delay, the healing of the fracture. Every time the bone is loaded, i.e. with every step, the nail will bend a little, and the upper fragment will slide forwards / the lower fragment will slide backwards, by the amount allowed by the difference between the nail and the medullary-cavity diameters. When the bone is off-loaded, the elastic force of the nail will restore the fragments to their former positions. The distance travelled by the fragments may be as little as 0.5 to 1 mm; however, the shear movement is repeated with every gait cycle, and will suffice to delay, or even prevent, bony union (Fig. 14).

Before a detailed description of the technique, we would like to briefly mention some general points concerning the philosophy of intramedullary nailing.

Since the fracture is nailed “from a long way off”, and since the surgical wound is at most a few centimetres long, there should be very little risk of infection.

Intramedullary nailing is not major, life-threatening surgery. However, it goes without saying that, like other procedures, nailing should not be performed while the patient is in shock.

Minor fat embolism is likely to occur (Maatz). It does not produce clinical symptoms; however, it is obvious that severely compromised patients should not be exposed to this additional risk.

Good callus formation is predicated upon stable “internal fixation” having been obtained by nailing. Bone marrow issuing at the fracture site can lead to very abundant callus formation (Kuntscher); however, that does not mean that the fracture will consolidate well. “Chemical irritation” by the nail metal may provoke extensive turnover in the nailed bone, with abundant periosteal callus formation. This process is undesirable, and may, in fact, delay consolidation (Maatz). This is why the nails should be made of the most corrosion-proof material available.

The rules stated below for the performance of the technique should be scrupulously followed. This is surgery with a high engineering content, which some surgeons may not find congenial. Some cases are easier to nail than others. A surgeon doing intramedullary nailing must always be prepared for the difficult-to-nail cases. The mistake to guard against is to consider a case as “over and done with”, once the procedure as such has been finished. Good intramedullary nailing always involves careful follow-up of the patient, both during and after his hospital stay, in order rapidly to detect and treat any complications that may occur post-nailing. These requirements must be met for this new technique to demonstrate its superiority over existing methods of fracture management.
2. Nails and Instruments

Nails

From the mechanical conditions of intramedullary nailing described above, it will be clear that the intramedullary nails currently available will not ensure "stable internal fixation" in each and every case. The goal is to have the nail lie in close contact with the inner cortex, both at the fracture site and for as great a distance as possible from that site. For this goal to be attained, the nail must have great cross-sectional compressibility, since the calibre of the medullary cavity may vary widely. The required compressibility far exceeds what can be achieved by the most favourable cross-section of the nail at a sufficient metal thickness. This is why there is a need for nails that can spread where required, and may even have lobes that can be made to protrude at the required sites, so as to press themselves into the inner cortex to prevent rotation of the fragments. However, designers of new nail patterns should bear in mind that complex designs are wrong and undesirable. It must always be remembered that the nail must be able to withstand large amounts of mechanical stress; that nail breakage should be an extremely rare event; and that intramedullary nailing should not be the preserve of a few highly skilled specialists, but will be fully justified only if it is mainstream surgery.

The wartime conditions we are experiencing, with the resulting shortage of labour and materials, have been a great obstacle to progress in this field. For the time being, we have to live with the hardware and instruments currently available, regrettable though this situation may be. Undoubtedly, intramedullary nailing will develop further. However, as things stand, it would be neither possible nor useful for each centre that introduces intramedullary nailing to have the complete range of nails available in the immediate future. For the time being, the most commonly required sizes will have to suffice; orders for other items, required for the management of less standard cases, will have to be wired to the manufacturer. This will, obviously, mean a delay of the operation; however, given the times we live in, that is a comparatively minor disadvantage.

Femoral Nails

The cross-section is roughly V-shaped. The sheet metal thickness, chosen for nail stability, has been slightly reduced on the back, so as to allow easier approximation of the two limbs (Fig. 15). This feature provides greater cross-sectional compressibility of the nail. Nails for particularly wide (up to 16-mm diameter) medullary cavities may be made from sheet metal of lesser thickness. This will provide them with significantly greater compressibility.

![Fig. 15 Standard femoral nail](image)

Tapered nail for subtrochanteric fractures.

![Tapered nail for subtrochanteric fractures](image)

The common sizes are:
- For adults: Lengths – 30, 34, 36, 38, 40, and 42 cm. Diameters – 8, 9, and 10 mm (special diameters of 11–16 mm are required fairly frequently).
- For children: Lengths – 24–32 cm (at 2-cm increments). Diameters – 6 and 7 mm.

For the management of subtrochanteric fractures, a tapered nail to fit the medullary cavity at this site has been designed; this nail is intended to prevent the lateral displacement of transverse fractures, and, above all, the shortening that would inevitably occur if an oblique fracture were to be managed with an unduly thin nail (Fig. 16).

In some cases (e.g., refracture, delayed callus formation), the bone to be nailed may contain central callus. In order to obviate, as much as possible, the need for exposure of the fracture site, a nail with saw teeth at its tip may be used (Fig. 17). These teeth will cut a track for the nail as it is being inserted; without these teeth, nailing may prove impossible.

The Y-nail is a 32-cm-long, 10-mm diameter tapered femoral nail of V-shaped cross-section. A slot in the intramedullary nail, angled at 45° to the long axis of the nail, accommodates an I-section nail that is driven into the neck and the head of the femur. The centre of the slot is 8 cm below the head end of the intramedullary nail. The transverse nail is 11.5 cm long; its head end protrudes ca. 2 cm from the intramedullary nail, to obtain firm seating in the cortical drill hole (Fig. 18).

For the management of Fischer & Maatz Group III and Group V pertrochanteric fractures, the intramedullary nail will need to be customized to fit the patient pattern, to ensure that it will be wedged sufficiently firmly in the bone to provide rotational stability (for further details, see section on the Y-nail).

The targeting device for the Y-nail, which allows the nail to be inserted percutaneously, is described in Section 20.

Tibial Nails

The nails in this category are double nails. Their cross-section is U-shaped. They are curved, with a radius of curvature that is less at the ends, and approximating infinity in the middle (Fig. 19).

For adults: Lengths – 24–39 cm, at 1.5-cm increments. Largest diameter – 8 and 9 mm.

For children: Lengths – 15–27 cm, at 1.5-cm increments. Largest diameter – 7 mm.

![Y-nail](image)
Two designs of spreading nail have been used successfully for the management of tibial fractures: the deflect-to-spread nail; and the rotate-to-spread nail. The former is made up of two conventional tibial nails which are spread distally by means of an inclined plane on the outer nail (Fig. 20). The inclined plane (a) and the rear wall of the bone tube (b) provide the deflecting surfaces which make the inner nail veer in a posterior direction. The siting of the inclined plane is crucial to the action of the nail, and has to be carefully chosen on the roentgenogram (see section on Nail Selection). A 32-cm-long and 8-mm-diameter deflect-to-spread nail with an inclined plane finishing at a distance of 6 cm from the nail tip is referred to as a tib-spread 32/6cm/8mm.

The deflect-to-spread double nail is very resistant to bending. This is why it must be used in all fractures distal to the narrowest point of the medullary cavity that have markedly oblique fracture lines or segmental bone loss, especially at the anterior edge, which make the fracture prone to angulation (Fig. 21).

The rotate-to-spread nail also consists of two nails. The outer nail is a standard pattern. The inner nail has a circular cross-section and a lazy-S shape (Fig. 22). The distal end of the nail is inserted in such a way as to place its concavity anteriorly. Next, a screwdriver is inserted into the head of the nail, and the nail is rotated 180°. While the fully inserted inner nail is steadied with a cross-pin or a stay wire to prevent it advancing further down the cavity, the outer nail is driven in.

The rotate-to-spread nail is suitable only for the management of transverse or of short oblique fractures which will not angulate if held together by “pegging”. This device can act only as a “peg”, since the inner nail will be comparatively loose within the medullary cavity, and will be too elastic to adequately withstand any greater amount of lateral pressure (Fig. 23).

Humeral Nails

These nails have the same lengths and diameters as the tibial nails used in children.

Humeral and Tibial Wedges

These devices are intended for the management of fractures of the proximal one-half of these bones. For the time being, only made-to-measure wedges are available (Fig. 24).

Forearm Nails

These nails are of V-shaped cross-section. They are supplied straight, and are contoured by the surgeon to fit the patient’s bone pattern (Fig. 25).

Fig. 22 Rotate-to-spread nail for the tibia. A = outer nail; B = inner nail

Fig. 23 Rotate-to-spread nail for the tibia.

Fig. 24 Tapered supplemental steel nail for the humerus.

Lengths: 10–24 cm, at 1-cm increments.
Diameter: each of the above lengths is available in 3-, 3.5-, and 4-mm diameters. The *special nail* for the management of ulnar fractures close to the elbow has a length of 20 cm; its diameter in the one-third closest to the nail head is 6 mm, while the diameter in the one-third closest to the tip is 3.5 mm. Over the middle one-third, the nail tapers. The head end of the nail is flattened and widened over the final 3 cm (Fig. 26).

**Nail Guide**

*For the femur:* Solid; circular cross-section; for paediatric femoral nails, triangular cross-section. Lengths: 64 cm and 44 cm (for children, 35 cm). Diameter: 3 mm and 4.5 mm (Fig. 27).

*For the forearm:* Length: 25 cm. Diameter: 2–2.5 mm.

The *simple nail* guide is angled at its end. The guide protrudes a few millimetres beyond the handle, to facilitate the use of a hammer for nail insertion.

**Awl**

For use in the tibia, an awl with an offset four-sided tip has proved the most useful pattern (Fig. 28).

*Fig. 25 Forearm-bone nail.*

*Fig. 26 Special nail for ulnar fracture near the elbow joint.*

*Fig. 27 Simple nail guide.*

*Fig. 28 Awl.*

*Fig. 29 Nail driver II for the femoral nail.*

*Fig. 30 Tibial nail impactor.*

*Fig. 31 Slotted hammer.*

**Nail Drivers / Impactors**

*Nail driver I* for the femoral nail is a 20-cm-long section of a femoral nail. It is placed upon the femoral nail when the head end of the nail is level with the top of the nail guide before the guide may be removed.

*Nail driver II* for the femoral nail facilitates positioning the femoral nail in such a way as to have the nail protrude the requisite distance from the greater trochanter. The sleeve is placed over the nail, and pressed down firmly onto the bone. The upper end of the rod which is pushed into the sleeve and onto the nail is marked in centimetres, to show the amount of nail protrusion from the bone. The sleeve is deeply scooped out on one side; this allows the sleeve and the rod to be firmly gripped, to prevent the sleeve recoiling as the nail is being driven in (Fig. 29).

The impactor for the simple tibial double nail facilitates the insertion of the nail, since it allows the hammer blows to be directed along the main axis of the middle portion of the nail, and thus to prevent excessive springiness of the nail (Fig. 30).

For driving home tibial, humeral, or forearm nails, a ca. 10-cm-long, 1.5-cm-diameter metal rod is used as a simple drift.

The most suitable instrument for the extraction of even very firmly seated nails is the *slotted hammer*, which transmits the kinetic energy of the hammer blows directly and in a straight line onto the nail. For the removal of large nails, the long and large hooks are used; small nails are extracted using the short hook (Fig. 31).

The Küntscher extractor shown in Fig. 31 a
combines traction and hammer blows. In order not to damage the bone at the instrument placement site, a spacer with a ball-and-socket joint is interposed. The threaded rod and spring system provides “pretension”, which needs to be reset as the nail is being loosened with hammer blows. The extension is used when the nail is still protruding a long way from the bone.

For the removal from the medullary cavity of the distal portion of a broken straight (femoral, forearm) nail, the same hammer is used with a 75-cm-long extraction hook, known as the nail catcher (Fig. 32). This instrument is introduced into the medullary cavity from the nail entry portal; once it is against the nail fragment, the central space in the nail is located, and the instrument is advanced down that space, with the hook placed in the open slot of the nail. When the hook is past the end of the nail, it is rotated 120° (not 180° – see Fig. 33), and the nail is pulled or tapped out. The nail catcher for the ulnar nail is slightly curved and elastic; the instrument is inserted with the hook facing the closed side of the nail, and the hook is made to engage the tip of the nail as soon as it is clear of the nail. This manoeuvre does not involve rotation.

The **extracting hook** is suitable for easy-to-remove nails (humeral or forearm) (Fig. 34).

The **nail bender** (Fig. 35) allows nails (other than femoral nails) to be contoured as required; it obviates the damage to the polished surface of the device that would readily be caused by the use of bending pliers.

The **stepped scale** (Fig. 36) serves to establish the diameter of the medullary cavity. It is attached to a counterweighted belt, and is placed on the limb with a fracture likely to be manageable with intramedullary nailing, prior to the first roentgenogram. The scale will sit at the mid-shaft level, halfway along the a.p. distance of the bone. The central ray is directed midway between the bone and the scale. Each step of the scale is 2 millimetres wide.

The **dressing frames** (Figs. 37 and 38) for the thigh and the leg, respectively, are intended to facilitate asepsis. They provide a 4-cm-high “screen” between the sterile and the non-sterile areas, leaving only a small area of skin exposed, which will accommodate the small incision required by this technique.

The **reduction apparatus** (Maatz) is used, as its name implies, for the reduction of the fracture fragments (Fig. 39). It is, as it were, an extension of the reducing assistant’s arms. It is placed on the floor, without any link to the fracture table. Since the forces acting on the limb roughly cancel out, the apparatus does not need attaching to the floor: friction between the device and the floor will be sufficient to prevent it tumbling over. A first approximate setting places the grasping arms at the desired level. A universal joint transmits the movements of the lateral handles in the sense of the movements applied to the handles; a gearing system reduces the force required on the handles, but also reduces the movement of the grasping arms. The reduction apparatus allows impacted fragments to be disimpacted, circumducted, and reduced, in the most suitable pattern, as required by long oblique and by spiral fractures. Crepitation of the bone faces in contact with each other is transmitted so well by the system that it can be felt by the manipulator of the apparatus. Reduction in each plane can be locked in with a screw. This is of particular importance in transverse fractures and in the case of oblique fractures that have been overdistracted.

The semicircular grasping arms are exchangeable to fit the thickness of the limb. The leather strap, which has two large openings, is pulled over the grasping arms in such a
way as to form a complete ring, with half the ring (at any diameter) made of metal, and the other half of leather. This will ensure that the limb is firmly gripped. The straps have to be tightened very firmly, since any slack would reduce the efficiency of the reduction apparatus movements. The grasping arms have a joint that allows them to be rotated, so as to place them roughly at right angles to the long axis of the limb, leaving the fracture site unobstructed at fluoroscopy.

Fractures (such as supracondylar femoral fractures) that require great force for their reduction cannot be reduced with this apparatus. They are preferably dealt with using commercially available block-and-tackle systems mounted on wall and ceiling hooks.

Other reduction systems have been devised by Herzog, Linsmayer, Zottl, and Wittmoser.

3. Indications, and Details of Aftercare

Patient selection may be more liberal, or more restrictive. The following policies are conceivable:
1. If a fracture is “nailable”, it will be nailed.
2. Nailing will be done only in patients that are at particular risk if kept at bedrest, in a cast, or on traction.
3. Nailing will be performed to manage fractures that are notoriously difficult, such as smooth transverse fractures, which frequently malunite with lateral displacement and tend to refracture.
4. Nailing will be performed to manage fractures which can be reduced, but which cannot be maintained in reduction since the fragments tend to redisplace repeatedly. In such cases, open reduction would be indicated, and the rationale for intramedullary nailing would be the avoidance of open fracture treatment, with all its attendant risks and liabilities. Such cases are encountered comparatively frequently.

5. One particular indication is the management of spontaneous fractures of bones containing tumour metastasis. For some reason, the majority of these fractures are subtrochanteric. Since neither irradiation nor other treatments will produce union, the patients concerned will be bedfast and in a plaster cast for the rest of their lives. If managed with an intramedullary nail, these patients would at least be comfortable in bed, and may even become ambulatory again, even if there is no prospect of the fragments knitting.

Given the spectrum of indications described above, a surgeon wishing to practise this new technique could start with those patients who would be the most obvious candidates, and extend the procedure to other patient categories as his experience increases. Since its introduction, intramedullary nailing has proved so beneficial that one may safely state that if a fracture can be nailed, it should be nailed. Now that this technique is available, the question is no longer one of which fractures cannot be managed conservatively, but of which fractures cannot be nailed.

Children constitute a special patient category. Their fractures heal rapidly, and there is no risk of joint stiffening; there is no major concern over immobilization in a plaster cast and bedrest; and it is amazing to see how minor degrees of malunion will eventually remodel and correct spontaneously. For these reasons, patient selection should be the more restrictive the younger the patient is. In toddlers, the only fracture that should be nailed is the smooth transverse fracture of the femur that cannot be reduced with gallows traction. However, the older the child, the more readily one will opt in favour of intramedullary nailing, to shorten the period of recumbence, the inpatient stay, and the disability time; although, for the reasons given above, patient selection will always be more restrictive in the paediatric than in the adult population. Technically, there is no contraindication to the use of intramedullary nails in toddlers.

The following discussion is based upon the proposal that any fracture that can be nailed should be nailed.

The nailability of a fracture will depend upon the shape of the long bone as well as upon the site and the pattern of the fracture. In many cases, the situation may be quite complex, and there are no definite cut-offs between suitability grades; this is why fractures are best classified as

“very suitable”
“suitable”
“borderline”
and “unsuitable”.

It should be borne in mind that these guidelines reflect the present state of the art; however, we hope and trust that, as the technique develops, significantly more fracture patterns will move into the nailable categories. At present, strict criteria need to be applied, since intramedullary nailing is a newcomer that seeks to outst other, tried-and-tested techniques.

Intramedullary nailing is ruled out in all intra-articular fractures, since the nail may force apart fragments that are still in reasonable contact; the device will not be able to obtain an adequate purchase; and the joint may be at risk from nail intrusion. The only exception to
this rule is the condylar T-fracture of the distal femur. This pattern is dealt with elsewhere in this treatise.

A fracture’s suitability for nailing is not only dependent on the extent to which the nail can wedge positively and firmly in the bone ends; other factors may also be important. This fact is well illustrated by supracondylar fractures. Conditions for sound nailing are extremely adverse, since the nail will be a peg, with a very small diameter, protruding into the very wide medullary cavity of the distal fragment, which makes supplementary casting mandatory. And yet, there is no better treatment modality, since none of the other techniques available can fasten the fragments together as efficiently as intramedullary nailing can.

This is why the indication for nailing must be considered in the light of each patient’s affected limb and fracture pattern. Since the conditions that govern a fracture’s suitability for nailing also affect the nature of the post-nailing management, a brief outline of the recommended aftercare will be given together with the indications, in order to avoid unnecessary repetition. However, the wider aspects of aftercare are discussed in a separate section of this treatise.

A. Femur

The adult femur is, roughly speaking, a bone tube of uniform internal diameter. A straight nail can be introduced from the greater trochanter. In other words, conditions for nailing are ideal.

(a) Pertrochanteric fractures
    “unsuitable” because the head end of the nail would not obtain a sufficient purchase in the proximal part of the trochanter. Suitable for nailing with a Y-nail (see page 19).

(b) Subtrochanteric fractures
    “very suitable” Secure against angulation. Minor lateral displacement can be prevented by the use of a tapered nail.

Stabilized against rotation, since the V-shaped design allows firm seating of the nail in the cancellous bone of the proximal trochanter; while, in the distal part, sufficient friction can be obtained.

No supplementary support required. Weight-bearing not before the end of Week 3, since premature loading may make the nail back out laterally, through the cancellous bone of the proximal part of the trochanter.

(c) Transverse fractures and oblique fractures
    with a short-fragment medullary cavity providing at least 8 cm of “nail-suitable” medullary cavity
    “very suitable” Secure against angulation, lateral displacement, and shortening. Risk of rotation will depend on the amount of friction between the nail and the bone; little risk if jagged ends interdigitate, and with oblique fractures; greater risk with smooth transverse fractures. Supplementary support required only in the event of incipient rotation. Immediate weight-bearing may be allowed.

(d) Spiral fractures
    “suitable” Secure against angulation and lateral displacement. Shortening will occur with rotational malalignment, since the smooth fragments will slip past each other when loaded.

Supplementary support required only in the event of incipient rotation.

No weight-bearing before the end of Week 3.
(e) Butterfly, segmental, and comminuted fractures

1. Large fragments with a bone defect on one side only
   “very suitable”
   Lateral displacement ruled out. Secured against angulation only by the stability of the nail. Shortening impossible, since the large fragments are continuous across the fracture line on one side. Malrotation very likely, since no interdigitated ends, and since rotational stability provided only be friction between nail and bone. Supplementary support required only if there is a risk of malrotation.
   Immediate weight-bearing may be allowed.

2. Non-comminuted third-fragment
   “very suitable”
   Conditions as described under (c).

3. Comminuted fracture
   “suitable”
   Secure against lateral displacement. Secured against angulation only by the stability of the nail.
   Great risk of shortening and malrotation, since rotational stability provided only be friction between nail and bone. (See also Gunshot Fractures.) Supplementary support, possibly skeletal traction, will probably be required.
   Weight-bearing once sufficient callus has formed.

(f) Supracondylar fracture
   “very suitable” since poorly manageable with other techniques.
   The nail prevents the short fragment tilting into flexion. Minor displacements in all directions may occur, since the nail constitutes a peg in

an excessively wide medullary cavity. Optimal reduction should be the goal.
   Supplementary support (long-leg cast, if need be Braun frame) for four weeks, in all cases. Weight-bearing after six weeks.

(g) Supracondylar fracture with separation of the condyles (Y- or T-fracture)
   “unsuitable” for fixation with a standard intramedullary nail. Since management with currently available techniques is very difficult and outcomes are uncertain, these fractures should be managed using a special nail.
   The younger the individual, the more adverse the conditions for femoral nailing will be in the femur, since, during growth, the medullary cavity is markedly constricted at the mid-shaft level. This fact must be borne in mind in patient selection and in the aftercare. Patterns suitable for nailing are confined mainly to fractures of the middle-third of the femur. This is not a major problem, since the majority of paediatric femur fractures are in that region.

B. Tibia

Compared with the femur, conditions for nailing are markedly more adverse, even in adults. The medullary cavity is considerably waisted at the mid-shaft level; the nail has to be curved, since it is introduced from a lateral entry portal; and, for the same reason, the device has to have a degree of flexibility and elasticity that may very adversely affect the stabilization of the fracture. Since the nail has to be inserted from an anterolateral portal, it has to be anteriorly concave. Middle-third tibial shaft fractures have a pronounced inherent tendency to displace into recurvation. Since the nail has to be curved, however slightly, in the same direction, it may, very frequently, be unable to control the forces producing a displacement of the fracture into recurvation. This is why this displacement – the most common of all the patterns encountered in the tibia – will need to be looked for in all cases, throughout the entire postoperative treatment period. Even casting will not protect a nailed fracture against this displacement: unless the cast is changed in good time, the tibia will be able to curve backwards as the calf muscles atrophy in the cast. A minor degree of recurvation should not cause impairment.

Given that conditions are adverse, patient selection and aftercare must obey certain specific rules. The minimum length of the short fragment cannot be specified in centimetres, since everything depends upon the shape of the medullary cavity. If there is much difference between the smallest and the greatest cavity diameter, i.e. if there is a major mismatch between the diameter of the nail and the width of the medullary cavity, the fractures that can be nailed will be concentrated around the mid-shaft level. Nailability ceases where
the difference between the cavity diameter (m) and the nail diameter (n) is equal to or greater than the thickness of the cortex (k), in which case the fragments will no longer be held in apposition, but can topple off each other (Fig. 49).

Fig. 49 The crucial parameter in tibial fractures is the relationship of the nail diameter (n) and the medullary-cavity diameter at the fracture site (m) to the thickness of the cortex (k):

where \( m - n \leq k \), the fracture is “suitable” (depending on the fracture pattern); where \( m - n > k \), the fracture is “unsuitable”.

It is strongly recommended that these fracture parameters be accurately measured, to determine a fracture’s suitability for nailing. Preferably, this should be done by using the magnified image on the roentgenogram. The required nail size will be indicated by the stepped scale.

The use of a spreading nail will allow more fractures to be selected for nailing, albeit in the distal tibia only. However, in this region substantially more fractures will be candidates, the only unsuitable patterns being the ones that involve the joint. At the proximal end, the use of a wedge inserted between the inner and the outer nail may make some fractures suitable for nailing.

Experience with these new nail patterns has been so encouraging that the guidelines below refer mainly to the use of the spreading nails. Surgeons new to the technique would be well advised to use these devices: the simple double nail has too many disadvantages.

1. Proximal-third fractures

The suitability for nailing of proximal-third fractures will depend on the ratio of the nail diameter to the medullary cavity width. There are two possible patterns:

(a) The difference between the medullary cavity diameter and the nail diameter is equal to or greater than the thickness of the cortex. In that case, all fracture patterns are “unsuitable” for fixation with the standard double nail.

Inherently, a transverse fracture would be the most favourable pattern in this group, whereas all the other fracture patterns have additional adverse features. This is why the unsuitability for nailing of \( m - n \geq k \) fractures will be explained using the example of a transverse fracture (Fig. 50).

The fragments are secured against rotation only, but may displace in all the other directions. As the nail is being impacted, it will drive the distal fragment backwards. Even with a very large radius of curvature in the upper part of the nail, this displacement will be very difficult, if not impossible, to correct once the nail is in situ. However, even if the second attempt at reduction is successful, the nail will not protect the fragments against redisplacing. Even if the fragments do not displace, they will not be adequately stabilized by the springy nail lying virtually “loose” in the medullary cavity; and the nail will not be able to neutralize the considerable displacing forces that act at the fracture site. These forces adversely affect bone healing—witness the fact that it is at this site that fatigue fractures are seen. This fracture can be made suitable for nailing only by the use of a wedge driven in between the inner and the outer nail. This produces a “pegged” construct, which places the fragments in correct alignment and protects them against angulation.

(b) The difference between the medullary cavity diameter and the nail diameter is less than the thickness of the cortex.

(a) Transverse fractures (proximal third)

\((m - n < k)\)

“borderline”

The fragments cannot tilt off each other (Fig. 51). Rotation is prevented, in the proximal fragment, by the lateral track of the nail; and, in the distal fragment, by friction between the bone and the nail. Interdigitation of jagged fracture ends is likely to be an additional factor.

The fracture is rated “borderline” because the nail–bone friction near the fracture site is insufficient for the stabilization of the fracture, which means that rapid bony union cannot be achieved without the use of supplementary support.

A long-leg cast will be required. The patient may be mobilized out of bed immediately after casting.

This fracture may be soundly “nailed” by using a wedge driven in between the inner and the outer nail.

(b) Oblique fractures (proximal third)

\((m - n < k)\)

“borderline”

There will always be lateral displacement and shortening, albeit it to a negligible extent (Fig. 52).

The construct will be protected against all other displacements by the great friction between the bone and the nail (at x). This will also adequately stabilize the fracture site.

No supplementary support required.

Mobilization out of bed at the end of Week 3.

The use of a wedge is recommended.
(c) Spiral fractures (proximal third)
(m–n < k)
“borderline”

The conditions are the same as those for oblique fractures (2b); however, there is also a strong torquing force, which cannot be entirely neutralized by the nail because of the excessive distance between the proximal nail track and the site of sufficient friction between the nail and the bone in the distal fragment (Fig. 53).

Supplementary long-leg casting required. Mobilization of the casted patient not before the end of Week 3. The use of a wedge is recommended.

(d) Butterfly fractures (proximal third)
(m–n < k)
“unsuitable”

The detachment of a large, or even a small, fragment of bone abolishes the one factor that makes proximal-third fractures reasonably good candidates for nailing: the apposition of the fragments in correct alignment. The fragments will slip, or, if they do not, they will be poorly supported on the wide side of the third fragment; and since the nail will not be supported by bone, it will not be able to stabilize the fracture, and angulation will occur (Fig. 54).

(e) Comminuted fractures (proximal third)
“unsuitable”

These fractures present an even more severe form of all the unfavourable conditions described under butterfly fractures.

2. Middle-third fractures

Since the diameter of the medullary cavity will be the same, or approximately the same, as that of the nail, all fractures in this part of the tibia will be suitable for nailing. Owing to its cross-sectional compressibility, the nail will fit snugly into the medullary cavity of both fragments, and adequate friction will be obtained.

(a) Transverse fractures (middle third)
“very suitable”

Lateral displacement and shortening cannot occur. Angulation is unlikely, since the nail is stably seated, and, above all, since the fragments are apposed in correct alignment.

Rotation will occur only if the interdigitation of the fragment ends fails, and if there is insufficient friction between the nail and the distal fragment – in other words, rotation will be the more likely the further distal the fracture site is.

Generally, supplementary casting will not be required.

Mobilization from the end of Week 3. The recurvation observed not infrequently even in this fracture pattern can be prevented by the use of a rotate-to-spread nail.

(b) Oblique fractures (middle third)
“very suitable”

Optimal stabilization by all the factors mentioned under transverse fractures (2a). Additionally, there will be increased friction as a result of the axial compression of the fragments at x, and enhanced protection against rotation, since rotation could not come about without distraction, a process that is prevented by the action of all the muscles in this region of the leg.

Generally, supplementary casting will not be required.

Mobilization from the end of Week 3.

(c) Spiral fractures (middle third)
“suitable”

Secure against lateral displacement. The chief risk is rotation, since the smooth surfaces of the fracture ends will tend to slide against each other, and since this tendency is prevented only by the friction of the nail in the distal fragment. Rotation will be accompanied by shortening.

Generally, casting will not be required. Mobilization not before the end of Week 5.
(d) Butterfly fractures (middle third)
“suitable”
The butterfly fragment is usually on the anterior aspect; posterior or lateral butterfly fragments are less common (Fig. 58).

While these patterns will be protected, by nailing, against lateral displacement and shortening, there will be little protection against rotation, since the fragments will be unlikely to have interdigitating ends. The main problem is that these fractures have a great tendency to go into angulation, at the site of the bone defect. The tibial nail is not sufficiently stable to reliably prevent angulation. The situation is particularly unfavourable in patterns with an anterior butterfly fragment, since the curvature of the nail will encourage displacement into recurvation.

Where a simple double nail has been used, supplementary (short-leg) casting will almost always be required.

Weight-bearing (in the cast) as dictated by the fracture pattern; no weight-bearing before the end of Week 3. Better stabilization may be obtained by the use of the deflect-to-spread nail; where this device is used, no supplementary support will be required.

Segmental fractures of the tibia (Fig. 59), with a longer or shorter third fragment situated between two transverse fractures, are prime candidates for intramedullary nailing. The middle fragment is taken onto the nail. If the two fractures are in the favourable region of the tibia, conditions will be optimal. If one of the fractures is in an unfavourable region, this disadvantage is readily acceptable: at least one fracture site will be held in correct alignment. The other site will be protected, by supplementary casting, against unacceptable displacement of the fragments. In this way, nailing will still be of superior benefit in the management of these fractures. Depending on the site and the pattern of the fracture, a wedge or a spreading nail may be used to stabilize these fractures, too, without any need for supplementary casting.

(e) Comminuted fractures (middle third)
“borderline”
These fractures can be adequately stabilized only by the strength of the nail.
Lateral displacement is ruled out. All other forms of displacement must be prevented with a short- or a long-leg cast.

Weight-bearing must not be resumed prior to the formation of sufficient callus, since otherwise the fragments may telescope.

In all comminuted fractures, a deflect-to-spread nail should be used.

3. Distal-third fractures

Here, too, a fracture’s suitability for nailing will depend on the amount of medullary cavity-to-nail diameter mismatch. This is why, in this part of the tibia, a spreading nail will be vital: the splayed pattern at the distal end of this double nail can provide a substantially greater overall diameter than the narrowest point of the medullary cavity at about mid-shaft level. While simple double nails can be used only for the management of transverse fractures with interdigitating ends, above the level where m–n is less than the thickness of the cortex, the spreading nail will, in many other cases, allow nailing with a good prospect of a successful outcome. This is why the discussion of the management of lower-third fractures in this section presupposes that the device used will be a spreading nail.

(a) Transverse fractures (distal third)

Shortening is not possible. Protected against lateral displacement by the nail; against rotation by interdigitating ends, possibly also by the nail; against angulation by the compression of the fragments by the surrounding muscles, and possibly also by the nail.

No supplementary support required.

Mobilization after the end of Week 2. The use of a rotate-to-spread nail is recommended.

Fig. 61 Transverse lower-third tibial fractures:
\( m–n < k \) “borderline” for standard nail; “very suitable” for rotate-to-spread nails.
\( m–n > k \) “unsuitable” for standard nail; “very suitable” for rotate-to-spread nail.
(b) Oblique fractures (distal third)

I. Fracture sloping obliquely downwards, from medial to lateral or vice versa.

(a) Difference between medullary cavity and nail diameters greater than thickness of the cortex: “unsuitable” for simple double nail, since displacement may occur in all directions. The deflect-to-spread nail will secure the fragments sufficiently, providing that the spreading plane is in the coronal plane (see Nail Insertion).

(b) Difference between medullary cavity and nail diameters less than thickness of the cortex: “Suitable”. Only one type of displacement is possible: sideways displacement with shortening. The displacement will be minor, and once it has occurred, the nail will wedge firmly in the bone. Any further lateral displacement will be prevented by the nail; angulation will be ruled out by the apposition of the fragments; and rotation will be prevented by the interdigitigation of the jagged ends as well as by the surrounding muscles, which counteract distraction.

Casting not required. 
Mobilization after end of Week 3. 
Deflect-to-spread nail recommended.

II. Fracture sloping obliquely downwards in an anterior or a posterior direction

Without a spreading nail, the situation is as described under I. Where a spreading nail (deflect-to-spread pattern) is used, the overall diameter of the two nails will suffice in all cases to prevent tilting of the fragments. In this case, the remarks made under I(b) will apply. The more tightly the outer nail is pressed against the anterior cortex, and the inner one against the posterior cortex, the better the fragments will be secured against slipping.

Casting not required.
Weight-bearing after end of Week 3.

(e) Butterfly, segmental, and comminuted fractures (distal third)

In a few cases, the nail may be useful by providing lateral support for a large fragment, securing it against major displacement. However, the chances of this happening cannot, as a general rule, be judged by the preoperative roentgenogram, which means that the outcome of nailing would be completely unpredictable. Also, the majority of distal-third multi-fragment fractures will involve the ankle joint or be associated with fractures of one or both malleoli. In such cases, nailing would be contraindicated because of the risk of intra-articular damage; and pointless, since ankle fractures would in themselves mandate casting.

C. Humerus

A straight nail cannot be inserted into the humerus without endangering the shoulder joint. The introduction of an elastic flexible nail can be performed from the proximal or from the distal end of the medullary cavity, using a lateral entry portal. As a result, patient selection can be very liberal, since a short fragment can be picked up with the nail, both close to the elbow joint and close to the shoulder joint, so as, at least, to prevent the slipping of the fragment.

This is why all fractures that have at least a few centimetres of medullary cavity in the short fragment will be “very suitable”, since there is no better method to keep the fragments from slipping. At the proximal end, the nail tip may be driven into the cancellous bone of the humeral head, to enhance the fixation. In this way, surgical-neck fractures can be very efficiently managed with an intramedullary nail.

The site and pattern of the fracture are important only for the choice of the nail entry portal (antegrade or retrograde nailing), and for the aftercare of the patient. Since the nail has to be introduced through a lateral portal, nailing will rarely be “ideal”: more often than not, the nail diameter will not be adequate for strong friction between the nail and the bone to be obtained over great distances (see general considerations). For this reason, there will be many cases in which the nature of the post-nailing management can be decided only after nailing has been performed. The most important sign of insufficient stability of the construct is continuing pain once the initial wound pain has subsided: minor movements at the fracture site cannot be detected by any other means.

The aftercare programme to be adopted will also be a function of the age of the patient. In children and young people, the arm may safely be immobilized in a sling and swathe. In adults, and especially in the elderly, this treatment would carry a risk of joint stiffening, and an airplane splint or airplane cast would have to be used.

Experience has shown the risk of rotational displacement of the fragments to be very slight; only rarely will this risk require special consideration. It would appear that the highly mobile shoulder joint will get out of the way sufficiently for rotational displacement at the fracture site to be prevented.

It would be difficult and unproductive to discuss all the humeral fracture patterns. This is
why only a few examples will be given here. The points made can easily be applied to the patterns not specifically mentioned in this section.

From the point of view of nailing, the arm is usefully divided into four quarters, with the first quarter closest to the shoulder joint.

(a) Third-quarter transverse fracture

“very suitable”

Nailed retrogradely, in order to give the nail an optimal purchase in the shorter fragment. Very favourable conditions, since, despite its inevitably insufficient diameter, the nail will be in multi-point friction contact with the wall of the medullary cavity, and will thus adequately stabilize the fracture. Such angulation as may occur will be negligible.

Supplementary support not required.

Exercise physiotherapy may be started immediately.

Fig. 66 A transverse third-quarter humeral fracture is managed with retrograde nailing.

(b) First-quarter transverse fracture

“very suitable”

Nailed retrograde, since that is the only way in which fracture site exposure can be avoided, and since the hold of the nail tip will be enhanced by impaction into the cancellous bone of the humeral head.

Supplementary support will rarely be required.

Exercise physiotherapy may be started immediately.

Fig. 67 A transverse first-quarter humeral fracture is managed with antegrade nailing.

(c) Fourth-quarter transverse fracture

“very suitable”

Nailed antegrade, since the distal fragment would be too short. Secured against lateral displacement, and probably against rotation. Nail diameter must be much smaller than the diameter of the medullary cavity; and the nail must not extend to the distal end of the cavity, so as not to cause distraction. The nail is intended to act as a peg, preventing only lateral displacement.

Airplane cast for three weeks; at the end of this time, the cast is bivalved and active arm exercises are initiated.

Cast removal at the end of Week 5.

Fig. 68 A transverse fourth-quarter humeral fracture is managed with antegrade nailing.

(d) Second- or third-quarter comminuted fractures

“suitable”

Nailed retrogradely or antegrade. Fracture protected against lateral displacement, and probably also against rotation. Stabilization by the nail is sufficient, since angulating forces are not strong. Equally, little likelihood of shortening, since axial compression forces are not major.

Supplementary support (airplane cast) not always required, but strongly recommended in all cases.

D. Forearm bones

With forearm-bone fractures, patient selection and aftercare are comparatively straightforward, which is why a statement of the general rules should suffice.

All fractures with at least a few centimetres of medullary cavity in the short fragment that will allow the nail to wedge in them are suitable for nailing (Fig. 70). In the radius, fractures down to, but not including, the level of a Colles fracture may be nailed; in the ulna, the limit of nailability is very proximal, near the elbow joint, since the nail will obtain a purchase in the cancellous bone of the olecranon. If both forearm bones are broken, both should be nailed. Supplementary casting will be required very rarely if, regardless of the level of the fracture, the nail runs the full length of the medullary cavity. Both the radius and the ulna have a roughly conical medullary cavity. Adequate nail–bone friction can be obtained only by using a very long nail. Even though the displacing forces are not very strong, the use of too short a nail will surprisingly often result in nail back-out at the olecranon or at the styloid process of the radius. Since the nailed bones splint each other, angulation is very unlikely to occur.

Fig. 69 A comminuted second- and third-quarter humeral fracture is managed with antegrade or retrograde nailing.

Fig. 70 Zone of nailability in the forearm bones.
Examples:

(a) Transverse fractures at mid-forearm level

“very suitable”

Friction between the nail and the bone, interdigitation of fracture ends, apposition of fragments in correct alignment, and mutual splinting, will protect against all forms of displacement.

Supplementary casting not required.

Exercise physiotherapy may be started immediately.

Fig. 71 Transverse mid-shaft fracture of the forearm bones: “very suitable”.

(b) Forearm-bone fractures near the elbow joint

“very suitable”

The radius is nailed in customary fashion. For the ulna, a special nail, with considerable reinforcement of the proximal third, is required, since this fracture involves strong bending forces which have to be neutralized by the nail alone. A short thick nail is not useful, since friction in the long fragment would be inadequate and the nail would tend to back out. The special nail also has a very broad head end (see page 22).

Fracture secured against all forms of displacement.

Supplementary casting not required.

Fig. 72 Forearm-bone fractures near the elbow joint.

Exercise physiotherapy may be started immediately.

E. Clavicle

There will be few cases requiring nailing of the collarbone, since virtually all clavicular fractures can be managed with bracing, which will result in rapid and sound union. If it is decided that the clavicle should be nailed, it must be remembered that many collarbones do not have a sufficiently large medullary cavity. In such cases, the nail track will need to be reamed, and reduction will almost invariably involve exposure of the fracture site.

Fig. 73 Nailing of the clavicle.

4. Timing and Preoperative Treatment

As a general rule, nailing will be the more straightforward the less time has elapsed since the traumatic event. At any rate, care must be taken to prevent excessive muscle shortening, which might make it impossible to apply traction, even with considerable force, and foil attempts at reduction. This is particularly true in femur fractures. Reduction is easiest in the first few hours following the accident. At this stage, it tends to be very straightforward. If, for whatever reason, surgery has to be postponed by a few days, wire traction should be applied in cases of femur fractures. Skin traction is insufficient, and is not infrequently a cause of pressure ulcers. Ulceration is all the more likely since the most frequent reason for the postponement of nailing is shock. Nailing must not be performed while the patient is in shock. This is in keeping with the general rules of surgery. Nailing must not be done either in patients who have only recently recovered from shock, since it is never an emergency procedure. Even shortly after recovery from shock, the patient will still be at considerable risk.

Minor pulmonary fat embolism is to be expected (Maatz). It is so slight that in patients in good general condition, without major associated trauma, at the time of nailing, we have never observed any clinical evidence of pulmonary embolism post-nailing. However, in high-risk, multiple-fracture patients, even these minor embolisms may be life-threatening, which is why these patients must not on any account be exposed to the additional surgical shock and to the additional risk of fat embolism entailed by nailing. If, because of the nature of the injury, and because of major soft-tissue swelling and bruising, it must be assumed that there has been unusually extensive fatty-tissue contusion in the thigh, the fracture must not be nailed, even if there is no evidence of fat embolism. Nailing involves a certain degree of movement and of rough handling of the tissues. This can result in the massive release of fat globules into the circulation. The introduction of a foreign body into
the medullary cavity would appear to be a factor of lesser importance.

If a closed femur fracture cannot or must not be nailed on the day of the accident, wire traction is applied.

This minor procedure will greatly facilitate reduction, and will make the patient more comfortable during the waiting period.

Where an older femur fracture has undergone much shortening prior to surgery, wire traction will be mandatory in the preoperative period. Even in fractures several months old, with greatly displaced fragments, continuous skeletal traction over a few days should allow the restoration of thigh length.

Tibial, humeral, and forearm fractures may be “kept” on a Volkmann or a Kramer splint. Tibial fractures, too, should be nailed early on. The procedure will be easier before major swelling has occurred; blistering is very uncommon after nailing; and the sooner the fracture is ideally reduced by nailing, the rarer cases of pressure necrosis will be.

5. Anaesthesia

The type of anaesthesia to be used will depend upon the foreseeable time for surgery, and upon the degree of urgency of complete muscle relaxation to obtain reduction. Femur fractures cannot be nailed unless the muscles are relaxed. In these cases, lumbar anaesthesia has proved very useful. Children, adloescents, and adults under the age of 40 are anaesthetized with ether, since, in these age groups, lumbar anaesthesia still carries an unnecessary risk for the patients. For tibial, humeral, and forearm nailing, light anaesthesia with short-acting hexobarbitone (Evipan®) is usually sufficient; if required, this may be followed by ether. Children are, again, managed with ether only. Since, generally, early recovery of muscle tone is desirable (see Aftercare), anaesthesia should not be deeper or more prolonged than absolutely necessary. This should be borne in mind in the choice of anaesthetic technique; in all other respects, the policy of the individual centre should be followed.

Experience with local anaesthesia remains confined to forearm-bone nailing, where infiltration of the nail entry portal and the fracture site have been found to suffice. There is insufficient knowledge of the sensitivity to pain of the medullary cavity. Some patients report no pain at all, while others complain of intense pain.

6. Patient Positioning and Fracture Reduction

Positioning must be such as to allow reliable traction, ready insertion of the nail, and as much room as possible for the fluoroscopy and reduction equipment. This is why the limb should be positioned with all-round access, rather than on a traction frame. Hooks mounted on the walls and ceiling, and a block-and-tackle system, are extremely useful. Proper patient positioning, with reliable traction, is of the utmost importance.

Before going into details of the different positioning patterns and of the devices and manoeuvres required, we wish to make some general points regarding fracture reduction. Manual reduction in front of the fluorescent screen may be permissible in isolated cases. However, it would cause radiation damage to the hands were it to be practised consistently. Quite apart from this consideration, there are cases in which reduction of the fracture fragments requires greater lateral force than can be produced by hand. It would be particularly difficult, during fluoroscopy, to maintain the reduction achieved in one plane, while performing manual reduction in the other plane. This is why special devices are required. Obviously, the simplest means consists of two straps pulled on by one or more persons each, to produce traction and countertraction. In very many cases, these straps will be perfectly adequate. However, in order to consistently obtain reduction, something more sophisticated will be required. The reduction apparatus described above has proved its worth in clinical practice (Fig. 74). Its handling is very straightforward. Its grasping arms are, as it were, an extension of the reducing assistant’s arms, except that the system is geared in such a way as to apply greater force with less movement of the grasping arms. Reduction obtained in one plane can be locked in with a screw, and maintained while the fracture is being reduced in the other plane. The device does not require brute force; instead, it permits the delicate release of locked fragments, “circumduction” of the fragments for reduction from the most favourable side for the particular fracture pattern, etc. The operation of the system is described in greater detail in the Nails and Equipment section of this treatise; intending users of the device would be well advised to study the short list of instructions. The device can be used in all cases except for those in which sufficient distraction of the fragments cannot be obtained, and in those requiring very strong forces for fracture reduction.

In such cases, or in the absence of a reduction apparatus, a block-and-tackle system can render useful services. Femur fractures near the knee joint may require so much sideways traction to overcome the flexion of the short fragment that a block and tackle is the only...
the system that will produce the necessary force. If sufficient traction force cannot be applied to the limb, it may be possible to appose the fragments only in considerable angulation at the fracture site, using the principle described under Osteotomy (Fig. 75). However, since the site of a closed fracture should preferably not be exposed, strong rope traction with decreasing fracture-table traction, followed by even stronger countertraction with slightly decreasing rope traction and slowly increasing fracture-table traction will need to be used. Manual attempts would be fruitless. The manoeuvres require a well-trained team of assistants. Success will depend on absolutely correct lines of traction and countertraction. This is why the operating theatre walls and ceiling should be fitted with an ample number of hooks.

Reduction should be performed when the nail guide or the nail are about to enter the distal fragment. This shortens the period of soft-tissue contusion, quite apart from the fact that, in certain cases, the nail protruding from the bone can constitute a useful handle to assist the repositioning manoeuvre.

Patients with femur fractures are positioned on their side (Fig. 76), with the uninvolved limb lowermost. The hips are in moderate flexion. This positioning pattern dispenses with the need for extreme adduction of the thigh, and even allows nailing in abduction. This is of particular importance in patients with a stiff hip joint. The lower limbs, in particular the uninvolved one, are abducted. This makes for easy traction, reduction, and fluoroscopy. With a little skill, the positioning pattern should be obtainable on most fracture tables. The important point to remember is that both limbs must be attached to the same traction bar of the table, or that both bars must be towards the same side. A very wide pelvic support, to facilitate side-lying, is recommended. A stockinet tube stuffed with cotton wool is placed around the hip on the involved side and attached to the side of the table top, towards the head end; a spring balance is inserted between the stockinet tube and the table. This balance gives a rough idea of the traction force acting at the fracture site. With correct pretreatment (early surgery or prior wire traction), the force will rarely need to be in excess of 60 kg. Traction is provided via a Böhler canvas boot. It must be remembered that, as traction starts, the patient will be pulled towards the foot end of the table; therefore, he will need to be positioned further towards the head end of the table before traction is commenced.

One X-ray tube is placed between the patient’s legs, the other at the extensor aspect of the thigh, with the reducing assistant working on the flexor side.

Next, reduction is performed as described earlier in this section, as the nail guide is about to enter the medullary cavity of the distal fragment. Some cases will require a different technique. If the fracture is very close to the hip joint, only one grasping arm of the reduction apparatus will be applied, to control the long fragment, while the short fragment will be manipulated by the surgeon grasping the nail that has been inserted into the fragment. In segmental fractures, it may be useful to employ the reduction apparatus and the block and tackle simultaneously, so as to optimally steady the middle fragment.
For all-round access to the tibia, the patient should again be placed on a fracture table (Fig. 77). The patient is positioned supine, with the involved leg on a support. The knee is in 45 degrees of flexion, the leg is placed in horizontal traction. The long tray of the leg support is placed against the thigh, so as to leave the leg free. Countertraction is not required. Traction is provided via a Bohler canvas boot. This provides ample space for the X-ray tubes and the reduction apparatus. The uninvolved leg is allowed to hang down vertically.

In the absence of a reduction apparatus, or if greater force is required (e.g. in cases of old fractures, or where a spreading nail is to be used), a modified Bohler traction system is strongly recommended. The device is supplemented by the addition of a few longitudinal bars that take sliding hooks (Fig. 78). Small straps and a block-and-tackle system capable of working in four planes (in general, only two planes will be required) allow safe and easy reduction to be obtained. As a means of overcoming major resistance, of the type that may be encountered in old fractures, this system is superior to the reduction apparatus. Accommodating the fluorescent screen is difficult; this is why a small screen will be required. Tibial fractures should be reduced as accurately as possible. This is due to the special conditions for intramedullary nailing in the tibia, which are discussed in detail in the section on Aftercare.

Humeral fractures are also operated on with the patient supine (Fig. 79). The patient is placed on a fixed stretcher, with the shoulder joint on the involved side flush with the edge of the stretcher. Traction is applied via a wrist cuff. The elbow is in extension, and limb is abducted 45 degrees. Countertraction is provided via a wide upholstered belt passed through the ipsilateral armpit and diagonally across the chest and the back, in the direction opposite to that of the traction at the wrist.

Reduction by this means is usually straightforward. If the nail entry portal and the fracture site are very close together, the entire limb should be draped sterile, leaving a small window in the drape to expose the skin at the surgical site. The surgeon and his assistant are scrubbed. Reduction is performed partly by hand; previously attached and tested lateral traction straps may assist in the manoeuvre. The system is described in greater detail in the section on forearm fractures, in whose management it is of much greater importance. For humeral nailing, it is useful to have a scrubbed assistant, since the drill hole in the bone will need to be made by an assistant.

Patients with forearm-bone fractures will need positioning with particular care, since the confined space available has to be used to maximum advantage; frequently, reduction will be difficult, and the required reduction aids will need to be allowed to work under optimal conditions.

The patient is positioned supine on a fixed stretcher (Fig. 80). The arm is abducted at right angles. The elbow joint is flexed 90 degrees. Traction is applied via so-called Chinese finger-traps attached to all the digits of the hand. In order to distribute the traction evenly, a thin line is run back and forth to transmit the force via rollers in the loops of the traps and the spreader. The spreader is connected to the block-and-tackle system. Countertraction is applied to the ipsilateral arm and the contralateral foot (!), using a wide upholstered belt on the arm to exert cranial traction in the line of the body axis. This belt is attached rigidly to a wall hook. Caudal traction in line with the body axis is provided via a canvas boot on the contralateral foot, with adjustment by a block-and-tackle system when the patient’s body starts to stretch as traction is beginning to be applied at the hand. The block and tackle acting at the hand will exert caudal traction parallel to the body axis. In the absence of a Pohl “swan-neck” X-ray system, whose tubes can be accommodated in very narrow gaps, the arm, with the elbow flexed 90 degrees, will need to be pulled cranial until sufficient space has been provided for horizontal fluoroscopy with the larger-size X-ray machine.

Without countertraction on the contralateral foot, the rigid countertraction at the olecranon would lever the patient up the table, and any reduction obtained would be extremely short-lived.

With typical forearm nailing, i.e. with percutaneous nail insertion at the olecranon and at the styloid process of the radius, respectively, and a middle-third fracture of the shaft, the reduction apparatus can be used to very good effect. If the fracture is close to the elbow joint or to the wrist, auxiliary, manually controlled straps are useful. Prior to the procedure, once traction and countertraction have been properly established, the straps are attached to the forearm with Mastisol liquid adhesive, to prevent them slipping off sideways, and tested to ensure that they are working in the desired direction. The straps are pulled as the nail guide is being introduced into the medullary cavity of the second fragment. The time spent in preparing the system will be saved at surgery. Using this system obviates the need for fracture site exposure, which is frequently practised in the forearm. Soft-tissue interposition is not a reason for open reduction.
7. Fluoroscopy

It may seem surprising that an entire section of this treatise should be devoted to fluoroscopy. However, from what we have seen at our hospital and at other centres, we feel that this is not excessive. At a centre that has only recently adopted intramedullary nailing, everyone’s immediate concern will be with aspects of surgical technique, and roentgenological aspects will not receive the attention they require. Compared with the stringent protective measures applied in departments of radiology, what happens during medullary nailing procedures is nothing short of reckless; this almost grotesque difference can only be explained by the fact that those working in theatre have forgotten just how dangerous X-rays can be.

Undoubtedly, the patient is not the person at greatest risk: for him, this is a one-off exposure; it is the surgeon, his assistant, and the rest of the theatre personnel who, depending on the case load, are exposed to noxious radiation on an almost daily basis.

The patient, too, may, however, suffer harm. A difficult reduction which, in less-skilled hands, may take two hours will involve a number of fluoroscopy times, which will add up to an unacceptably high radiation exposure. Also, it is customary to place the X-ray tube very close to the limb, in order to obtain as sharp a screen image as possible. This can easily result in such a high dose that skin damage may be caused. Surgeons performing intramedullary nailing are strongly advised to consider, not only the technical complexity that a given case may present, but also these roentgenological aspects. It should also be remembered that, with some X-ray machines, the tube housing tends to heat up with prolonged use, and may cause thermal burns, especially in the uninvolved thigh, which is against the tube during upward-directed fluoroscopy. This damage can be readily prevented by an insulating layer of cellulose wadding.

It goes without saying that the surgeon and his assistant will be at much greater risk. War-time restrictions will not, in the foreseeable future, allow all mobile X-ray machines to be linked to the fluorescent screen and to have adequate radiation screening. With the current arrangement, a great deal of the radiation bypasses the protective lead glass screen and irradiates the observer. This is why it is totally wrong to go for very small and very light screens, convenient though they may be. The best protection is afforded by the larger screen. Preferably, the tube should be so close to the screen, or the screen should be so large, that all the radiation is absorbed in the glass. Even then, there will still be a worryingly large amount of secondary radiation.

The following recommendations should enable surgeons to practise safer fluoroscopy under the current suboptimal conditions:

Fluoroscopy times should be kept as short as possible. The fluoroscoper should be instructed to flash up the image for a second at a time only. For a skilled surgeon, this should provide sufficient information.

In order to do this, good visual adaptation is required. This is why surgery should be performed under low white-light or, preferably, under red-light conditions. Everything the surgeon has to do can be readily performed under low-light conditions.

The tube and the screen should be placed as close together as possible; alternatively, coning should be used to confine the beam to within the area of the fluorescent screen. If a proper cone is not available, a small lead diaphragm made by a theatre technician will have to do.

For carrying the screen, lead gloves must be worn.

All those working in the vicinity of the patient must wear lead aprons.

One mobile X-ray unit is a must; two units are preferable, so as to have a spare should the first unit fail. If, in the event of a failure of the X-ray machine, the surgeon does not wish to expose the fracture site, he would, in many cases, be forced to discontinue the procedure. Nailing without fluoroscopy is easiest in the tibia. It should, however, be attempted only when all else fails, and may not always work.

We particularly appreciate the “swan-neck” units made by Messrs Pohl; these small, highly efficient X-ray machines have a small tube and three joints, which enable the tube to be placed in a very small gap without obstruction by the tube column.

8. Asepsis

There is a risk of asepsis being broken during the periods of working in the dark while fluoroscopy is being performed, and, above all, because everyone is working in a very cramped space. If reduction is done manually, the reducing assistant may also be scrubbed. In that case, the entire part of the limb needs to be draped sterile. However, the fluoroscope and the fluorescent screen may seriously compromise asepsis. It would, therefore, be preferable to keep the operating surgeon’s area strictly separate from that of the reducing assistant. This separation is essential where reduction is performed non-manually. The stricter the separation, the more readily it will be respected. This is why a screen providing a “wall” between the two areas is recommended (Fig. 81). The draped wire frame shown in the illustration has a 4-cm-high divider at its foot end, close to the window in the patient drape. From the side away from the surgical site, the fluorescent screen may be placed right up against the divider, even in the dark. The window drape with the wire frame is glued to a wide area over the greater trochanter, with Mastisol liquid adhesive. The operating surgeon’s side is covered with a large drape. During each
fluoroscopy to ascertain the position of the nail guide, a new small drape is placed over the surgical site, since the screen will intrude into the surgeon’s area. With increasing experience, these checks will be required less and less frequently, since the surgeon will be able to “feel” his way into the medullary cavity, and all that will be needed is a check of the nail guide position from within the reducing assistant’s area, i.e. near the fracture site, in the non-aseptic area.

In proximal femur fractures, too, it is advisable to separate the area of the scrubbed surgeon from that of the unscrubbed reducing assistant. In this case, the assistant will control the distal fragment only, with the surgeon manipulating the proximal one with the nail.

In the tibia, too, this separation is readily achieved, with the draped wire frame covering the flexed knee joint (Fig. 82).

For the humerus and the forearm bones, complete draping will be the more advisable the closer the nail entry portal is to the fracture site. Separation is made difficult by the limited space available. If the reduction apparatus is used, separation is mandatory. Further details will be found in the section on the reduction of fragments. The straps described in that section must be attached and tested prior to draping. For the surgical wound, 1–2-cm-long slits in the drapes will suffice. Here, too, the drapes will need to be glued to the skin in the area surrounding the window. The auxiliary straps are included in the draping; obviously, though, their ends will protrude from the sterile field.

9. Nail Selection

The length, diameter, and shape of the nail will be a function of the calibre and the shape of the bone, as well as of the fracture site and pattern. It should be emphasized once again that the principle is one of fracture nailing, which means that the nail is intended to wedge as tightly as possible in the medullary cavity of both fragments. Too thin a nail would make for easy surgery, but would jeopardize the outcome. This is why the width of the medullary cavity at its narrowest point has to be ascertained as accurately as possible. At a distance of 75 cm from the focus, magnification on the plate will, on average, be 1 mm. It is also possible to place the potentially suitable nail next to the limb prior to taking another roentgenogram; the bone and the nail will be subject to the same magnification, and a comparative measurement may be performed (Ehrlich). It would be easier, and hence preferable, to use a stepped metal scale with a counterweighted belt, which is placed over the bone prior to the first roentgenogram of the fracture being taken. The central ray is placed midway between the scale and the centre of the bone, to obtain the same magnification on the film (Fig. 83). Each step of the scale is 2 mm wide. The steps mount along the axis of the limb; in this way, tilting of the scale will not introduce an error in the measurement. Where this scale is used, the width of the medullary cavity can be read off the very first roentgenogram.

For the femur, it is advisable to choose a thinner rather than a thicker nail. The medullary cavity is of the same calibre over a long distance; hence sufficient friction should be obtained. If an excessively thick nail is used, this friction may become so great that the nail seizes. However, at surgery, all three diameters of the selected length should be available (see section on Nail Insertion).

For the tibia, the largest possible nail diameter should be chosen. The constriction of the medullary cavity does not extend very far. The nail may be driven in with a certain amount of force, since it will fit itself into the cavity thanks to its cross-sectional compressibility. This has the advantage of having the nail wedge in the medullary cavity over the greatest possible distance.

In the humerus, it will rarely be possible to select a nail whose diameter matches that of the medullary cavity, since a nail of that thickness would be difficult to introduce through a lateral portal. Choosing a nail a few millimetres below the measured width will make for easy nailing, and the two nails will provide sufficient hold. For fractures near the elbow joint, the nail diameter must be sufficiently small to ensure that the device does not wedge in the tapering cavity near the joint. A nail wedged there would not provide sufficiently stable “internal fixation”; supplementary casting would be required; and if the nail wedges, it would distract the fragments. In these cases, all that a nail can do is to act as a peg.

In forearm-bone fractures, typical nailing will usually involve the use of fairly thin nails, since the tapering portions of the medullary cavities of both the radius and the ulna are very narrow. This disadvantage is compensated for by the fact that there will be very many sites all along the cavity where the long nail can wedge. Short nails introduced from a lateral portal and closer to the fracture site can and should be thicker. However, since they are introduced through a lateral portal, their diameter cannot be such as to make full use of the medullary cavity diameter; and the stabilization provided will not be sufficient. These nails, too, will merely act as pegs.

The length of the nail is of major importance only with fractures that are near a joint and at a distance from the nail entry portal. In these cases, the choice of the correct length is cru-
cial, since a centimetre too short may lose some of the benefit of nailing, while a centimetre too long may spoil the construct.

With all other fractures, it should always be remembered that unduly deep insertion of the nail into the distal fragment will be superfluous, but will never interfere or be detrimental. Length is best measured in the uninjured limb; in the thigh, the distance is taken from the trochanter tip to the knee joint line. Subtract 3 cm from the length at the knee joint line, and add 3 cm at the trochanter to allow for the protruding part of the nail. This means that the measured distance will be equivalent to the permissible nail length.

In the leg, the distance is measured from the dimple between the tendons of extensor digitorum longus and tibialis anterior, at the level of the inferior extensor retinaculum, to the centre of the tibial tubercle. Since the nail tip must always be kept at least 1 cm proximal to the ankle joint surface, 1 cm has to be added to take account of the curvature of the nail, the measured distance will be equivalent to the desired nail length. For the tibia, the longest possible nail should be used.

The tibial spreading nail must be chosen with particular care. It is extremely important that the inclined plane in the outer nail, which deflects the inner nail backwards, should be correctly sited. If the inclined plane is placed too far distally in the medullary-cavity flare, it will be inefficient, since there will be no resistance from the bone. The end of the inclined plane should be at the point where the cavity is just wide enough to accommodate the two nails side by side (e). It is best to start the measurement distally, i.e. at the ankle joint. Since the nail tip must be kept 1 cm proximal to this joint, this distance should be subtracted (f–1 cm = distance from end of inclined plane to the nail tip) (Fig. 84).

In the humerus, the length for antegrade nailing is measured from the intended entry portal to the customary entry site near the elbow joint, which is where the medullary cavity ends. If, in retrograde nailing, the humeral head is to be included, the arm should be measured accordingly.

For typical nailing of the forearm bones, the longest possible nails should be used, since this will provide the best support for the fractures and will prevent nail back-out, which is particularly common in the forearm, both at the wrist and at the olecranon. For the radius, the nail extends from the radial styloid process to a point 2 cm distal to the head of the radius; for the ulna, it extends from the olecranon to a point 2 cm proximal to the ulnar styloid process.

The longitudinal pattern of the nail will generally be predetermined and prescribed. However, where required, this pattern should be modified to suit the pattern of the fracture. In northern Germany, the straight femoral nail should be suitable for most cases, since it will be compatible with the slight bow of the femur; however, in other parts of the country, the femur may be bowed to such an extent that the nail will need to be bent prior to its insertion. On no account should one expect the nail to follow the bone: if the fracture site is at the apex of the femoral bow, the nail may comminute the cortex (!). It is unlikely that a straight femur will be split by a well-centred intramedullary nail that is firmly and evenly wedged all round; however, under the adverse conditions presented by a bowed femur, an advancing nail directed against one cortex only may very easily cause a wide piece of cortex to be broken out at this site (Fig. 85).

In the tibia, every effort should be made to keep the middle part of the nail very straight, in order to prevent recurvation. To enhance wedging, the inner nail should be curved more than the outer one. It must be emphasized here, too, that double nails contoured in this way must be inserted first one after the other, and then together.

The humeral nail, too, should be as straight as possible in its middle portion. If the nail tip only just picks up the short fragment, the tip must be perfectly straight.

In the forearm, only the radial nail needs to be bent, at its head end. This will ensure that, with the nail in situ, no forces will be generated that could act on the wrist. To facilitate insertion, the nail is bent towards the radial aspect of the forearm only when it is about two-thirds in the bone. Apart from this, the nail is kept straight. The ulnar nail is always used straight (Fig. 86).

Fractures near the elbow joint are managed with a special nail; this nail is thicker than the other forearm nails, and tapers distally (Fig. 26). This pattern is required since the nail must be particularly firmly seated at the fracture site, and must also be capable of being impacted sufficiently far down the ulna to prevent it backing out. Also, the head end of the nail is broad, to provide maximum contact with the cancellous bone; a thin nail would cut through the soft spongy bone (see Section 1).
10. Nail Guide Insertion

A nail guide is used for the nailing of femoral and of ulnar fractures, to facilitate the insertion of the nail into the proximal medullary cavity. The instrument also has the advantage of being readily advanced once reduction has been obtained, to maintain the fragments in correct alignment. When a nail is being tapped in, the fragments may easily displace; and while a malpositioned nail guide can be pulled back very easily, tapping back a nail is fraught with considerable difficulty, especially in the femur. In the ulna, too, it is very useful to be able to engage the distal medullary cavity at the moment when the fragments have been correctly reduced. In the radius, the technique would be desirable; however, in this bone it is preferable to dispense with the guide, since it is essential to avoid any unnecessary stress that might compromise the radiocarpal joint.

Great care must be taken to ensure that there is enough play between the nail and the guide; a nail must be used only with the guide it is designed for. If the guide is too tight inside the nail, it will jam during nail insertion, since the nail will need to follow the shape of the bone, and, in doing so, will need to bend to a greater or lesser degree.

For the insertion of the nail guide into the femur, the direction of the medullary cavity is marked on the lateral and the flexor aspect of the thigh, using a skin marker (see Fig. 74). These lines are obtained with vertical and horizontal fluoroscopy. To avoid radiation exposure of the hands, a long guide should be aligned at fluoroscopy with the direction of the medullary cavity, and used as a pattern for the lines drawn on the skin. Obviously, all that matters is the direction of the cavity in the proximal fragment. The lines are extended proximally and distally, all along the thigh. With correctly established fluoroscopy planes, the lines should meet at the intended nail guide insertion site on the greater trochanter. Very frequently, though, they will intersect further proximally. This point is, therefore, of no use for determining the guide insertion site. It is better to go by palpation. The tip of the greater trochanter is readily palpable even in obese subjects. A little cranially and medially to the tip, a ca. 2-cm-long stab incision is made, and the guide is tapped into the trochanter. The awl may be used to fashion a small pilot hole in the bone, following which the nail guide is inserted manually, with slight twisting movements. This will ensure that the guide does not jam unduly in the trochanter, and the surgeon will be able to feel much more easily whether the guide is advancing in the medullary cavity or maltracking. The lines marking the medullary cavity show the way in which the guide has to be held. The proximal thigh will have been draped sterile by this stage, with the drapes hiding the lines; this is why, as pointed out above, it is recommended to extend the lines to the distal thigh.

The nail guide tip must not be too sharp, since a sharp tip would be prone to becoming incarcerated laterally in the cortex. This is of particular concern in children.

Let us first look at the technique of nail impaction. The surgeon may be tempted to advance the nail with a large number of gentle, cautious taps. It is, however, preferable to use strong, well-delivered blows, which drive the nail in powerfully. The bone is less often exposed to the stress of the hammer blows. Prolonged tapping with a hammer may dislodge fat globules into the blood stream (Larsen). Also, advancing the nail with proper carpenter’s hammer-blows is less time-consuming and vastly more elegant.

If the nail has been chosen correctly and the nail guide has been properly inserted, the introduction of the nail into the femur is straightforward. It is of no importance whether the guide is placed through both fragments before the nail is inserted, or whether the nail is advanced into the proximal fragment before the distal fragment is engaged with the nail guide. The latter technique is preferable only where the proximal fragment is so short that it has to be manipulated with the nail in order to obtain reduction.

Since the nail has roughly equal bending strength all round, it does not matter which way the slot is made to face. As the nail is being driven through the trochanter mass, it will...
encounter considerable resistance. Once it is in the medullary cavity, it will advance about 2–3 cm with every forceful blow delivered by a 0.5-kg hammer. There is no danger of the bone being split. The risk of the nail seizing in the cavity is much greater. One complication to watch out for is penetration of the cortex in the subtrochanteric region. This may happen where the nail guide had first been driven into the cortex, and only then into the medullary cavity. In such cases, the bone may be comminuted! (Fig. 88).

Since friction between the nail and the bone is largely a function of minor irregularities of the inside of the cortex, the chosen nail diameter will, in some cases, prove inappropriate. If the nail threatens to seize, or if there is too little friction, immediate action should be taken to remove the nail in good time, and to replace it with the appropriate size, which should be readily available in the operating theatre. What matters is the timely recognition that the nail is about to seize. By ‘timely’, we mean at a time when the nail can still be removed without difficulty. Undoubtedly, this is where the beginner may get things wrong, and needs to take very special care. Beginners are recommended to use a much lighter hammer for impaction, with a weight of at most 50 per cent of that of the slotted hammer. Where this is done, there is very little risk of the slotted hammer not providing sufficient energy for extraction.

If the head end of the nail is level with the top of the nail guide, and the guide cannot yet be removed, the femoral nail driver I should be used (Fig. 89). Once the nail has penetrated a few centimetres into the distal fragment, the guide may be removed. Traction is decreased or discontinued altogether, to firmly appose the fragments. At this point in time, care must be taken to ensure that any malrotation of the fragments is corrected. Firm axial pressure is applied distally, and the nail is driven home. In adults, the nail should be left protruding 3 cm; in children, the distance should be 1–2 cm, depending on the age of the child. With the femoral nail driver II, it is easy to assure this distance.

The tibial nail is introduced into the medullary cavity from the tibial tubercle. The tubercle is exposed with a curvilinear incision with a medial or a lateral apex; the flap is reflected and held with a towel clamp. The incision should be designed in such a way as to place the nail entry portal in the distal corner of the wound. This will protect the proximal wound edges from excessive damage by the obliquely introduced awl and nail. The awl is applied fairly vertically at the centre of the tubercle, and as the tip advances into the soft bone, the handle is progressively lowered. The offset tip of the awl allows the hole to be made very tangentially (Fig. 90). This makes nail insertion much easier. Right from the first hammer blows, the head end of the nail should be lowered as much as possible, to enable the nail to readily slide along the posterior wall of the medullary cavity. The direction of the nail is towards the second toe. The skilled surgeon will be able to tell from the resistance felt whether the nail is in the correct position or not. If the lateral fluoroscopic view shows the nail bending after reaching the posterior wall, fluoroscopy in the other plane can be dispensed with.

Since the pattern of curvature of the double nail has been changed, to provide a lesser radius at the ends and an almost straight middle portion, the inner and the outer nail must always be driven in together. If this is not done, nasty jamming may occur. Insertion is greatly facilitated by the use of the impactor, which transmits the hammer blows in the direction of the middle portion of the nail (Fig. 91). Once the nail is in the distal medullary cavity, attempts will be made to obtain optimal reduction without sideways displacement of the fragments. This is of particular importance in the tibia. Following reduction, traction is decreased, and firm axial pressure is applied.

The insertion of spreading nails may prove difficult. With the deflect-to-spread nail, a problem may arise if the second (the inner) nail threatens to exit sideways from the fracture site. It is advisable to first drive home the outer nail, which bears the inclined plane. Weighted wire countertraction should be used to prevent it descending further into the cavity. Once this has been done, strong displacement, with traction and countertraction, of
the fracture site may be required, using a modified Böhler system with a block and tackle, to enable the inner nail to go down into the distal medullary cavity (Fig. 92). If the outer nail has advanced too far, as it will if the inclined plane has been placed unduly proximally, part of the stay wire left as a loop in the depth of the wound should facilitate the subsequent extraction of the nail. For the spreading plane to lie in the coronal plane, the nail insertion site will need to be, not in the centre of the tibial tubercle, but to the side of that structure. A portal medial to the tubercle is preferred. Where this is done, the plane of curvature of the nails, and the spreading plane, can be readily positioned to optimally fit the fracture pattern (Fig. 93).

With a rotate-to-spread nail, the inner nail will need to be driven home first, initially with the concavity of its distal portion kept facing anteriorly. Once the nail tip is in the flare of the distal medullary cavity, a screwdriver is applied to rotate the nail 180°. This rotation has to be performed before the nail tip could have entered the cancellous bone in the distal tibia. Once the nail has been driven home, it is protected against further advancement during the insertion of the outer nail, by a stay wire or a cross-pin inserted through a transverse hole in the nail head and well supported on the tibial tubercle. Should the outer nail still threaten to exit anteriorly from the fracture gap, appropriate fracture site displacement will need to be performed as the nail advances into the distal cavity (Fig. 94).

The humerus offers two nail insertion sites, one near the shoulder joint and the other near the elbow joint. Both sites are readily accessible, and the choice of portal will be governed by the site of the fracture. Two principles should be borne in mind: firstly, the nail should be more firmly seated in the short fragment by being made to pierce the cortex laterally; and, secondly, the procedure should not open up the fracture haematoma. This means that, where the fragment is very short, nailing must not be performed from the side of that fragment, since doing so would be tantamount to exposing the fracture site. It follows that second- and fourth-quarter fractures should be managed with antegrade nailing, while retrograde nailing should be used for fractures in the other quarters (Fig. 95).

The proximal nail entry portal is exposed by a ca. 5-cm-long longitudinal incision over the deltoid. The muscle is split in the direction of its fibres. With a crown drill, a hole is made in the lateral cortex to open the medullary cavity. This will allow the two nails to be inserted obliquely. The nails should be left protruding ca. 1.5 cm from the humerus.

Where the nail is to be introduced from the distal portal, the drill hole is made ca. 2 cm proximal to the olecranon fossa. At this site, the medullary cavity may be so flat that the drill hole may need extending in a proximal direction. The nail should be left protruding ca. 1 cm.

If the antegrade-ly inserted nail is found to be too long, it must on no account be driven in too far, since it would jam where the medullary cavity ends proximal to the elbow joint, drive the distal fragment ahead of it, and distract the fracture. If the nail head is found to be protruding too much, a different nail will need to be used. So as not to lose reduction, a thin guide (if need be a K-wire) should be inserted prior to the removal of the nail.

Nailing of the ulna does not require detailed description. The straight nail can be inserted over a nail guide of appropriately small diameter.

In the radius, the entry portal is between the tendons of the extensor pollicis longus and brevis muscles. A 5-mm-long stab incision is made over the centre of the radial styloid process, and a thin hole directed obliquely towards the medullary cavity is fashioned with the awl. A fluoroscopic check with the awl applied to the bone will ensure that the routing is correct. The nail should always be tapped in with slight finger pressure directing it away from the wrist. Before the nail is finally buried in the bone, its head end is bent (see Longitudinal Nail Pattern). Both in the radius and in the ulna, the skin wound is closed with a single suture.
12. Aftercare

The aftercare of ideally-nailed fractures does not require lengthy discussion. Where nailing has provided definite protection against fracture-fragment displacement, the time when the limb may be moved and when weight-bearing may be resumed will depend upon the general condition of the patient, and upon the degree of associated, and often very painful, soft-tissue bruising. Effusions in neighbouring joints appear to be much more common than with the earlier techniques of fracture management, and are attributable to forceful traction during surgery only to a limited extent; patients with joint effusions may need to be kept at bedrest for extended periods of time. In the follow-up of a large number of patients, we were surprised to see that only few patients with femur fractures were able to, or allowed to, be out of bed in the first week after nailing. The rate of associated trauma, especially concussion and ankle fractures, is surprisingly high.

Experience has shown the aftercare to be undemanding on the health care professionals. However, constant medical vigilance is required all the more. Without careful monitoring, there will be a substantial number of patients who are discharged early, only to return a few weeks later with unexpected displacements that will then need to be treated. Displacements must be detected in time, to ensure that they are corrected under a brief anaesthetic, so as to avoid later osteotomies.

Aftercare starts as soon as the incision has been closed, while the patient is still under anaesthesia.

1. The more readily bent constructs (tibial, humeral) are checked with fluoroscopy to ensure that the nail pattern is correct. The tibial nail is at particular risk from being driven into recurvatum as it is being inserted, and corrective action can be taken if such a displacement is detected.

2. With the nail in situ, a check is made to see whether the fragments can still displace. If angulation is still possible, supplementary casting will be mandatory. If rotation can still occur, a cast will have to be applied whenever the fracture pattern suggests that, after the return of muscle tone, the fracture faces will not be kept in position by interdigitation. If interdigitation is likely to occur, a splint will suffice to prevent tilting of the limb while the patient is still under anaesthesia. The further management will be decided in the light of an examination the following day. It should be remembered that a heavy log cannot be yanked through thick mud; however, with sufficient patience it can be readily dragged through, with little force. Friction between the nail and the bone may be so great as to prevent rapid rotational displacement, but cannot withstand the persistent, albeit lesser, force exerted by the foot tilting into rotation.

3. Once the jagged edges have been resorbed, interdigitation may no longer be a stabilizing factor.

4. Over the weeks, the nail will loosen in the medullary cavity. Under favourable conditions, the fragments may slide along the axis of the nail, but will not be at risk from rotation. However, the possibility of rotational displacement at this later stage must be taken into account.

In order to avoid unnecessary repetition, details of aftercare are given under Patient Se-

13. Nail Removal

In general, nails should be removed at three months, since, by then, sound union of the fracture fragments should have been achieved.

Earlier removal may be indicated, for the following reasons:

1. The fragments have displaced, and the nail is making it impossible to obtain renewed reduction (angulation or rotation).

2. The nail is migrating, and is threatening neighbouring joints or the soft tissues covering its head end.

3. The nail has bent.

4. The nail has broken.

5. In children, sound union obtained well before the end of Month 3.

Suppuration at the nail entry portal or at the fracture site (osteotomy, compound fracture)
Nailing of Compound Fractures

If the compounding wound heals by first intention, the benefits of intramedullary nailing will be the same as in the management of closed fractures. First-intention healing is likely to occur more frequently than with other techniques, since the bone and soft-tissue immo-
Nailing of Compound Fractures

1. Suppuration may track along the nail. In that case, suppuration will remain confined to the bone marrow, and will not spread to the bone (A. W. Fischer and Reich). Even after several weeks, this tracking infection may cause abscess formation at the nail entry portal, underneath a surgical wound healed by first intention. Once this abscess has been opened, the nail will act as a drain for what may be a copious purulent discharge.

2. The fracture is ideally immobilized, which makes it less likely that the soft-tissue suppuration will spread to the bone. If the fracture site itself is involved in the inflammation, immobilization will produce a favourable course of the suppuration.

3. The limb is readily accessible from all sides; it can be monitored daily; and any necessary incisions can be made in a timely fashion.

4. There are, however, also certain disadvantages: 1. Suppuration may track along the nail. In that case, suppuration will remain confined to the bone marrow, and will not spread to the bone (A. W. Fischer and Reich). Even after several weeks, this tracking infection may cause abscess formation at the nail entry portal, underneath a surgical wound healed by first intention. Once this abscess has been opened, the nail will act as a drain for what may be a copious purulent discharge.

2. At the fracture ends, ring sequestra may form (A. W. Fischer and Reich). These sequestra will be surrounded by callus, and removed once the fracture has soundly united.

To date, the following guidelines for the nailing of compound fractures have been evolved (Maatz and Reich):

- Nailing should be performed as early as possible. The time from the traumatic event cannot be specified in terms of hours. Nailing must not be performed at the stage of acute infection.

- Another useful time for nailing comes when the first, florid inflammation has subsided. It would appear that once sufficient immunity to the germs in question has been obtained, the suppuration has entered into a “cold stage”, the body will tolerate the procedure without ill effects (see Gunshot Fractures).

- During nailing, care must be taken to ensure that the compounding soft-tissue wounds are not made worse. This is why the technique employed in percutaneous nailing should be used also for compound fractures. The nail guide should not be introduced into the fracture site retrogradely, as in osteotomies. Even without an X-ray machine, the nail guide may, with a little skill, be inserted percutaneously. With this technique, reduction and the insertion of the nail into the distal medullary cavity can be done under direct observation. However, where the wound is small, it would be preferable to perform these manoeuvres with fluoroscopy, to avoid having to enlarge the wound.

- Wherever possible, compounding wounds should be managed with primary excision and suture. Very dirty wounds will not be suitable for excision and immediate closure. They should be debrided, with removal of gross contamination and badly bruised tissue. The wound is then packed loosely with gauze, and left wide open. If there are any undermined areas, the wound may need to be extended, to ensure free drainage of secretions. Sutures to approximate the wound edges must not be used. The technique described above will be the quickest means of obtaining a clean wound that will heal by second intention. In suitable cases, healing may be speeded up by approximating sutures inserted at a later stage. This is the best way of preventing a spread of the infection into the deeper tissues.

In the further course of wound management, too, full use should be made of the all-round accessibility of the limb; the goal should be to keep the wound wide open from the start, in order to ensure ready drainage of secretions.

- Supplementary casting should be avoided wherever possible. This will rule out nailing in certain patients. In the management of compound fractures, intramedullary nailing has the advantage of providing absolute immobilization and all-round access to the limb. If it is clear, prior to nailing, that a supplementary plaster cast will definitely be required, nailing should not be used, since, with compound fractures, the success of the procedure is predicated upon stable internal fixation being obtained with the use of the nail.

- In general, the policy of immobilizing a limb with soft-tissue infection on a splint will be followed here as well. In this way, dressings can be changed easily.

- If at all possible, the nail should remain in situ until bony union has been obtained. Even very copious suppuration (for which the presence of the nail tends to get blamed) is not a reason for removing the nail prematurely; certainly, removal should never be contemplated during the first 8–10 weeks. The V2A (CrNi) and V4A (CrNiMo) stainless steels used for the nails are the least irritant metals known to date for use inside the human body; however, the body will surround the foreign material with a fibrous layer, and, if infection has occurred, it will try to expel it by suppuration. However, the benefits of leaving the nail in situ are still so great that an increase in the purulent discharge is undoubtedly acceptable. Callus formation will not be delayed by the presence of the nail. Obviously, suppurating fractures with a nail in situ may, not infrequently, fail to form callus for several months. This is attributable to the pus, and not to the nail. It would always be wrong to remove the nail at a stage when major fragment displacement is still possible. This may still be the case several months from nailing. If a fracture is protected, by scar tissue or by callus, against lateral displacement, it may be justifiable to remove the nail, especially with a view to controlling very copious suppuration. In such cases, protection against angulation will need to be afforded by a plaster cast. The goal, however, should always be to obtain bony union with the nail in situ. Often, this will be a matter of patience, and of remembering that, even without nailing, compound fractures may suppurate and fail to form callus for many months. In terms of fracture management, the nail will still provide the best conditions.

15. Nailing of Gunshot Fractures

Gunshot fractures must be considered as completely distinct from compound fractures. Whereas the latter may very frequently be managed with wound excision and suture, this procedure would not be permissible in gunshot fractures.

- Because of the special nature of these fractures, some specific rules will need to be observed.

- Nailing should be performed as early as possible. However, there is no mandatory time from injury within which this should be done. Successful nailing can be achieved at any time (Küntscher). Patients with copiously suppurating wounds and high fever will recover almost instantaneously once the fracture has been stabilized with a nail (Küntscher).
However, a gentle technique and wide opening of all the wounds are a must. The nail entry portal, too, must be larger than normally, and will not be closed with sutures, but loosely packed with gauze. Sufficient counterincisions should be made to ensure good drainage of the pus. If need be, wound spreaders should be inserted.

Where a bone defect has been created, shortening should be prevented by the insertion, into the nail slot, of a metal spreader, which will keep the fragments the desired distance apart (Küntscher). The spreader will also keep the wound open (Fig. 96).

The nail guide should not be introduced via the fracture site, since doing so might spread germs from the site. Experienced surgeons will find the medullary cavity from the trochanter, even without fluoroscopy. Inexperienced surgeons should not tackle the nailing of gunshot fractures. Similarly, it is not advisable to reduce the fracture in front of the fluorescent screen, since any rough handling of the tissues must be avoided. It is preferable to extend the wound with a smooth incision, as described above, in the discussion of infection control in the management of compound fractures. As with infected compound fractures, gunshot fractures will need to be managed with stable internal fixation if the inflammation is to be controlled and callus formation is to proceed undisturbed.

After wound debridement, healing may be speeded up by the use of secondary sutures or the taping together of the wound edges.

16. Nailing For Delayed Callus Formation

In delayed callus formation, nailing is “aetiological treatment”, since, in the overwhelming majority of cases, the causes of delayed union are mechanical. The nail suppresses detrimental shear forces, and encourages compressive forces, which promote bony union.

In some very rare cases, delayed callus formation will go on to non-union (cessation of healing). This is extremely unlikely to happen where favourable mechanical conditions have been created at the fracture site. This is why the technique for nailing in delayed callus formation is fundamentally different from the one to be used in cases of non-union. In delayed callus formation, there is no need for creating new conditions for callus formation: bleeding bone does not have to be exposed; the bone ends do not need to be freshened or treated with petaling, drilling, or sawing, as proposed by Kirschner, Beck, and Brandis, respectively. All that is required is the introduction of a nail, to stabilize the fracture from within the medullary cavity. Where the fragments are correctly positioned, i.e. where the medullary cavities of the two fragments are correctly aligned, the fracture site should not be exposed, and percutaneous nailing should be attempted, so as not to put the patient at risk from infection. This risk is particularly great in cases of compound fractures which, for some reason, were not managed with primary nailing and in which nailing is felt to be desirable following the healing of the soft-tissue lesions.

In general, nailing is performed as described elsewhere in this treatise. The only stage of the procedure that may require special measures is the reduction of the fracture, in cases where the medullary cavities are not adequately aligned. In such cases, the necessary displacement of the fragments cannot be achieved manually or with the reduction apparatus. The block-and-tackle system of the Fischer-Maatz modification of the Böhler traction device has been used with good results. If the forces generated by this device are insufficient, an osteoclast may produce the desired result. The effort is very worthwhile, if it avoids fracture site exposure. However, there will be cases where exposure will have to be resorted to.

Sharpening the nail tip has not been found helpful. The blunt nail will easily go through the immature bone and fibrous tissue at the fracture site, and will enter the distal medullary cavity more readily than will a sharp nail, which may also damage or pierce the cortex. The fitting of saw teeth a short distance from the nail tip has, however, been found to be useful (see Nails and Instruments).

Where the nail is well-seated and fragment stabilization is adequate, weight-bearing should be resumed early on, since the best treatment for delayed callus formation is weight-bearing (Fig. 97).

In the leg, resection of the fibula may be considered in order to abolish the tethering action of that bone.
17. Nailing For Non-Union

Given the surprisingly rapid and ample callus formation at nailed fracture sites, with the bridging of major bone gaps, it was thought that non-union, too, could be managed with nail stabilization only, in the hope that bony bridging of the defect would, eventually, occur along the nail. However, it was unlikely, even with the greatest optimism, that full-fledged pseudarthroses, with joint surfaces and articular cartilage, would be amenable to this treatment. On the other hand, the transformation of wide fibrous-tissue bridges into bone was not an altogether unlikely prospect. However, attempts made along these lines proved unavailing (Fig. 98). This means that, even where an intramedullary nail is being used, fracture-site conditions will need to be created in order to obtain union. The non-union will need to be resected so as to put freshened bone against freshened bone (Fig. 99). Resection should be as sparing as possible, to prevent unnecessary shortening. The non-union should be opened up bluntly or with sharp dissection, and the ends should be nibbled with a Luer rongeur to expose bleeding bone. If need be, the medullary cavities at the bone ends should be enlarged. If it is desired or essential to avoid bone shortening, such techniques as petaling, sawing, or drilling of the bone ends would be justified. Nailing is performed as described elsewhere in this treatise. Except in the femur, it is always advisable to insert the nail percutaneously, in customary fashion, prior to the exposure of the old fracture site, so as to minimize the time during which the bone wound is kept open and at risk of infection. Once the bone ends have been suitably prepared, the nail is driven home under direct observation.

![Fig. 98 Humeral non-union, 4 months after percutaneous nailing.](image)

![Fig. 99 Humeral non-union, 8 weeks after resection and nailing.](image)

18. Osteotomy

In its narrowest sense, an osteotomy is the division of a bone. The procedure is most frequently performed for the correction of malunion. Also, congenital bone deformities, and those acquired as a result of bone disease, may be corrected with this open procedure. Nailing has been eminently successful in the management of fresh fractures; equally, some osteotomies, especially in the femur, have been made possible only with the advent of intramedullary nailing. Certainly, many patients who, in the past, would have been rejected because of the unpredictability of the outcome and because of concern over the stiffening of neighbouring joints, can now be candidates for osteotomy. The reason for the previous reluctance to perform osteotomies was that the displacing forces acting at the site of an osteotomy are very great, since the muscle balance will have been upset by the procedure; this is the case, for instance, with old, malunited femoral fractures. Following a fresh fracture, the tensile and compressive forces produced over the entire cross-section of the muscles (agonists and antagonists) will amount to several hundred kilograms. The bone will be subjected to what, in engineering, is known as crumpling. The net result will be angulation at the fracture site. If, as typically happens after an osteotomy, the action of one muscle group predominates, crumpling will occur all the more readily, and cannot be corrected with the currently available means such as ivory pegs, Lane plates, circumferential wiring, plaster casts, or traction. The only device that has the requisite mechanical strength is the stainless steel nail driven into the medullary cavity.

There are four further reasons for the superiority of intramedullary nailing over all the above-mentioned techniques for the stabilization of osteotomy fragments. Firstly, the technique is much easier to perform. Secondly, the infection risk is much lower, since the skin incision may be kept much smaller than the one required for the insertion of Lane plates against two sides of the bone. Thirdly, stripping of the periosteum is not required for nail insertion. Leaving the periosteum in situ means that the Langenbeck principle of subperiosteal surgery for internal fixation may be abandoned. This is of paramount importance for callus formation, in which the periosteum plays a major role. Also, the periosteum is the most important source of blood supply to the external layers of the cortex. This is why the stripping of the periosteum will, undoubtedly, greatly compromise the blood supply and, hence, the defences against infection, of the underlying bone. This is certainly a contributory factor in the notorious susceptibility to infection of osteotomy sites. Stripping of the periosteum also produces a larger wound surface area, which is yet another risk factor for infection. Fourthly, foreign bodies placed against the outside of the site tend to delay callus formation, whereas a nail in the medullary cavity will certainly not impede the formation of new bone tissue. To these reasons could be added the fact that intramedullary nailing obviates the need for plaster casts, which always put the patient at risk for renewed major damage to the joints and muscles as a result of prolonged immobilization.

Osteotomy plus nailing may be required for:

1. malunited fractures. Correction will mainly be required for shortening and angulation; since the advent of intramedullary nailing, also for rotational deformities
2. congenital deformities, or acquired deformities resulting from conditions other
than fractures, of the long bones; the chief patterns are genu valgum and genu varum

3. lengthening of growth-delayed long bones

4. bone shortening, e.g. to enable nerve or vascular sutures to be performed (Böhler), or, in certain rare cases, to match the length of the healthy limb to that of the fellow limb shortened, for instance, by a comminuted fracture and unsuitable for a lengthening osteotomy (Bauer)

5. resection of bone tumours.

The insertion of a nail into the medullary cavity is easier at osteotomy than it is in percutaneous nailing. At osteotomy, the medullary cavity will have been exposed, and insertion is done under direct observation. In many cases, the medullary cavity will be open; in others, it can readily be opened using an awl, a gouge, or a drill, since the tissue closing it will be comparatively soft. In the tibia, the humerus, and the forearm bones, the nail entry portals should be away from the fracture site, as with percutaneous nailing. The nail tip is seen in the depth of the wound, emerging from the medullary cavity of the first fragment; it is then inserted into the cavity of the other fragment, and the nail is driven home, to complete the internal fixation procedure. For femoral osteotomies, the patient should be positioned side-lying, with the involved limb uppermost. The skin incision is usually made on the lateral aspect, which provides good access to the bone without the risk of injuring major vessels. A guide is inserted into the opened medullary cavity of the proximal fragment, and advanced to the tip of the greater trochanter, where it will be readily felt as it pops through the cortex, which is very thin at this point. Its tip can then be palpated under the skin of the buttock. A short incision is used to expose the tip (Fig. 100), the nail is pushed onto the guide, and impacted until it protrudes 0.5 cm from the medullary cavity of the proximal fragment. In the thigh, too, it is usually possible to appose the fragments and to drive the nail into the distal cavity. In robustly-built men, with longstanding shortening as a result of old malunited fractures, even maximum traction with the traction apparatus will not overcome the shortening. Usually, the femoral malunion will also be in varus. However, once the malunion has been broken up at the site of the old fracture, it will always be possible to place the fragments against each other at an angle. The apex of the angle will be facing laterally, into the incision. An assistant should push the apex inwards, with all his strength, to place the fragments in correct alignment (Fig. 101). Once they have been aligned, the nail is driven home. On no account should the nail be inserted earlier, in the hope that it would align the fragments on its way into the distal medullary cavity. This is not something that the nail can do. Any attempts to drive it in would invariably lead to extensive comminution of the end of the distal fragment! Another technical trick needs to be used where the osteotomy is being performed very proximally, at about the level of the lesser trochanter. At this site, the bone should not be fully divided immediately, and the osteotomy should be confined to the opening of the medullary cavity. Part of the medial wall is left standing for the time being. A small guide is introduced into the opened medullary cavity, and the nail is impacted over the guide as described above. If the malunion at this site were to be completely osteotomized straight away, the proximal fragment would immediately go into extreme abduction and flexion, because of the preponderant action of the relevant muscle groups. This would make nail insertion difficult, since, as a rule, the nail guide would not be strong enough to correct the position of the fragment. However, the procedure may be facilitated also by the temporary insertion, into the medullary cavity of the proximal fragment, of a second nail, which will constitute an excellent handle for the manipulation of the fragment until the antegradely inserted nail has been advanced the requisite distance.

The periosteum should be preserved as much as possible. Almost always, it will be possible to reach the malunion and the intended osteotomy site by bluntly pushing the muscles apart. Admittedly, though, the exposure provided may be poorer than it would be
with extensive detachment of the periosteum; and, as a result, the procedure may be more
difficult to perform. Where a femur has malunited with shortening, the fragments can
ten be freed by levering with a very stout periosteal elevator inserted between the frag-
ments. All that remains then is to smooth
the fracture surfaces a little, so as to make
them fit together; also, if the medullary ca-
vities are closed, they will need to be ope-
ned as described above. Any jagged edges
and protrusions of the abundant callus, and
the callus bridge, should be left standing,
so as to avoid damaging the periosteum and
compromising the soft tissues. They will
provide useful building material at the frac-
ture site.

If the malunited fracture is several years
old, a chisel or a saw will need to be used.
Here, too, all that is required is to create
the two mating surfaces. This is most rea-
dily done with a rotating saw held in both
hands. The position of the dividing planes
will be a function of the site and the pattern
of the original fracture surfaces.

With transverse fractures malunited with
angulation and overriding of the fragments,
the two saw cuts, at the distal end of the
proximal fragment and at the proximal end
of the distal fragment, will need to be at ex-
actly right angles to the axis of the medul-
lary canal, in order to ensure optimal appo-
sition once the nail has been inserted (Fig.
102). Similarly, with malunited oblique
fractures, the saw cuts will need to be ob-
lisque. The cuts are made through the intact periosteum, at the original fracture site, passing
through the callus caps at the fracture ends. When the fragments are brought together, the
sawn-through callus will produce broad supporting shelves that promote speedy and sound
union. The saw cuts must not be made too high or too low, to avoid limb length inequality
between the operated and the uninvolved side. It should be noted that a small amount of
bone will usually have been resorbed laterally, leaving a small defect after fixation. The
saw cuts will usually open the medullary cavity; where this is not the case, entry into the
cavity will be readily accomplished from the cut surface.

Once the saw cuts have been made, a large chisel is inserted between the fragments,
and the fragments are separated with blows from a large chisel directed accurately at the
former line of the cortex. In this way, the fragments can soon be levered apart. Nailing is
performed in standard fashion (Fig. 103). Here, too, care must be taken to ensure that the distal fragment is not left in external or internal malrotation.

Osteotomy for the correction of malunion in pronounced angulation can be performed yet more readily, since, after sawing through the fracture ends, all that remains to be done is a correction of the axial alignment.

Derotational osteotomies used to be rare; with the advent of intramedullary nailing, they are bound to be more frequently required as the technique is becoming more widely used by surgeons who may not always pay sufficient attention to the imperative need for monitoring in the post-nailing period. Again and again, there will be cases of malrotation not being detected until it is too late for closed correction under brief light anaesthesia.

The procedure as such is straightforward. First, the degree of malrotation will need to be established. The patient is placed with the knee flexed at right angles and the hip slightly flexed, following which both hips are maximally internally rotated. The difference in the positions of the legs provides a sufficiently accurate measure of the number of degrees by which the deformity has to be derotated. In many cases, it will be advisable to osteotomize away from the original fracture site. The site selected should be the one that offers the best conditions for nailing, and will thus be as far as possible at the mid-shaft level; also, a tooth-and-notch pattern should be created at the osteotomy site, so as to dispense with the need for casting whilst still protecting against renewed rotational displacement. First, the nail is loosened with a few hammer blows. Next, with the nail in situ, the bone is sawn through with a Gigli wire saw, to leave only a bone bridge, which will automatically result providing that the two limbs of the wire have been kept parallel during sawing (Fig. 104). A rotating saw is used next, to make two cuts sloping upwards or downwards from the bone bridge in such a way as to fashion a tooth in the proximal or the distal fragment. The remaining small bone bridges are divided with a thin chisel.

For the tooth created in one of the fragments, a notch will have to be fashioned at an appropriate site in the other bone fragment. For this, the nail should be knocked back beyond the osteotomy site, to enable the fragments to be angled for access with the rotating saw. Once the fragments have been correctly rotated, it only remains for the surgeon to drive the nail home again (Fig. 105).

Securing the construct with a tooth and notch is safer than using a new, larger-diameter nail. For one thing, a thicker nail might become incarcerated in the fracture callus; for another, even a properly fitting nail may loosen after a few days, and rotation would be all the more likely to occur since the osteotomy surfaces would be perfectly smooth, without any jagged ends (Fig. 106). Where the long-bone deformity is congenital or acquired as a result of conditions other than fractures (mainly genu valgum or genu varum), intramedullary nailing will be of more limited application, since, inherently, the nail will seek – automatically, as it were – to restore the former pattern of the bone. Thus, with a bowed tibia as a late sequela of rickets, the nail would have to follow the varus curvature in both fragments, and would need to bend at the fracture site, as shown, with slight exaggeration, in Fig. 107. Where
such osteotomies have been managed with a nail, callus formation tends to be delayed, since, apparently, the nail will distract the fragments rather than making them slide into apposition; the main reason being that, under these conditions, the tibial nail cannot function properly, and the site will not be sufficiently immobilized.

When – as is not uncommon in rachitic genu varum – the radius of the curvature is comparatively small, and the deformity is short, a Helferich osteotomy may be performed and a straight intramedullary nail may be successfully inserted (Küntscher). Usually, this will also require derotation, which can be readily accomplished by the removal of an appropriately designed bone wedge (Fig. 108).

In supracondylar osteotomies for the correction of genu valgum or of a fixed flexion deformity of the knee, the nail can be used with advantage (Güntz). Obviously, the patient will need to be casted; however, the fragments will not be able to slip, and the period in the cast may be kept shorter. Nailing is performed in standard fashion. We wish to emphasize that the bone ends should fit together optimally, so as to align the bone correctly. The nail will protect against lateral displacement; and the better the apposition, the earlier the cast may be removed (Fig. 109).

Bone lengthening by a few centimetres can be performed even without the distracting nail that is currently being designed. Two problems need to be overcome: firstly, the stretching of the soft tissues; and, secondly, the possibility of the fragments re-approximating once they have been distracted.

Stretching of the thigh soft tissues by 4, 5 or more centimetres, using traction, cannot be accomplished in one session, i.e. in about one hour. Angulation at the fracture site, as described above in the discussion of malunion with shortening, is ruled out here: malunion involves two stout fragments, whereas, in bone lengthening, the bone tube is weak and may fracture if excessively stressed. This means that soft-tissue lengthening will need to be performed over several days. A nail to facilitate this procedure is undergoing development.

With the devices currently available, a lengthening osteotomy may be performed as follows:

Stage 1

1. A Z-shaped osteotomy is made at the narrowest point of the medullary cavity (Fig. 110).
2. The fit of the nail selected from the roentgenogram is tested.
3. A V2A stainless-steel nail guide (without a cross-handle; with an eye near the tip) is inserted into the proximal fragment, from the osteotomy site. Before the tip of the guide pierces the skin over the trochanter, the skin should be tightly pulled sideways, so as to allow the second-stage operation to be performed through a skin incision a few centimetres away from the one used first time round.
4. The guide is driven into the medullary cavity of the distal fragment.

Stage 2

5. Supracondylar skeletal traction is applied.
6. When the requisite length has been obtained, the bone is nailed. For nailing, the tip of the nail guide is exposed, seized with forceps, and pulled out sufficiently for a stay wire to be passed through its eye. Reduction should be done in front of the fluorescent screen, in such a way as to ensure that the nail does not impinge on the distal cortex. Reduction must be performed very gently, to avoid comminuting the bone ends (Fig. 111).
7. The nail guide is removed.
8. Skeletal traction may be removed, or left on with little weight.
If, for any reason, Stage 2 cannot be performed, the osteotomy will need to be left to heal in traction. The V2A-steel nail guide will keep the fragments in correct alignment.

Following successful nailing, weight-bearing must not be resumed until the defects created at the osteotomy sites have filled with bone. If weight is borne at all prematurely, limb shortening will result.

In the majority of cases, osteotomy will be performed to facilitate suturing of a nerve, or, more rarely, of an artery. Shortening of a healthy lower limb should be resorted to only if there is no other means of achieving limb length equality, unless an unusually tall patient is happy with being “cut down to size”. The cut should always be oblique (Güntz), in order to create favourable conditions for healing (see general section of this treatise).

The roentgenogram of a forearm in Fig. 112 shows one of the less common uses of a shortening osteotomy.

Following the resection of a bone segment of appropriate length, the osteotomy is managed with an intramedullary nail, in standard fashion. In order to prevent subsequent distraction of the bone ends (humerus; forearm bones), every effort must be made to achieve “ideal” nailing. This should not be too difficult since, in general, the osteotomy can be placed at a site that offers the best conditions for nailing.

Nailing after the removal of bone tumours is performed in standard fashion.

19. Nailing of Spontaneous Fractures

The nailing of spontaneous fractures is a subject in its own right. These fractures occur mainly in bone that has been weakened by tumours; less often, osteoporosis or other conditions will be aetiological. For some reason, tumour metastasis tends to occur in the proximal third of the femur, i.e. at a site that offers favourable conditions for nailing. From the point of view of nailing, spontaneous fractures differ from other fractures in that (1) as a rule, the nail will be required for stabilization for the rest of the patient’s life, since, even with radiotherapy, these fractures show little if any tendency to consolidate; (2) the bone will be mainly atrophic, with very thin cortices and correspondingly wide medullary cavities, which means that standard nail sizes will rarely be appropriate; (3) the bone will be comparatively soft; and (4) the nail will not be subjected to great bending stresses, since the patients concerned are mainly elderly and frail.

For these reasons, a special nail should be used.

Since the nail does not need to have great bending strength, the metal thickness may be less, and the nail may have particularly great cross-sectional compressibility. The special nail has a top-hat cross-section, which provides the requisite compressibility and has the great advantage of placing only three narrow longitudinal surfaces – the three “edges” – against the inner cortex. During the first few weeks, the bone will yield to the pressure of the nail, and grooves will be formed. When the nail has recoiled to resume its former shape, i.e. when it has loosened, these grooves will be deep enough to prevent the fragments rotating on each other.

In this way, even where there is no prospect of bony union, the bone will be splinted internally, and the patient will be able to ambulate without any other external support.

Apart from the use of a special nail, the technique of nailing is standard (Fig. 113). The only aspect to be borne in mind is the softness of the bone. This is of particular concern during nail insertion into the distal fragment. Alignment with the proximal fragment will need to be performed from the outside, rather than relying on the advancing nail, as one could safely do in solid bone.

In tumour cases, the fluid issuing from the medullary cavity will very often contain tissue that can be sent for histology, to provide a definitive diagnosis of the growth.
20. The Y-Nail

The nailing of pertrochanteric fractures warrants a separate section in this treatise. These fractures are readily reduced and fixated. Not infrequently, though, the hip will drift into coxa vara. However, there should be no problems with delayed callus formation or non-union. It should also be remembered that, with nailing, the special advantage of the new technique cannot be brought to bear: the fracture site will, unfortunately, need to be exposed. Any infection of the surgical wound will, in the majority of cases, lead to suppuration at the fracture site. Even so, however, the Y-nail marks an advance in the management of these fractures, since patients do not have to be kept at bedrest for extended periods of time, and since nursing will be much easier. Whereas patients who have undergone femoral neck nailing will not be allowed to weight-bear for some time, patients who have had a pertrochanteric fracture nailed may safely resume weight-bearing in the first postoperative days.

Patient selection is a function of the considerations detailed above. Thus, nailing should be used in all patients in whom prolonged recumbence would be hazardous; the risk of infection would be accepted in these cases. In all the other cases, nailing will depend on the wishes of the patient, who must have been fully informed of the pros and cons of this technique.

The nail to be used will be a function of the fracture pattern. Prior to surgery, as much fracture line information as possible should be obtained, although, admittedly, this may be difficult to achieve. Often, the necessary evidence can be obtained only from roentgenograms taken shortly before surgery, with the limb in traction. By then, the previously impacted fragments will have been disimpacted, and the fracture lines will be more readily discernible.

For purposes of nailing, fractures involving, or immediately adjacent to, the trochanteric area may be divided into six groups (A. W. Fischer and Maatz) (Fig. 114).

Group I, the subtrochanteric fractures, can be adequately managed with a tapered intramedullary nail.

For the nailing of the other groups, a Y-nail will be required; in such cases, patient selection and the surgical technique will be governed by the fracture pattern.

The basic principles of the technique are simple. The intramedullary nail is inserted into the femur to what is thought to be the appropriate depth; the cortex is opened 8 cm distal
The Y-Nail

Fig. 115 First check roentgenograms during Y-nail insertion. The nail has been inserted too far and is 30 degrees malrotated.

Fig. 116 Second check roentgenograms during Y-nail insertion. The nail is correctly placed, since the transverse nail is central in the femoral neck in both planes, which is why it is obscured by the intramedullary nail in the second plane.

to the head end of the nail; and the transverse nail is inserted a short distance through the slot in the intramedullary nail. Roentgenograms are taken, to establish whether additional reduction is required, and by how much the depth of insertion and the rotational alignment of the device may need to be corrected (Fig. 115). These corrections can be performed very accurately, since the insertion depth of the intramedullary nail can be set with great accuracy from the cortical drill hole extended, in the required direction, with a chisel or a rongeur; and the necessary rotational alignment in the medullary cavity can then be performed with the transverse nail inserted through the intramedullary nail. Further check roentgenograms should then show the transverse nail aligned centrally in the femoral neck in both planes. In other words, the transverse nail must not show in the second plane, since its image must coincide with that of the intramedullary nail (Fig. 116).

This technique requires wide exposure of the fracture site. The very large surgical wound involved may cause potentially fatal wound shock, and will, obviously, put the patient at high risk of infection.

This is why an “insertion jig” had to be designed, to allow the Y-nail, too, to be inserted “percutaneously” (Maatz). The device has been tried in clinical practice, and nailing of trochanteric fractures can be strongly recommended where the jig is used. Delayed wound healing has been seen more rarely, and the rate of wound shock has not been higher, than with other forms of intramedullary nailing. However, it would be prudent to restrict the use of this technique initially, reserving it for Group II patients who would be put at risk by prolonged bedrest. Increased proficiency should soon lead to a wider range of patients being selected.

The principle of the insertion jig is simple. It merely serves to introduce the transverse nail into the slot in the intramedullary nail, through a percutaneous approach. Understandably, surgeons may at first be baffled by the range of drills and holders involved, and reluctant to adopt this instrumentation. However this hardware is necessary, and surgeons will be rewarded for the extra effort required when they see the transverse nail disappearing in the small skin incision and safely moving through the slot in the intramedullary nail, on its way into the femoral neck and head.

Description of the Insertion Jig (Fig. 117)

The bow (A) with the spigot (B) is placed on the head end of the intramedullary nail, and fixed with the threaded bolt (C), which is passed into the extraction hole in the nail. There must not be any play between the nail and the spigot. If such play is found, any technician should readily be able to slightly raise the height of the lugs (D) by soldering on a small amount of metal and filing off the excess. The hole (E) accepts an extracting hook, which allows the nail mounted on the bow to be knocked out the requisite distance.

The tube (F) extends to a site close to the cortex. However, the entry point in the cortex must not be any play between the nail and the spigot. If such play is found, any technician should readily be able to slightly raise the height of the lugs (D) by soldering on a small amount of metal and filing off the excess. The hole (E) accepts an extracting hook, which allows the nail mounted on the bow to be knocked out the requisite distance.

Please note: The axis of the tube is aligned on a point 2.5 mm distal to the centre of the slot in the intramedullary nail. This “allowance” has proved necessary, since the drill-tipped wire, burr or guide wire will strike the cortex at an angle, and will be displaced upwards by ca. 1.5 mm, even at slow drilling speeds. A further 1 mm has been added as a safety factor (Fig. 118). The rationale for this eccentric alignment is as follows: if the transverse nail contacts the intramedullary nail somewhat too distally, it will be deflected in a proximal direction and finish up in the slot; whereas a transverse nail that contacts the intramedullary nail too proximally will seize and drive the intramedullary nail upwards, and the nail positioning achieved by that stage of the procedure will be brought to naught. This is why an additional safety feature has been added, in the form of a rounded upper edge of the transverse nail. In the event of a transverse nail fouling the edge of the intramedullary nail, this rounding would need to be increased by filing off some more of the transverse nail’s edge.

It is important to remember that the axis of the tube is 2.5 mm off the centre of the slot in the intramedullary nail, since, prior to the insertion of the nail, the surgeon will need to check that the jig has not been bent out of shape; and if the deliberately eccentric alignment is not taken into account, the surgeon may be tempted to correct what he considers to be a malalignment of the tube.

The tube (F) extends to a site close to the cortex. However, the entry point in the cortex must be made with a short, stout drill-tipped K-wire (H), to prevent excessive proximal migration. Once this pilot hole has been made, the nail guide wire (J), which tapers markedly towards its front end, may be inserted; for a better visualization on the check roentgeno-
grams, the nail guide wire has been designed long enough to penetrate all the way into the femoral head.

The final hole in the cortex is made with the large burr (K), which is screwed onto the burr holder (K1), and unscrewed after use, since lack of space makes it necessary for the burr holder to be introduced from outside. The length of the burr is such that damage from contact between the nail and the burr is ruled out.

A small amount of bone will, of necessity, be left standing at the proximal edge of the drill hole; this bone will need to be pierced by the transverse nail (Fig. 119). The nail will readily go through this bone, and the bony edge does not constitute a disadvantage, since it will push the nail “downwards”, i.e. in a favourable direction. However, the surgeon will need to be aware of the fact that some resistance will have to be overcome as the transverse nail is being inserted. If major resistance is encountered, it would be advisable to pull the transverse nail out again. If the transverse nail has fouled the proximal edge of the slot in the intramedullary nail, the upper edge of the transverse nail will have been deformed, and will need to be rounded off a little bit more.

The vertical member of the I-shaped transverse nail or femoral-neck nail (L) is placed in the springy fork (M1) of the nail holder (M). The nail holder fits exactly into the tube holder (F), from which the tube has been removed, and will thus be correctly aligned. The nail is tapped in with gentle blows. It will be left protruding from the cortical hole by the depth of the slot in the nail carrier (M).

All the drilling instruments are connected to the drill shaft by a connector (N), which allows the instruments to be changed frequently by simple plugging into or unplugging from the connector.

These details of the insertion jig should make the description of the nailing sequence easy to follow:

1. The patient is positioned supine on a standard fracture table. The involved limb is left unattached and undraped for the time being. For the insertion of the nail guide and the intramedullary nail, the hip is maximally flexed, and the thigh maximally adducted and internally rotated. The patient is pushed as close as possible to the edge of the table. In this way, the guide can be directed obliquely upwards through a percutaneous approach, and readily introduced into the medullary cavity (Fig. 120). Once the nail is definitely in the medullary cavity, the guide may be removed, since it is no longer
required; indeed, it must be removed, since the head end of the intramedullary nail would not leave sufficient space for it. Before the head end of the nail disappears beneath the skin, the targeting bow is applied, and the nail is driven into the bone, leaving only ca. 2 cm standing proud. Care must be taken to ensure that the nail is in correct rotation from the start.

The landmark to be used is the patella, which indicates the coronal plane of the lower limb. The plane of the bow must be posteriorly angled by 30 degrees in relation to the coronal plane, to take account of the anteversion, by that amount, of the femoral neck.

2. The patient is positioned as for femoral neck nailing.

3. The patient is definitively draped.

4. The tube is mounted, to indicate the direction in which a scalpel will have to be pushed through the skin and the fascia. Once the incision has been made, the tube is fully advanced.

5. The small entry point in the cortex is made with the short stout K-wire (H), using a low speed so as to prevent the tip straying upwards.

6. The nail guide wire (J) is introduced.

7. Biplanar roentgenograms are taken to check the fracture site and the position of the nail guide wire (Fig. 121).

8. Any necessary corrections are made. For this, the nail guide wire is removed, following which the necessary corrections to the fracture site are made, as are the adjustments to the insertion depth and the rotational alignment of the nail required in the light of these corrections. If the corrections are major, the tube may need to be removed and a new skin incision made; if they are minor, the soft tissues may have sufficient give to allow the use of the old incision.

Where corrections have been made, the following sequence is observed:

9. Another pilot hole is made, the nail guide wire is reintroduced, and biplanar roentgenography is performed.

10. When the nail guide wire is well centred in the femoral neck and head, the burr is used to fashion the hole in the cortex.

11. The nail guide wire and the tube are removed.

12. The nail mounted on the nail carrier is introduced and tapped in with gentle hammer blows.

13. Check roentgenograms are obtained (Fig. 120).

14. The bow is removed, and the incisions are closed.

The short incisions may be closed with two interrupted sutures each.

Initial concerns about the use of drilling instruments without any tissue protection have proved unfounded in practice. Even the large burr rapidly becomes covered in a layer of fibres from the adjacent soft tissues, which prevents extensive necrosis occurring; and wound healing has been found to be perfectly satisfactory.

Surgeons who, initially, are uncertain about the depth to which the intramedullary nail should be inserted, and the rotation it should be given, would be well advised to use a guide pin, as in the nailing of femoral-neck fractures. This nail is inserted at what is presumed to be the correct portal of entry and in what is presumed to be the right
direction. Roentgenograms are taken to indicate the necessary correction to be applied at the insertion of the intramedullary nail; and the targeting bow will be directed according to the guide pin (Fig. 122).

Group-I, -II, and -IV fractures can be readily managed using the technique described above. In Group-III, -Va and -Vb fractures, reduction may present major problems, especially where the axis of the femoral neck is not directed towards the centre of the medullary cavity, i.e. towards the site of the intramedullary nail. However, with these as with all other fractures, reduction is a prerequisite for nailing.

The Y-Nail

It must also be borne in mind that a “standard nail” cannot suffice. Standard nails are short and strongly tapered. They cannot protect against rotation, since there is insufficient friction between the intramedullary nail and the bone. Group-III, -Va and -Vb fractures would not be protected against rotation, since the outer end of the transverse nail would either be inside the fracture gap, where it cannot obtain a sufficiently firm hold to stabilize against rotation; or it would actually be proximal to the second fracture line.

This is why these fractures have to be managed with special, made-to-measure intramedullary nails (with diameters of up to 18 mm), so as to produce adequate friction between the nail and the bone.

These nails will, of necessity, be more difficult to insert; fracture fragments may be displaced by forceful hammer blows, especially where corrections are required. Even improving the position of the nail will be difficult, since the nail cannot be rotated unless it has been largely extracted from the medullary canal. It follows that, in these cases, special care should be taken to ensure that, from the start, the nail is correctly positioned in the distal fragment, using the patella as a landmark. Where this is done, very slight malrotation may be corrected by rotating the nail with the distal fragment (!)

Patients managed with a Y-nail are usually allowed out of bed as soon as their general condition and wound pain permit. Fragment stabilization will be excellent.

Nail removal may be performed at 3–4 months. The skin incisions required will, again, be small. The patient is positioned with the nailed limb uppermost. For the removal of the femoral-neck nail, the limb must be internally rotated 30 degrees, if the approach is to be through the old scar.

In elderly subjects who are not to be placed at the risk of another operation, this large nail, too, may be left in situ indefinitely. Patients nailed three years ago have not, to date, shown any adverse effects of this large metal foreign body.

21. Condylar T-Fractures

In this extremely severe fracture pattern, closed reduction and fixation will frequently not be possible, while any exposure of the fracture site puts the knee joint and the limb at great risk. This prompted us to consider whether the benefits of intramedullary nailing could not be brought to bear also in the management of these fractures. However, the nail by itself would have been insufficient, since it would, of necessity, force the condyles apart and penetrate into the knee joint, invariably making things worse rather than better.

The separated condyles must be joined by a transverse wire, and the tip of the intramedullary nail has to be united with the wire, to prevent the short fragment tilting backwards. Ideally, the transverse wire should be passed through a hole in the tip of the nail, under fluoroscopic guidance. However, whilst this would be perfectly feasible from a technical point of view, wartime restrictions are making it impossible to procure a device of this kind. For the time being, the makeshift solution shown in Fig. 123 will have to be adopted.

1. The transverse wire is inserted and tensioned with a Beck wire strainer. The wire should be placed fairly close to the fracture site, so as to minimize the risk of the nail not
redezvous with the wire.

2. The intramedullary nail is inserted in customary fashion. The nail has a V-shaped notch at its tip. Its length needs to be determined with special care.

3. The fracture is reduced. As a rule, great force will be required for this manoeuvre. The traction wire and stirrup in the distal fragment, and a strap for the proximal fragment, will be used as handles. The traction forces required are great, and have to be delicately controlled as the nail is being placed on the wire; these requirements can be met only by the use of a block and tackle.

The procedure is much hampered by poor visibility (since the wire strainer will obscure the site). However, it is well worth the effort.

Depending on the position of the fragments and on callus formation, it will be advisable, for the first 6–8 weeks post-nailing, to apply slight additional traction at the leg (tibial tubercle or calcaneus), since this is, after all, a multi-fragment fracture, and since the construct is exposed to very considerable muscle forces (femoral and crural muscles). The limb is placed on a Braun frame. After the removal of the nail and the transverse wire, a cast is applied to prevent redisplacement of the fragments.

During the initial post-nailing period, the entry and exit sites of the transverse wire must be closely monitored. The final position of the tensioned wire will be different from the position at insertion. This is why relief incisions are advisable, to prevent the wire cutting through the skin and putting the patient at risk from infection.

22. Atypical Nailing Patterns

Atypical nailing patterns may be required where a fracture has occurred in a context of bone deformity, or where there is stiffness or a fixed deformity of a neighbouring joint. The
Atypical Nailing Patterns

examples given below show just some of the many possible patterns.
1. Transverse fracture of the tibia just distal to a knee joint with a fixed flexion deformity causing a 45-degree extension deficit. The straight nail was inserted into the tibia from an entry portal half-way up the femur, and passing through the knee joint. As a result, the extension deficit was improved to 20 degrees, and the (female) patient was able to walk at three weeks, without any problems (Fig. 124).
2. A 16-year-old male patient with a pronounced fixed recurvation deformity underwent osteotomy. The femur was osteotomized just above the knee joint, and a 60-cm-long intramedullary nail was percutaneously introduced at the trochanter and advanced as far as the mid-tibia, to stabilize the construct. At two weeks, the patient was able to ambulate with a straight leg (Fig. 125).

Fig. 125 Osteotomy in a patient with a pronounced fixed recurvation deformity of the knee.

Fig. 126 Subtrochanteric fracture in a patient with an ipsilateral stiff hip joint.

Atypical Nailing Patterns

Fig. 127 Humeral non-union above a stiff elbow joint. a = before nailing; b = after nailing.
3. A subtrochanteric fracture in a patient with a stiff ipsilateral hip joint may be nailed in customary fashion (Fig. 126). However, it must be borne in mind, in the positioning of the patient, that the distal fragment will need to be aligned according to the proximal one; and that traction will need to be installed accordingly. Also, in the postoperative management,

it must be remembered that the redisplacing forces will be particularly strong, since the hip joint cannot move to reduce the lever action. This is why prolonged bedrest, for a period of 4–5 weeks, will be required. During the first few weeks, the patient should lie free in bed, and care must be taken to protect against repeated trauma, since the long lever arm constituted by the lower limb could bend the nail or cause it to break out of the trochanter.

4. A humeral non-union above a stiff elbow joint may be managed with a straight femoral nail (in this case, a 10-mm-diameter device), since the nail can be passed through the joint. This compensates for the disadvantage of the long lever arm, which otherwise tends to affect healing very adversely in such cases (Fig. 127).

5. Oblique fracture of the tibia, at the junction of the middle and the distal third, in a patient with a very narrow (6-mm-diameter) medullary cavity. Since the rotate-to-spread nail cannot cope with this pattern, and a deflect-to-spread nail would harbour too great a frac-
ture risk in a 6-mm canal, the fracture may be managed with a tapered nail inserted from the medial malleolus. This produces a nail diameter of 9 mm at the fracture site (Fig. 128).

6. The intramedullary nail may also be used in bone grafting. In the case shown here, the proximal end of the ulnar shaft had been resected, for recurrent fibrous dysplasia; at 2 months, the defect was as shown in the drawing on page 96 (Fig. 129a). The radial shaft opposite the defect was divided, and the segment thus obtained was used as a free bone graft to fill the ulnar defect; both bones were fixed with intramedullary nails (Fig. 129b).

At 3 weeks, the radial osteotomy site was well healed, and the graft was partly surrounded by callus. Follow-up to date has been too short to judge the longer-term outcome.

7. Knee-joint fusion with a long nail has been tried three times so far. One patient, with tabes dorsalis, failed to return for follow-up despite several invitations. He stated that he had no complaints; however, given the nature of his disease, that information cannot be taken as evidence of bony union. The second patient died one year after nailing, before her follow-up examination. In the third patient, who was also female, bony union could not be detected. While the 60-cm-long nail introduced percutaneously at the greater trochanter is very stable, this stability would appear to be insufficient for the elimination of all shear movements at the bone ends, since the femoral and tibial sites in intimate contact with the nail are at least 25 cm apart from each other. Over this distance, limb stabilization is provided solely by the strength of the nail. If there is movement or springiness in the nail, the bone ends will angulate; more often than not, there will even be shear movement, since tilting would lengthen the limb. This lengthening is counteracted by all the muscles and by gravity, which allows the fragments to move only with shear. The amplitude of these movements will be the greater the further apart points a and b are (Fig. 130). This is why the resection should be V-shaped. In this pattern, the bone faces are firmly compressed together, as in an oblique fracture, and shear movement is ruled out (Figs. 131 and 132).

8. Another special pattern is the nailing of a fracture sustained, at a different or at the same site, in a previously nailed bone. In such cases, it must be borne in mind that, after the removal of the old nail, the medullary cavity will be left much restricted by central callus. This is why (regrettably) a thinner nail than at the index procedure will need to be chosen, since a nail of the same diameter would become incarcerated in the callus (Fig. 133). It would be more useful to fit some saw teeth at the tip of the nail, to allow it to cut a new track.

9. In one case, at the request of the patient, we prophylactically used an intramedullary nail to support a femur containing a subtrochanteric breast-cancer metastasis (Fig. 134). At 3 months, following radiotherapy, the metastasis was no longer demonstrable, and the nail could be removed.

10. Subtrochanteric osteotomy may be performed, with excellent outcomes, using a very...
curved femoral nail.

In this case, the longitudinal flexibility of the nail will provide a tight fit in the bone, and supplementary casting will not be required (Fig. 135).

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