ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM 112

From the Department of Orthopaedic Surgery,
University of Gothenburg, Sweden
(Head, Professor Carl Hirsch)

Internal Fixation in Hip Joint Arthrodesis

EXPERIMENTAL STUDIES IN AUTOPSY SPECIMENS

BY RAGNAR KALÉN

MUNKSGAARD COPENHAGEN 1968

From the Swedish by Lois Goldie-Carlson

Orstadius Boktryckeri Aktiebolag, Göteborg, 1968

Contents

Acknowledgements

This investigation was carried out at the Biomechanical Laboratory of the Orthopaedic Clinic, University Hospital, Göteborg.

I wish to express my gratitude to all those who have helped and supported me in my work.

Professor Carl Hirsch, Head of the Ortopaedic Clinic, has guided and advised me. I am much indebted to him for his never-ending interest and encouragement.

Tore Waltersten, Mechanical Engineer, helped me in developing the measuring technique, the experimental appliance and the other designs. I wish to express my sincere thanks for this. Lektor Esbjörn Carlström and Assistent Bo Eriksson, Division of Statistic Analysis, University of Göteborg, have supervised the statistical part of this work. At Chalmer's Institute of Technology, University of Göteborg, I wish to thank Professor Jan Hult, Division of Strength of Materials, Professor Bengt Jakobsson, Division of Mechanics and Professor Erik Stemme, Division of Computer Research. I am also very grateful to Docent Bertil Stener and Docent Ian Goldie for valuable and appreciated discussions, to Engineer Hans Hellström for assistance with the experimental work, to Miss Gerd Grundén, Mrs Inga-Lisa Elzer and Miss Lena Johansson for secretarial work.

This investigation was supported by grants from The University of Göteborg, the Medical Society of Göteborg, Gustaf and Ulla af Uggla's Foundation and the EIR Insurance Company.

Introduction

At the end of last century arthrodesis was introduced as an operative technique for various disabilities and lesions of the hip. Since then, however, the attitude towards and the indications for this method have varied. It is now accepted in orthopaedic surgery and has become one of the classical treatments. Many problems are involved in the use of this technique and, therefore, extensive research work, especially clinical, has been carried out.

The operation is of a major kind and for a long time implicated primary mortality at a rate which could not be disregarded. The improved technique of anaesthesia and the control of fluid balance have almost eliminated these risks. Longstanding immobilization is necessary to achieve fusion. This results in a high frequency of post-operative complications such as thromboses, embolism, stiffness of the knee-joint, respiratory and urinary tract infections and so on. To shorten the time of immobilization numerous methods of internal fixation have been suggested. The aim has been to make the primary fixation of the joint components stable enough to allow the patient to get out of bed early and also to avoid plaster immobilization of other joints.

The proposed methods of osteosynthesis have been elaborated clinically. The efficiency of these methods have been reported as part of all the factors which are involved in the clinical healing results.

In this study an attempt is made to explain, theoretically and experimentally, the conditions of osteosynthesis in arthrodesis of the hip. Furthermore, experiments were carried out to establish the effectiveness of different methods in achieving primary stability. For this purpose a suitable technique was elaborated.

PART I

Historical Review

The surgical procedure, *arthrodesis,* carried out to prevent mobility of a joint by fusion, was denominated by Eduard Albert in 1877. In 1878 he performed this operation in a knee-joint and in 1892 in a hip joint. At that time, however, several other authors had described the operation in the hip. Heusner (1884) and Lampugnani (1885) had performed operations on a few cases of congenital dislocation. Lagrange (1886), Dollinger (1891) and Daraignez (1891) described operative techniques using different kinds of internal fixation. In 1892 von Winiwater also applied arthrodesis of the hip.

Besides Albert, Albee contributed at an early stage, by introducing arthrodesis of the hip. His first case, reported in 1908, was very successful. The indication was osteoarthritis, and the arthrodesis was performed by using an intra-articular technique, adductortenotomy and fixation with a larger plaster hip spica. Five weeks later the plaster was removed up above the knee, and after nine weeks the patient was mobilized. After four months he was back working as a patrol man.

An important indication at this time was the various types of infection in the hip, especially tuberculous arthritis. The aim was, if possible, to avoid engaging the actual joint in the operation. In 1913 Maragliano and Albee performed the first extra-articular arthrodeses with bone grafting. The graft was applied in an ilio-femoral position. Various positions of the graft were described during the 1920's by a number of surgeons. Maragliano (1919) described a technique of ischio-femoral bone grafting as well as Trumble (1931). Brittain (1952) developed this technique to the so-called ilio-femoral V-arthrodesis.

During the 1930's attention was again directed to a combination of the different techniques of arthrodesis with internal fixation.

Van Nes (1932), Burns (1935, 1939) and Watson-Jones (1934, 1938) emphasized the importance of stable immobilization to obtain a successful result. The immobilization was not considered satisfactory unless internal fixation completed the plaster spica. The technique of osteosynthesis, recommended by these authors, and gradually coming into usage was fixation with a three-flanged nail.

Some methods elaborated during the last decades include derangement of the joint. This was done by resection of the caput, dislocation of the caput through the acetabulum (either by fracturing the acetabulum or reshaping the caput and dislocating it into a bore in the acetabulum) or by pelvic osteotomy with dislocation (Charnley, 1953; Küntscher, 1953, 1956; Müller, 1953; Dwyer, 1961).

Arthrodesis was during the last two to three decades challenged by competitive methods, such as different types of arthroplasty and osteotomy. At the end of the 1930's it was believed that one plastic operation was carried out in ten arthrodesis, while twenty years later plastic operations and arthrodesis were performed in a ratio of two to one (Friberg, 1958). At present the reverse seems to prevail as compared to the 1930's. Many authors advocate the great advantages of arthrodesis. Albee (1921) thus writes: "There is hardly any operation that gives a larger percentage of very grateful and satisfied patients than the arthrodesis". Watson-Jones (1956) maintains: "No operation is more advantageous to the patient, more satisfactory to the surgeon, more reliable for restoration of the function". Blount (1956) says: "Arthrodesis of the hip is one of the most valuable procedures for the relief of disease, pain or disability of the hip".Crawford-Adams (1966) points out the advantages of arthrodesis: "Its reliability in abolishing pain, the stability it affords, its capacity to stand up to hard work and its permanence". Höbler (1964) believes: "Die Arthrodese .... schafft ein stabiles Bein, führt zu Schmerzfreiheit, bürgt für ein relativ gutes Gangbild, und ist unabhängig vom Muskelgleichgewicht". He also quotes Creyssels: "Bedauert man manchmal eine Arthroplastik gemacht zu haben so bedauert man selten den Endschluss zur Arthrodese gefasst zu haben".

The main disadvantage of arthrodesis of the hip is the actual object of the operation, namely the loss of mobility in the joint. The motor function of the body changes, the gait may be affected and it may be difficult to carry out certain movements; especially the lumbar spine will be subjected to further tension. If ankylosis can be achieved in a functional position which is the most suitable for the individual, the restrictions will be reduced. It is also noteworthy that the indications for the operation are generally based upon severely restricted movements of the joint, connected with pain. The pain is often associated with muscular contractures which are believed to result also in restricted lumbar mobility. With abolishing pain, the patient often gets a paradoxical sensation of a greater range of movement.

Besides the general complications as a consequence of the operation the difficulty is associated with ensuring successful union. In so-called fibrous healing, some authors have reported good clinical results (Charnley, 1953; Mortens, 1960; Morris, 1966). As opposed to bone union pain was however not always abolished. "Die Arthrodese kann natürlich nur zur Schmerzfreiheit führen wenn eine vollkommene ossäre Ankylos eintritt" (Schindler, 1958).

The high frequency of non-union as reported by some authors (inter alia Stinchfield-Cavallaro, 1950; Cholmeley, 1956; Lipscomb and Mac Caslin, 1961; Williams, 1962) accounts for the hesitation in adopting this technique.

Attempts have been made to improve the union by large and well fitting contact surfaces, bone grafting, by improved methods of fixation, subtrochanteric osteotomy and longstanding immobilization in plaster.

The surgeon's aim is to bring about a union in the best functional position with the shortest possible bedrest.

Important factors of the operative technique are:

I. Position of Arthrodesis
II. Contact Surfaces and Bone Grafting
III. Technique of Internal Fixation
IV. Subtrochanteric Osteotomy in Arthrodesis.

I. Position of Arthrodesis

In the literature published during the last three decades, the authors seem to agree upon the recommended positions. The usually recommended position is flexion at 20—30 degrees, neutral position between abduction and adduction, and outward rotation at 0—10 degrees (Table I). The lack of a well-defined initial position from which the angles are measured is remarkable, however.

Usually, the desired flexion is achieved by using the technique recommended by Burns and Watson-Jones. The patient is lying on his back with his leg in contact with the table. The lordosis of the lumbar spine is then supposed to correspond to a flexion in the hip of 20—30 degrees. Lindahl (1966) measured the angle between the normal leg at maximum extension and the leg to be arthrodesed. The angle between the legs should then be about 45 degrees. Together with Ahlbäck (1966), Lindahl also described a roentgenological measuring technique.

In the frontal plane the position should be neutral. Abduction is recommended, when leg shortening has to be compensated. Lindström (1956) however warned against compensating shortening through abduction as the gait will deteriorate. Konforti (1962) claimed that an abduction position will cause increased back pain.

Several authors point out the difficulty in measuring the angle for abduction/adduction. Furthermore, the neutral position gives an angle between the longitudinal axis of the femur and the vertical plane at 5—10 degrees in a standing position (Weinreich, 1959; Herbert, 1960; Crawford-Adams, 1966).

Adams (1931) adopted Kingsley's and Lovett's methods from 1888 for measuring flexion and abduction. Dickson (1951) designed a so-called coxometer in order to facilitate angle measuring in both the sagittal and the frontal planes. Lindahl (1965) introduced a technique for determining the abduction by measuring the distance between the medial malleoli with the legs together. A difference of 1 cm means an abduction of approximately 3 degrees.

The adduction position ought to be avoided due to the risk of disturbed balance and gait. Herbert (1960), however, stated that an adduction of 10 degrees would be suitable and Alvik (1962) suggests 2—5 degrees. The

TABLE I

Author	Year	Degree of Flexion	Degree of Abduction	Degree of outward Rotation
Albee, F. H.	1908	10	10	0
Watson-Jones, R.	1938	25—30	0	0
Bailey, E.T.				
Jackson-Burrows	1939	30	0	0
Burns, B.H.	1939	25	0	0—5
Girdlestone, G. R.	1940	10 years 10 15 years 15 20 years 25 adults 30—35		
Karlén, A.	1944	25	0	0
Niebauer, J.				
King, D.	1946	35—50	0	—
Smith A. de F. et al.	1949	25	—	—
Stinchfield & Cavallaro	1950	35	10	15
Merle d'Aubigné, R.	1952	30	—	—
	1965	20	0	0
Mayr, H.	1953	25	0	0
Charnley, J.	1953	10 Women 30	0	0
Ehalt, W.	1954	20	0	5
Stone, M. M.	1956	30	10	15
Lindström, N.	1956	20—30	0	0—5
Blount, W. P.	1956	30	0	0—5
Thompson, F. R.	1956	20	— 5	0
Watson-Jones, R.				
Robinson, W. C.	1956	30	Max 15	0
Lanciotti, G.	1958	20—25	0	0
Herbert, J.	1960	25	—10	5
Sicard, A. & Gerhard, J.	1960	20—25	5—10	0
Cozzolino, A.	1960	20—25	0	0—5
Lipscomb, P. R.				
Mc Caslin, F. E.	1961	15—20	0	0—5
Vesely, D. G.	1961	20	10—15	0
Konforti, B.	1962	5—10	0	0
De Palma et alt	1962	20	0	0
Alvik, I.	1962	25	—2 — —5	0—5
May, V. R. & Mauck, W.	1962	15—25	10—15	0
Graham, E. C.	1963	10—15	5	5
Tsoukas, G. S. et alt	1964	Max 20 (25—30 in persons working in a sitting position)	0	0
Verheugen & Navarre	1964	Max. 30	0	5—10
Höbler, W.	1964	25	0—8	10—15
Lenoble, J-C.	1965	20	0	0
Cauchoix, J. et alt	1965	10—20	0	0
Crawford-Adams, J.	1966	15—20	0	0
Lindahl, O.	1966	45 (angle of flexion measured from the maximum extension of the healthy leg)	0	0—5
Fox, T. A.	nd	40	10—15	10—15

initial position from which these degrees were measured has not been specified. Merle d'Aubigné (1963) defined the neutral position thus: The line transversing the centre of the femoral head and the centre of the medial condyle of the femur should be perpendicular to the line through the acetabulae. He believed that a slight adduction will not cause any disturbance while abduction causes limping, compensatory scoliosis and back pain.

For the rotation, zero-position or slight outward rotation is recommended. Charnley (1953) warned against inward rotation as it will then be impossible to take a normal step.

In order to get a suitable position from the point of rotation, it is recommended that the patella should be directed upwards when the patient lies on the operating table.

II. Contact Surfaces and Bone Grafting

1. Intra-articular Contact

The first arthrodeses were performed as intra-articular procedures. Albee (1908) used a chisel to plane the upper part of the caput so that this would fit against an equally planed acetabulum. By dislocation of the joint and removal of the cartilage from the joint surfaces, attempts were made to improve the contact surfaces. Watson-Jones (1938) recommends this technique, combined with internal fixation. Attitudes towards dislocation of the joint vary. The critics, especially Charnley (1953), maintain that the contact surface actually becomes smaller by the caput being reduced relative to the acetablum. According to his technique the caput/collum are converted into a cylindrical or cone-shaped plug which will fit in a drilled bore through the acetabulum into the pelvis. Dickson (1947) tries to avoid reducing the caput in relation to the acetabulum by laminating the cartilage, so that the surfaces will remain congruous. Another method is to adjust the cavity in the acetabulum according to the size of the caput by using a suitable milling tool. Smith and Baab (1949) recommended dislocation in order to remove the cartilage entirely. At the same time they drilled several bores in the caput to facilitate the healing. Vogl (1950) described a method where the caput is not dislocated. Instead he used a chisel through the collum/caput chipping the joint surfaces. Schindler (1958) dislocated the caput and inserted an ilio-femoral bone graft. A similar procedure is recommended by Tsoukas (1964).

The advantage of completely removing the articular cartilage is that a large bone contact is obtained. The disadvantage is that the operation will be more extensive, that the nutrition of the caput will be jeopardized by the dislocation, and that the position of the joint adjusted prior to operation may not be maintained. Lange (1958) believed that dislocation of the caput will not improve healing, but instead increase the risk of non-union. Lindström (1956), Höbler (1964) and Chapchal (1965) amongst others do not believe in a better result if the joint is dislocated. The operation becomes more extensive and the nutrition of the caput will be impaired. In connection with internal fixation Chapchal also believes that the ligament and the capsule will offer resistance when the nail is hammered into the acetabulum. Verheugen & Navarre (1964) reported non-union in 10 per cent of their cases of intraarticular arthrodesis with luxation of the joint and 15 per cent without dislocation.

2. **Bone Grafting**

Since Maragliano and Albee in 1913 performed their first cases of bone grafting, the development of this technique became of current interest. The use of bone grafting was to obtain a bridge between the pelvis and the femur, to stimulate the bone regeneration and achieve stabilization. The bone grafting also enabled bridged healing without engaging the actual joint. This was considered advantageous when infections occurred in the joint, especially tuberculosis, which at that time was a usual indication for arthrodesis of the hip.

There are several ways of classifying the methods of grafting. The easiest way is to classify according to the positions of the graft; a) the ilio-femoral and b) the ischio-femoral bone grafting.

a) *Ilio-femoral Bone Grafting*

The ilio-femoral bone graft can be placed in an extra-articular, a para-articular or an intra-articular position. The extra-articular technique is recommended by Albee (1919), Hibbs (1926), Key (1926), Wilson (1927), Schumm (1929), Girard (1935). Para-articular bone grafting has been described by Nové-Josserand (1921), Hass (1922), Mathieu (1926), Albee (1929), Sorell (1930), Henderson (1933), Harris (1935), Kellog Speed (1937), amongst others.

This procedure has also aroused much interest amongst several authors during latter decades. Thus, Davis (1954) used a crista graft with the muscular insertion intact, to ensure blood supply. The graft is placed in a groove across the joint after removal of the articular cartilage. Decoulx (1965) modified this technique. He did not dislocate the joint and performed subtrochanteric osteotomy. Cattaneo (1959) used a graft from the greater trochanter and displaced it into the ilium completing with a trans-articular graft from the tibia. His experimental investigations revealed that the tibial graft is the strongest, the femoral, on the other hand, is superior to a graft from the fibula.

Schindler (1958) described a technique resembling that of Hibbs. After removing the articular cartilage, a graft of about 12 cm is taken from the lateral side of the greater trochanter and the femoral shaft. It is rotated 180 degrees around its upper end and is fixed to the ilium. He believed that the graft will offer complete stability. Boytchev (1960) drilled a tunnel penetrating the greater trochanter and part of the ilium. Through this tunnel he hammered a suitable bone graft taken from the tibia. Boos (1963) chiselled off the upper parts of the greater trochanter and the femoral head, superseding these by a processed bone. Henssge (1967) also used a processed bone which is inserted as a 13 mm coarse bar into a drilled bore transarticularly via the neck and the head.

The procedure nowadays in general use, is to place a graft from the ilium across the upper part of the joint, possibly combined with removal of the articular cartilage and internal fixation (Ghormley, 1931; Watson-Jones, 1938; Lange, 1951; Lindström, 1956).

b) *Ischio-femoral Bone Grafting*

De Beule (1909) was the first to describe ischio-femoral arthrodesis. He resected the head and part of the neck and after medial displacement of the femoral end towards the ischium he used a screw for fixation. He did not use any graft. Maragliano (1919) published an ischio-femoral bone grafting technique. Trumble (1931) used a graft which was placed in a rectangular opening, cut in the posterior, subtrochanteric part of the femur, and continuing into a cleft made in the ischium. Other authors connected with this technique are: Galland (1931), Calvé (1932) and Gutiérrez (1935). As a rule, the graft was taken from the tibia or the fibula. Kirsch (1939), however, used the 10th rib as a graft.

Brittain (1942) developed the ischio-femoral technique into his standard method. He emphasized that in arthrodesis the leg tended to become adducted during healing due to the strength of the adductors. By placing the graft in an ischio-femoral position it will be subject to compression as opposed to a graft in an ilio-femoral position, which will be subject to tension. From the mechanical and healing points of view, he preferred the ischio-femoral position. Later he combined the operation with subtrochanteric osteotomy and internal fixation with a nail. Through the osteotomy the graft is placed into the ischium. The technique has varied with respect to grafting, osteotomy, and internal fixation. Howard (1950) considered that a long period of plaster immobilization was unnecessary and that the patient could walk with crutches after a few weeks' time. In his series of 17, he reported 14 cases of ankylosis. King (1952) stabilized the osteotomy with a plate to avoid plaster. Resina (1954) turned the graft 90 degrees on its side. His aim was to achieve a greater stability of the osteotomy. This does not coincide with Brittain's idea. He claimed that the osteotomy should not be fixed but remain unstable to reduce the stress which otherwise would occur in the arthrodesis, because of the long lever formed by the femur.

Crawford-Adams (1966) gave a survey of the results of various ischio-femoral procedures. In 7 series reported independently, totalling 115 cases, operated according to Trumble, there was a mean healing of 81 per cent. 11 series including 260 cases, operated according to Brittain without internal fixation, show the same rate of fusion. 5 series, 278 cases, operated with V-arthrodesis (ischio-femoral graft + nail fixation) fused in 84 per cent. In Crawford-Adams' opinion the disadvantage with Trumble's and Brittain's methods is the long period of immobilization in plaster. On the other hand, Brittain's technique of subtrochanteric osteotomy offers the possibility of correcting a malposition and of eliminating the long lever of the leg. Anyhow, there is a risk of pseudarthrosis in the osteotomy. Mayer (1948) warned against lesions of the sciatic nerve. In his experience it is unadvisable to take the graft from the tibia because of the high rate of post-operative fractures. He recommended that the graft instead should be taken from the ilium. An additional problem is the limited mobility of the knee-joint caused by long-term immobilization in plaster. Vesley (1961) kept the plaster on for six months. In his series of 44 cases no patient above 20 years of age regained full mobility of the knee-joint.

Finally, combinations of ilio-femoral and ischio-femoral grafting are reported (cf. Lapras, 1965). Greenberg (1952) inserted grafts through drilled tunnels into the ischium as well as the ilium and through the joint.

III. Techniques of Internal Fixation

Already when the first reports were published on arthrodesis of the hip, the authors were aware of the fact that stabilization was of importance for the union. The best healing conditions were created by eliminating the movement between the surfaces which were to be joined. During the first decades of the 20th century, this was attempted by using a full length hip spica. At the end of the 19th century, different types of internal fixation had been tried, however. Lagrange (1886) used two carpenter nails. Dollinger (1891) described one method with bolt reinforcement and another with a silver thread stretched between a plate on the inside of the pelvis and a plate on the greater trochanter. In the same year Roersch and Daraignez independently, suggested fixation by the use of an ivory pin.

The great problem was to obtain non-corrosive osteosynthetic material at this time. This reduced the interest for internal fixation. Not until the 1930's did the question arise again about improving the primary stability by internal fixation.

1. Fixation with Three-Flanged Nail

Van Nes (1932) used a thin nail for the osteosynthesis. He was discontented with the stability and, therefore, tried two crossed nails. Finally, he changed over to a three-flanged nail of a larger dimension than the usual Smith-Petersen nail. Watson-Jones (1934) pointed out that the bad results with failures up to 50 per cent were caused entirely by inadequate immobilization. In a series of 16 cases he had inserted a three-flanged nail through the joint, all of which fused. He compared this with the fixation in femoral neck fractures and emphasized the importance of counteracting rotation. In his report Burns (1938) mentioned that in 1935 he began to use a coarse three-flanged nail. He agreed that the bad union depended on the inadequate fixation. To begin with he used a three-flanged nail of 20 mm diameter, but experienced that in many cases it split the trochanteric region. Consequently, he changed over to using a nail of the Watson-Jones type with a diameter of 15 mm, slightly coarser than the Smith-Petersen nail (13 mm).

The three-flanged nail has since predominated. This method has been discussed by many authors, mainly from the following points of view:

a) Technique (position of nail, ability to stabilize, plaster immobilization)
b) Complications.

a. *Technique*

Watson-Jones (1938) described the technique he used for arthrodesis of the hip and advised that the nail should penetrate 2.5 cm into the acetabular roof and that the immobilization in plaster should be maintained for $2^1/_2$ months. In 1956, he stated that the position of the nail should be oblique in the collum. In his series of 120 cases, 94 per cent healed. Haggart (1945) reported a series operated according to Watson-Jones' technique. He pointed out that the nail prevents adduction and rotation but not completely, flexion-extension.

Burns (1939) indicated an inclined direction of the nail through the collum in the frontal plane. He mentioned that roentgenologically, an anterio-posterior view will not reveal if the nail is safely secured in the pelvis. The tip of the nail may seem to lie in the bone while in reality it lies inside the true pelvis. Thompson (1961) also remarked on this phenomenon. In order to avoid an erroneous position of the nail, Burns recommended that a special oblique view should be taken as well.

Bailey & Jackson Burrows (1939) advised a steeper direction of the nail than for fractures of the collum. The insertion should be made further down in the femoral shaft, about 1.25 cm behind the anterior surface of the femur. The nail will then perforate the upper area of the caput. The operation includes drilling of several bores through the head to achieve a more rapid union. An objection is that the resistance of the caput will be impaired with unsatisfactory securing of the nail as a result.

Harris (1943) suggested that the nail should be placed along the longitudinal axis of the collum through the acetabular internal cortex. Furthermore, he inserted a trans-articular graft, but was not satisfied with the fixation and, therefore applied a plaster hip spica. He believed that rotation still may be possible and drilled a Kirschner-wire through the distal femur with the ends outside the plaster. The immobilization in plaster continued for four months. A main complication is the limited mobility of the knee-joint which often occurs.

Karlén (1944) and Ehalt (1954) were of the opinion that the nail should be inserted 4 cm into the pelvis. The latter recommended a nail of the Böhler type, which is slightly coarser than an ordinary three-flanged nail. None of the authors discuss how to reach the desired depth. Arriola (1952) who used a van Ness nail said that "... ohne Zweifel ist die länge und Dicke des Nagel ein wichtiger Faktor der Fixierung".

In his textbook on orthopaedic surgery Lange (1951) described the normal procedure in arthrodesis of the hip; para-articular grafting, fixation with a three-flanged nail followed by immobilization for three or four months. The nail should be directed towards the deflection point of the ileo-pectineal line and the tip of the nail penetrate the internal cortex. Mayr (1953) stated the same direction in his series of 200 cases. Viernstein (1956) held forth that merely a three-flanged nail will not offer satisfactory fixation without immobilization in plaster. His series included 326 operated cases.

Among the authors who during the 1960's discussed the problem of the position of the nail and its stabilizing ability, Herbert (1960) suggested that it ought to be directed backwards-upwards through the collum towards the lower part of the sacro-iliac joint. Sicard & Gerhard (1960) instead placed the nail in the longitudinal axis of the neck, if possible slightly backwards. Thompson (1961) pointed out that when the nail is placed centrally, it will not have a safe grip in the pelvis. In order to obtain this, it must be directed backwards. If at the same time the nail is in the centre of the collum, it means that the arthrodesis must be carried out with inward rotation. He mentioned that Wright for that reason used a curved Smith-Petersen nail. Castaing (1962) showed pictures of a centrally positioned nail. Graham (1963) tried to direct the nail backwards and penetrated the internal cortex at the ilio-pectineal line by a more ventral insertion in the femur. Gardiner (1962) prefered a depth in the acetabulum of 2½ cm with the nail through the weight-bearing area of the femoral head. Kempf et al. (1964) attempted a more vertical direction of the nail so as to prevent flexion-extension. A Böhler nail was used at a depth in the acetabulum of 3—4 cm. Tsoukas et al. (1964) also employed a Böhler nail. They kept their patients immobilized in plaster for three months. Cauchoix et al. (1965) also advised a coarser nail but later changed over to fixation with two screws. Dickson & Hartman (1965) used a technique which on the whole corresponds to that of Watson-Jones. The patients were mobilized 4—6 weeks after the operation but plaster was not always applied. On the other hand, the patients must use crutches up to six months. The rate of non-union in the follow-up was bareley 12 per cent.

Crawford-Adams (1966) inserted the nail about 2 cm below the greater trochanter and directed it towards the centre of the iliac fossa with an inclination forwards at about 15 degrees. The tip of the nail will then emerge at the arcuate margin of the pelvis. Charnley (1953) and S:t Clair Strange (1965) emphasized the anatomical fact that an angle in the transverse plane is formed by the neck of the femur and the body of the ilium. This means that the nail in order to reach deeper into the ilium must be inclined backwards.

Radulescu (1964) suggested a completely different position. He inserted the three-flanged nail from behind through the caput into the acetabular portion of the pubic bone. He believed that the conventional position will not prevent rotation, on the contrary to his technique. The method has been tried on specimens, but no comparative experiments on stability have been carried out. The described position means that the nail will penetrate the thin cortical layer of the caput and that the bone available is not fully utilized.

b. *Complications*

The risks of complications which may arise are:
a) fracture at insertion, b) nutritional disturbances, c) diastasis of the joint, d) difficulties to insert the nail into the acetabulum, e) subtrochanteric, post-operative fractures.

All these complications can be more or less referred to the shape and the size of the nail.

a) The risk of splitting the femur at insertion is especially pronounced when using three-flanged nails of a coarser dimension. For instance, Burns for this reason changed over from a nail which had a diameter of 20 mm to a thinner one. It is also essential to prepare the entrance into the femoral cortex carefully which Watson-Jones (1956) and Chapchal (1965) amongst others have pointed out. When the cortex of the femur is fractured, the securing of the nail will be impaired (Karlén, 1944; Nyström, 1944).

b) Disturbances of the nutrition in connection with osteosynthesis of femoral neck fractures have been mentioned (Compere & Lee, 1940; Linton, 1944; Brodetti 1961). Campell (1937) reported that the nail disturbs the nutrition, partly through direct vascular lesions, partly by preventing revascularization. Furthermore, when arthrodesis is contemplated, the nutrition of the caput and the acetabulum is already disturbed in many cases. Merle d'Aubigné (1964) warned against extensive dissection of the proximal femur as this may result in necrosis of the femoral head.

c) Several authors mention that diastasis easily occurs in the joint when the nail is hammered into the acetabulum. Generally, diastasis is overcome by some blows with the hammer against the greater trochanter after the nail has been put into place (cf. Mayr, 1953). Lindström uses a modified nail extractor with which he compresses the head against the acetabulum. Unander-Scharin (1965) has described the instrument. Crawford-Adams applies a screw across the joint parallel and above the guide-wire in order to avoid diastasis.

d) Sometimes it may be difficult to hammer the nail into the acetabular roof. Karlén (1942) suggested that in these cases several bores should be drilled in the acetabular roof. The nail will then be easier to hammer in and the osteogenesis will improve according to the principle of Beck-drilling in pseudoarthrosis. He also designed a special shape of the three-flanged nail. Mayr (1953) reported a series of 167 cases of arthrodesis where in four cases the nail could not be hammered in because of a sclerotic acetabulum. In one of these, the acetabulum fractured.

e) The rate of post-operative subtrochanteric fractures is rather high. Bailey & Jackson-Burrows (1939) suggested that a short hip spica should be kept on for a long period because of the risk of subtrochanteric fractures. Lindström (1956) had one fracture in 41 cases followed-up. Chapchal (1962) had two fractures in 91 cases and in another series of 114, there were five subtrochanteric fractures. Haw (1964) had three in 30 cases and Merle d'Aubigné (1964) had 13 subtrochanteric fractures in his series of 240 cases, four of these occurred at the site of the insertion of the three-flanged nail. This was one reason for his changing over to fixation with screws. Ehalt (1954) suggested a nail and plate to avoid the fracture, a method which also was supported by Gardiner (1962) and Crawford-Adams (1966). Gardiner performed V-arthrodesis on his series and had 7 fractures in 54 cases. Verheugen & Navarre (1964) reported 70 cases, 28 of which were stabilized with double three-flanged nails and 42 with a single one. The rate of fractures among the first ones was 21.4 per cent and the latter 4.7 per cent. The weakening of the proximal femur caused by insertion of the three-flanged nail increases considerably when a parallel nail is introduced in addition.

2. Other Methods with Trans-Articular Nailing

The technique of osteosynthesis with a trans-articular nail has been modified by many surgeons. Küntscher (1953) pointed out that *one* nail is unsatisfactory as it does not prevent rotation. He recommended stabilization with two curved nails. In his opinion one nail could possibly suffice, provided that it is curved. A plaster hip spica is not required, instead mobilization can commence after two weeks. He suggested, furthermore, that the caput-acetabulum should be drilled in a coneshaped bore in order to avoid stress concentration, and refered to Martin's experiments. Lechten (1956) operated on 16 cases according to Küntscher's method. On the radiographs only ten revealed union, and four slipping of the nail. Weiss & Münzenberg (1962) published a critical article with a series of 30, out of which only 4 united. Witt (1965) criticized Küntscher and pointed out that on the pictures demonstrating his technique, the nail did not lie in the bone but inside the true pelvis which results in an unsatisfactory securing of the nails.

Witt (1956) has invented his own type of double nail. A three-flanged nail is inserted in a superior-posterior direction and then a thinner nail is introduced into a hole of the coarser nail, close to its head and at a pointed angle. The thinner nail will then be hammered into the relative centre of the acetabulum. The author believed that by using this method he could reduce the time of immobilization from between 16 and 20 weeks to between 6 and 8 weeks. He mentioned, however, that it must not be expected that even this technique will ensure an absolute primary stabilization, due to the thin, often sclerotic, iliac bone.

Piatkowski (1959) stressed upon the unsatisfactory fixation obtained by the use of a three-flanged nail. His technique is to introduce a three-flanged nail lengthwise into the collum through the internal acetabular layer, and a second nail of the same type in a transversal direction. No mention is made as to the dimensions used. If nails of the conventional type are used (diameter about 13 mm) it must be difficult, sometimes impossible, to fit them inside the cortex of the collum. An impairment of the bone construction will result due to a large amount of the bony substance being destroyed.

Alvik (1962) combined the three-flanged nail with a plate, which was formed individually at the operation and placed over the joint, reaching from the anterior-superior iliac spine to the ventral surface of the proximal femur. It is secured with several screws. The author kept the patient immobilized in a short hip spica for four months, but permitted weight-bearing already after 3—4 days. In 45 cases there was no pseudarthrosis.

At osteosynthesis of a fractured femoral neck, several authors contemplated using a few thin nails for stabilization. This would mean a reduced risk of unsatisfactory nutrition and a better fixation. Nyström (1944) thus prefers osteosynthesis with three thin nails. Compere & Lee (1942) showed by their experiments that several threaded stainless steel wires gave a very good fixation in the collum fractures. Similar experiments were also carried out by Harmon and coworkers (1948) and by Deyerle (1965). This technique has not been used in arthrodesis to the same extent. Blount (1956) described the so-called "pin and dowel arthrodesis". Several — four or five — pins are hammered into the greater trochanter and spread inside the ilium. Blount approved of this technique if, prior to the operation, the mobility of the hip was limited. Smith and coworkers (1949) used three nails. The technique was varied inasmuch as the nails were hammered from the inside of the ilium out into the caput. The reason of this has not been expressed. Of 14 patients who were operated upon, 12 united. In one patient the nail slipped into the pelvis. A number of drilled bores in the caput and the acetabulum would improve the union according to the author. In the described method the bone material is not fully utilized to secure the nails, and the resistance of the bone will become further impaired by the trauma caused by the drilling.

Stinchfield & Cavallaro (1950) had a series of 117 cases in which the mean rate of non-union was 23 per cent. Of 11 cases stabilized with a three-flanged nail, combined with intra-juxta-articular arthrodesis, all but one united. Of 10 patients on which fixation was carried out by using three thin Vitallium nails in different directions, all united.

3. Screw Reinforcement

Osteosynthesis with screws is mainly used in France and Italy. Zanoli (1935) described a trans-articular screw which together with a plate is fixed to the femur. Putti (1938) described a simple trans-articular screw without a plate. Delitala (1946) and Casuccio (1946) have also designed transarticular screws. The latter stabilizes with two screws which are placed at an angel to each other.

In their clinical series where the fixation was done by using a trans-articular screw with a femoral plate Branchiforti & Lanciotti (1957), reported 4 cases of non-union out of 31. Genovesi (1964) who used a trans-articular screw with or without a femoral plate, sometimes in combination with osteotomy, reported 32 operations and a nonunion rate of 40 per cent. Cozzolino (1960) described 35 cases stabilized according to Delitala and obtained union in 94 per cent. The patients were immobilized for five months. Ciuccarelli & Marchi (1962) used two screws for fixation. In a series of 79 cases the union amounted to 71 per cent, in addition 21 per cent were relieved of pain. Teinturier (1966) used 3 or 4 screws, one of which is placed in an ischio-femoral position.

Schumpelik (1955) found mechanical deficiencies when stabilizing a fractured collum with a three-flanged nail. The nail only gave support at one fixed point which is the lateral layer of the cortex. The author in his opinion had a superior technique of osteosynthesis. He used a supporting, coarse screw and a more cranially placed thinner screw, connected to the former with a metal plate. The upper screw is subjected to tensile stress and prevents the caput from slipping. The described technique of osteosynthesis has been employed by Henssge (1967) for arthrodesis of the hip. No spica is applied. The author has refrained from publishing the clinical results. To start with Merle d'Aubigné (1962, 1965) used a three-flanged nail of the van Nes type but later changed to two screws and then again to three screws, always in combination with plaster immobilization. In calculating the percentage of union in relation to each technique of fixation, he found that in a series of 195 operated cases, there was fusion in 76, 84 and 89.5 per cent, respectively.

Particularly in osteosynthesis with screws it would seem necessary to utilize the multi-point fixation. The reason being that the circular cross section of the screw will not prevent rotation around its longitudinal axis. Furthermore, the moment of inertia for a screw is less than that for a three-flanged or a four-flanged nail of the same dimension. Consequently, it will have a smaller resistance to bending stress. The screw is superior to the nail due to its greater ability to resist tensile stress in its longitudinal axis. In arthrodesis of the hip there is no stress of this type but instead the body weight and muscular force have a compressing effect. The motives assigned to preferring screw reinforcement thus seem diffuse.

4. Intra-Medullary Nails

Several authors have tried to perform arthrodesis with one nail into the medullary cavity of the femur. According to Schneider, a long broad nail is driven in from the crest of the ilium and through this, down into the femoral shaft. May & Mauck (1962) using that technique had four satisfactory fusions out of six operated cases. Mobilization with weight-bearing began two weeks after the operation.

A notable difficulty with the intra-medullary methods is that the elongation of the femoral diaphysis will be lateral to the ilium. Küntscher (1957) suggested transversal osteotomy through the collum/caput and the acetabulum to obtain a better position. The lower part of the pelvis and the femur will then be medially displaced, and an intra-medullary nail can be driven through the ilium into the femoral shaft.

Dwyer (1964) also used a Küntscher nail from the crest of the ilium into the femoral shaft. He obtained medial displacement by fracturing the acetabulum and sliding in the caput. In 9 cases out of 10 there was fusion. One of the disadvantages of stabilization with an intra-medullary nail, is the difficulty of getting the nail into position. Thus, in three of these cases an unsatisfactory position of the hip resulted as the abduction and outward rotation was too great. The author pointed out that the Küntscher nail does not prevent movements around its longitudinal axis.

Onji et al. (1965) also used a straight nail which is driven in from the iliac crest into the femur. Of 18 cases 16 united. The authors pointed out the difficulty of getting the correct position in the arthrodesis. Rütt (1958) was sceptic against the intra-medullary nail and thought that it was used too often and freely. His experience had been bad due to complicating infections.

De Palma and coworkers (1962) considered the hip in its normal anatomical position as the most suitable for arthrodesis. Thus they did not resect the caput nor did they perform osteotomy of the pelvis or similar procedures. The authors stabilized with a nail-plate which was hammered into the femoral shaft and attached to the ala ilii with through bolts. Earlier, screws were used for the fixation, but after a short period they detached from the ilium. Of 15 cases, two of which had been re-operated after an unsuccessful Schneider arthrodesis, one did not unite. De Palma declared that there will be compression in the arthrodesis caused by the body weight and the muscular force.

5. Osteosynthesis with Compression

Several authors have insisted that union will be more rapid and secure if the osseous surfaces are subjected to compression. Others, inter alia, Andersson (1965) are not of the opinion that the osteogenesis would improve by compression.

Compression may also contribute to better stability. The osteosynthetic material has consisted of nails, screws and plates.

Axer (1961) and Fox (n. d.) have independently, designed a compression nail following the same principle. The nail is driven in from the greater trochanter up through the collum-caput, penetrating the internal cortex of the acetabulum where it is locked with a stop-plate. On the trochanter side the end of the nail is threaded, and a plate is slipped over which rests against the cortex of the femur. Then a coil spring is passed over the nail end and finally, a nut is threaded on. In this way there will be a continuous compression in the arthrodesis.

Axer (1961) reported 19 cases. Out of these 7 were further stabilized with a hip spica for two to four months. According to the author, immobilization in plaster is not always necessary. 6 cases were re-operated. In 5 cases (26 per cent) there was no fusion. Fox has not published any clinical results.

Langenskiöld & Laurent (1967) reported a series of 13 cases operated with Axers' method. In 10 of these the follow-up was long enough to allow assessment. All of these were fused. Plaster was not used and mobilization began the day after the operation. Already in 1945 Niebauer designed a compression device according to the above principle (personal communication 1967).

Ostapczuk (1964) described a nail which is driven into the ilium through the acetabular roof. There is a hole in the tip of the nail. A pin is threaded from the outside of the ilium into the hole of the nail, thus locking it. A nut is used to bring about compression. Five cases were operated without complications. No mention is made of the rate of fusion.

Mac Kee (1957) utilized a coarse screw for the osteosynthesis. It is screwed into the acetabular roof. The part of the screw on the femoral side of the joint is smooth so that it will easily slide into the bone tunnel drilled in the collum/caput. By means of a plate and a nut, compression is caused. In view of the fact that the screw, running through the collum/caput is smooth with a circular cross section, it is unable to resist torque. The clinical report is favourable, however. Out of 50 operated cases, 94 per cent united.

Charnley (1953) also used a compression screw. He tried to maintain the compression with a coil spring. In his first series 13 out of 15 cases united. The healing is not verified by X-ray and probably also includes what the author calls fibrous union. Morris (1962) using Charnley's method distinguished between clinical and radiographically verified healing. In a follow-up series of 55 cases he found union on the radiographs in 80 per cent when a plaster hip spica had been applied, and in 60 per cent when no plaster was used. The clinical healing, i.e. abolishment of pain, on the other hand, was 86 and 90 per cent, respectively. Mortens & Jensen (1960) had improved patients in 33 out of 39. Only 17 of these 33 revealed fusion. Charnley (1955) reported fusion in 50 per cent, Debeyre (1958) stated 42 per cent and Piggot (1960) in 71 per cent.

Thompson (1963) did not approve of Charnley's technique and received the statement with scepticism that the so-called fibrous healing afforded as good a result as the radiographically verified fusion.

A complication, following the operation according to Charnley's technique, is fracture of the femoral neck, which by Morris (1966) was stated to occur in 9 per cent in a series of 55. Herbert (1960) made a theoretical analysis of the forces in a normal hip and a fused hip. He found that in a fused hip, the femoral neck was influenced by great forces. He calculated the compression and tensile stress at about 250 kp/cm^2 when the patient stands on one leg without a nail. This stress is reduced with 20 per cent using a three-flanged nail, and with 10 per cent when the nail has a circular cross-section.

The compression lessens and quickly disappears after the operation. Charnley found that without spring loading the compression had disappeared already during the first post-operative days. Morris stated that also the spring loaded compression screw lost its effect during the first post-operative weeks. Rydell's investigation (1965) revealed that the caput is subject to considerable stress even when the patient lies in bed, because of the muscular activity required to lift the healthy leg, for instance. Thus, compression develops in the joint without any special device. Pelvic osteotomy and compression belong to the method elaborated in Switzerland and designated the AO-technique. (Müller, 1953, 1967; Gertsch, 1966). After performing osteotomy in the upper edge of the acetabulum a plate is screwed to the outside of the ilium. The plate contacts the lateral side of the chiselled greater trochanter and the proximal femoral shaft. The plate is shaped individually at the operation if necessary. No plaster immobilization is used and after three weeks mobilization begins. The clinical results have not yet been published. The great problem here as in the earlier-mentioned intra-medullary methods is to obtain the desired position of the arhtrodesis. No mention is made of the difficulty in achieving a satisfactory attachment of the screws in this weak part of the ilium with its thin cortical layers. This also applies to other methods where plates are used for stabilization.

Stone (1956) applied a simple plate across the cranial part of the joint down to the greater trochanter. The plate is supposed to give compression. He immobilized for four months in plaster. The author reported good clinical results with a union rate of 95 per cent in an operation series of 41 cases. Daubenspeck (1966) screwed two plates to the upper part of the joint and used immobilization for six weeks. He believed that compression in the joint occurred by the spring load of the plates.

6. Other Methods

A method which completely differs from those earlier mentioned has been elaborated by Kirkaldi-Willis and coworkers (1958). The caput is fixed to the pelvis with a staple over the joint. A singular staple is from the mechanical points of view an unsatisfactory solution to the problem of stabilization. The forces arising will be transferred to a very small part of the bone with too great a stress in the bone as a result. The clinical results stated at a fusion rate of 54 per cent in a series of 37 cases also suggest unsatisfactory stability.

IV. Subtrochanteric Osteotomy in Arthrodesis

The osteosynthesis in arthrodesis of the hip will be subject to great stress because of the long lever formed by the femur. One way of increasing the relative stability of the osteosynthesis would thus be to eliminate the lever. This idea has caused several authors to suggest shortening of the lever by subtrochanteric osteotomy.

F. R. Thompson (1956, 1961) is spokesman for this. He claims that following arthrodesis of the hip, the femur with the caput acting as a fulcrum has a lever effect of 23:1. The shaft is approximately 35 cm and the radius of the caput aproximately 1.5 cm (cf. Figure 1 a). By merely stating these figures, a correct assessment of the problem cannot be made. This relation, 23:1, is furthermore incorrect. The centre of the caput does not act as a fulcrum but instead the mechanical model "beam with built-in end" is applicable. Loading of the femur will cause both bending moment and torque of the nail. Provided that the collum/caput is fixed with a nail in the longitudinal direction of the collum, Fig. 1 b illustrates that in subtrochanteric osteotomy, the eliminated lever will be shorter than the 35 cm calculated by Thompson. However, the full effect of the muscular force has been neglected here. In subtrochanteric osteotomy the adductors and the dorsal flexors as well as the rectus femoris muscle and the major gluteal muscle are eliminated, but the medium and minor gluteal muscles, the short rotators and also the iliopsoas muscle still act (cf. Fig. 2).

Originally, osteotomy was suggested in cases of tuberculosis. Abbott (1931) described a technique where the hip was widely abducted to make the adductor muscles cause compression. Correcting osteotomy was performed at a second operation, and the position was gradually adjusted. This technique was especially adopted for children with tuberculosis. Farkas (1939) used osteotomy in cases of tuberculosis in the hip to achieve a more rapid healing.

Blauth & Mau (1960) reported in a series of 21 cases 9 cases of non-union, 4 of which in the hip, 2 in the osteotomy and 3 both in the hip and the osteotomy. They considered it disadvantageous that two operations must be performed and that the time of immobilization is long (4 months), and the shortening of the leg pronounced (3.7 cm on an average).

King (1952) performed osteotomy to correct the position. He used a plate for internal fixation to avoid a hip spica. Lange (1958) also regarded

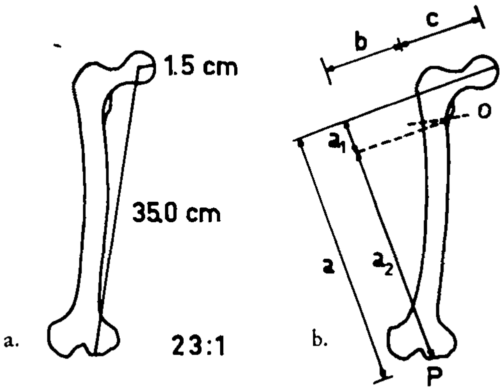


Fig. 1 a. The leverage 23:1 is supposed to be eliminated at subtrochanteric osteotomy. (According to F. R. Thompson)

Fig. 1 b. a = leverage for torsion around nail reduced by a_2 at subtrochanteric osteotomy.
b = eliminated part of leverage for bending moment in subtrochanteric osteotomy.
P = the assumed point of action of force. O = place of osteotomy.

N. B. Only the leverages in the frontal plane are calculated.

the osteotomy as important to correct the position and to reduce the risk of adduction appearing in the arthrodesis.

The main indication for osteotomy is to reduce the mechanical stress. Wilkinson (1946), Cholmeley (1956) and Thompson (1956) suggested this as a routine procedure in arthrodesis of the hip. The latter reported a series of 34 cases on which osteotomy was carried out at a rate of non-union amounting to 12 per cent; 3 in the arthrodesis, 1 in the osteotomy. In a comparative series of 20 cases without osteotomy the rate of non-union was 70 per cent! Internal fixation was not used. The author mentioned that non-union in the osteotomy is difficult to treat but that it is a rare complication. When the paper was read it was criticized by Smith who pointed out that osteotomy possibly eliminated the stress in the arthrodesis for some time. The reduced stress may disappear early if the osteotomy heals. He stated that in his own series he obtained union in 87 per cent without osteotomy. In a series of 103 patients who were arthrodesed according to different methods, Williams (1962) reported unsuccessful results in 60 per cent using ileo-femoral grafting. Osteotomy reduced this figure to 23 per cent.

Lipscomb & Mc Caslin (1961) published the series from the Mayo Clinic. They recommended Thompson's technique and a full length hip spica for four months. Then mobilization with a short spica for two more months. Of the patients treated according to this schedule the majority did not regain more than 70 degrees of flexion in their knee. The average

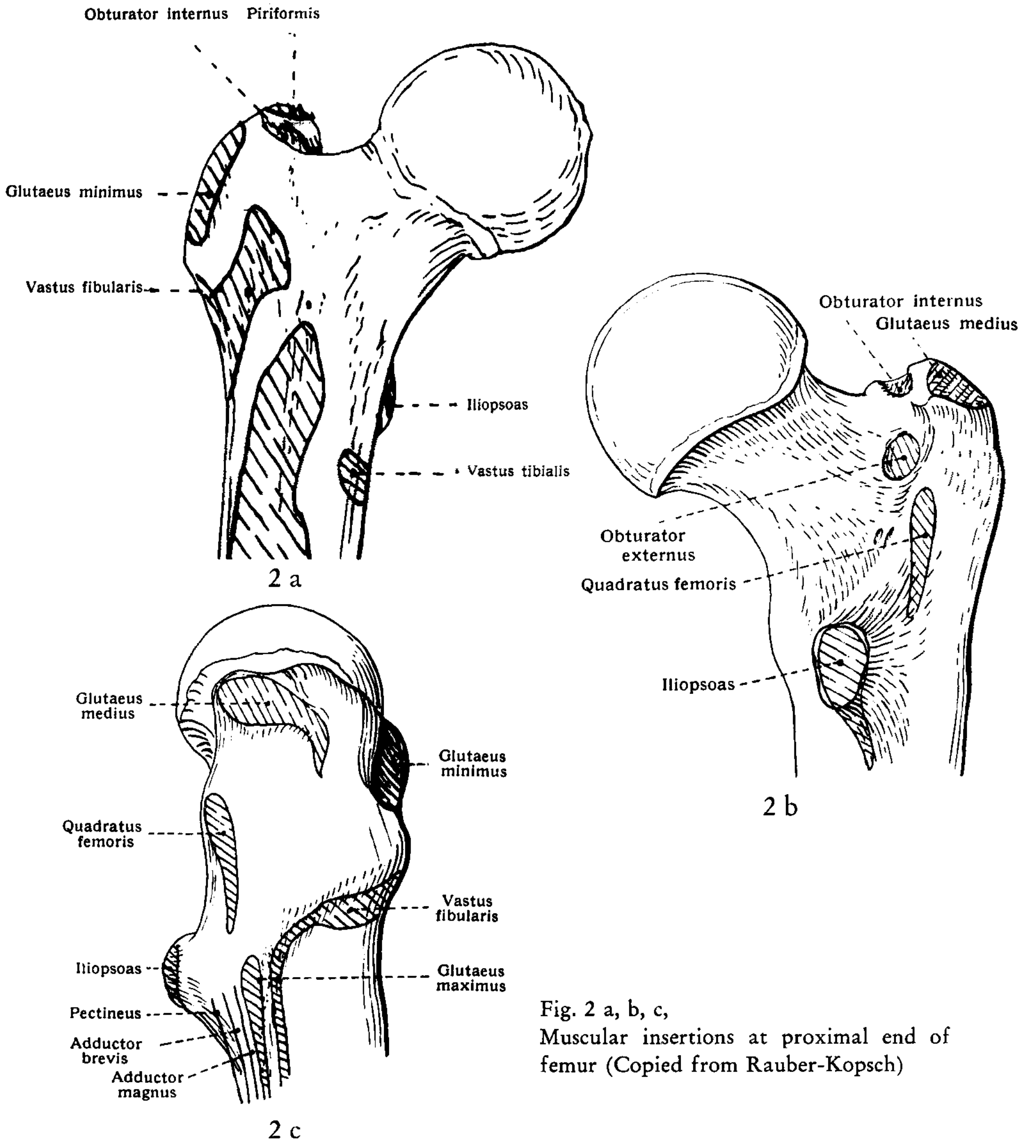


Fig. 2 a, b, c,
Muscular insertions at proximal end of femur (Copied from Rauber-Kopsch)

rate of fusion was 81 per cent without osteotomy, and 88 per cent with osteotomy.

Apley & Denham (1955) stabilized with a three-flanged nail and performed subtrochanteric osteotomy with traction treatment for six weeks. Then the patient was allowed to move about with a short hip spica for another six weeks. The advantage of osteotomy was expressed as follows: "Movement is thus transferred from a site where bone union is difficult and doubtful to one where it is easy and probable". Out of 23 cases treated according to the above technique, one did not unite while in a series of 33 cases without osteotomy fusion did not occur in 20 cases. Guilleminet and coworkers (1965) performed arthrodesis according to Davis' method with a pedicle crista graft. The authors stated that it is not necessary to perform osteotomy as a routine.

Morris (1962) published a series operated upon according to Charnley's technique. He believed that osteotomy may reduce stress in the arthrodesis and thus increase the rate of fusion, but that it may not reduce the time required for immobilization in plaster and for the union. Höbler (1964) also was of the opinion that osteotomy will not guarantee a shorter healing period or union at a higher rate. There is a great risk that non-union will occur in the osteotomy if the arthrodesis fuses. Jones & co-workers (1956) advocate that osteotomy causes further problems and doubted whether the osteotomy by eliminating mobility and stress in the hip can accelerate fusion of the joint. In these authors' view the osteotomy heals prior to the arthrodesis.

Nixon and coworkers (1962) reported 13 cases, operated according to Davis' technique. In 2 cases the arthrodesis did not unite and in 1 case the osteotomy. Stabilization was carried out with plaster for about 15 weeks but without nailing. 6 of the patient could flex their knee at a maximum of 90 degrees. Decoulx (1965) modified Davis' technique and had 2 cases of non-union out of his 10 patients operated upon.

Genovesi (1964) followed-up 32 cases of arthrodesed hip where stabilization was done by means of one or two trans-articular screws. In 29 cases osteotomy was performed and 11 cases of non-union resulted (38 per cent). Cauchoix (1965) published a series of 95 cases, in 22 of which osteotomy was performed. In the entire series there were 15 cases of non-union, one of which in the osteotomy. Out of the 14 non-united, 4 belonged to the group subjected to osteotomy. The rate of non-union in the group of osteotomy will thus be 22.7 per cent. In the group where no osteotomy was performed the percentage was 13.6.

Summing-up, the opinions are extremely controversial with regard to the results and the advantage of osteotomy. When intertrochanteric osteotomy has been performed as the only procedure in osteo-arthritis of the hip, a rate of non-union amounting to between 12 and 13 per cent is reported, despite internal fixation (Crellin & Simurda, 1965; Rousborough & Stiles, 1967; Scott, 1967; Hirsch & Goldie, 1967). The risk of non-union ought to be greater in subtrochanteric osteotomy which is performed as a supplement in arthrodesis of the hip, where merely a hip spica is used for the stabilization. By introducing osteotomy in arthrodesis of the hip, attempts have been made to solve one problem — by creating another.

Part II

OWN INVESTIGATIONS

General Aspects

The shape and physical properties of the reinforcement and of the object which is to be fixed, are decisive for the stability. In arthrodesis of the hip it is thus the anatomical structure and the physical properties of the bone as well as the technical data of the osteosynthetic appliance which determine the efficiency of the osteosynthesis.

The conditions afforded by the bone are set. The appliance can be adapted to suit different demands. Without doubt it is possible to achieve resistance of the appliance which would be superior to that of the bone. The weakness in the construction will thus be the bone. Consequently, the appliance must be designed so that the bone can carry a maximum of the transferred forces. This is done by avoiding stress concentration and distributing it in as large an area as possible.

The bone is a visco-elastic material. The deformation depends on the magnitude, speed and duration of the load. (Sedlin, 1965; Sedlin & Hirsch, 1965). If a certain load is exceeded, a longstanding deformation may occur and with even heavier loads fractures may result. The prospects of a stable osteosynthesis will then be considerably impaired. This means that there will be greater movement between the bone surfaces which are to be fused. The effect of the osteosynthesis is no longer the desired.

The extent of mobility between the articular surfaces in the arthrodesed hip when loading the femoral diaphysis, has in this investigation been used to determine the degree of stability. On this basis an experimental technique has been elaborated.

Theoretical Basis of Measuring Technique

When elaborating the measuring technique, the acetabulum has been regarded as the inside of a hemisphere in which the caput articulates. The caput is regarded as a sphere, its radius is assumed to be R (Fig. 3).

A perpendicular coordination system is placed so that the xy-plane will cover the edge of the acetabulum with the y-axis passing from the anterior-

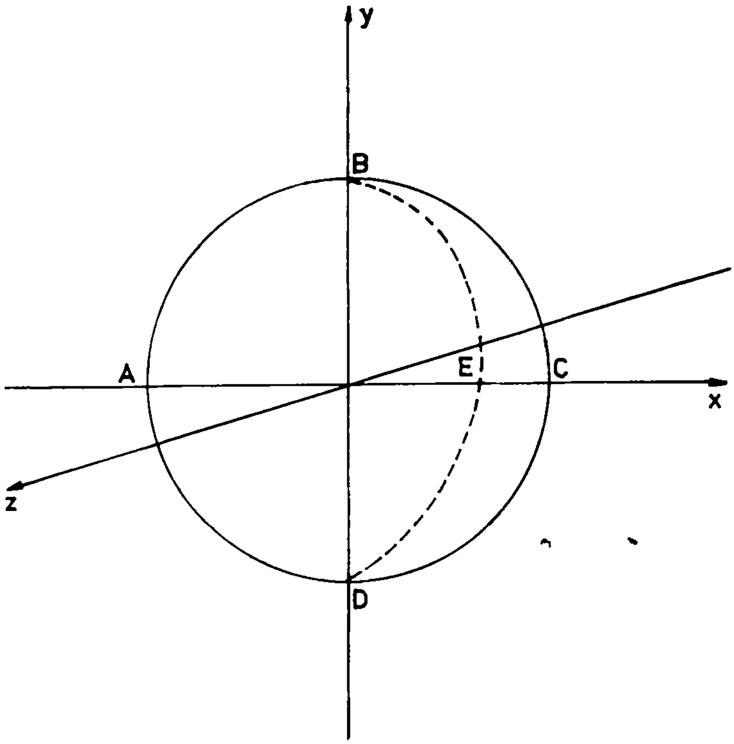


Fig. 3. Three-axes coordination system with measuring points A, B, C and points D and E for which values are calculated.

superior iliac spine through the centre of the caput; positive values are calculated superiorly. The origin of the coordinates is assumed to lie in the centre of the caput. x-values are calculated as positive in an anterio-medial direction. A z-axis is imagined from the origin towards the acetabular centre and is thus assumed to lie at an angle of 90 degrees against the other axes. Its values are calculated as positive from the orgin in a lateral direction. Right-sided specimens were used.

In the xy-plane three fixed measuring points are placed at the acetabular edge as follows:

A) (—R, O, O)
B) (O, R, O)
C) (R, O, O)

In addition two points are defined:

D) (O, —R, O)
E) (O, O, —R)

The latter values are calculated on those measured in A, B and C.

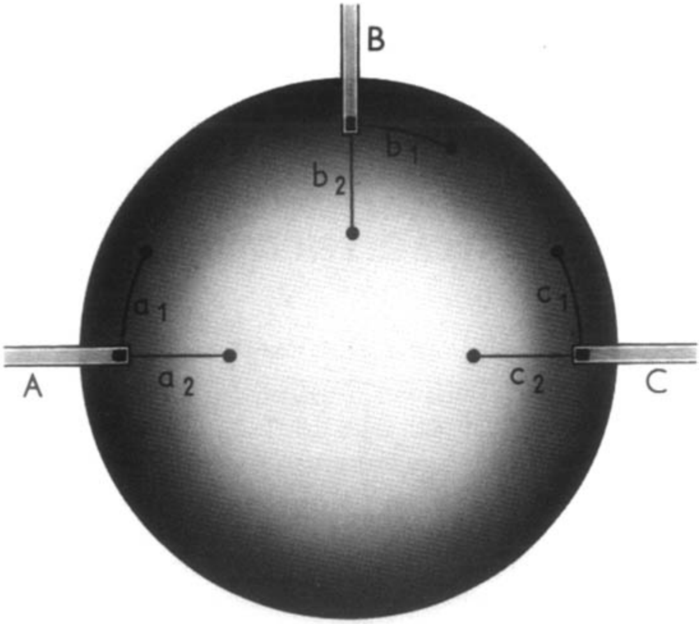


Fig. 4. Direction of measurements for each gauge a_1 a_2; b_1 b_2; c_1 c_2. Measuring point B placed at the acetabular edge below the anterior iliac spine.

Calculations

A body of the assumed shape and with the described initial position can be subjected to rotation and translation. This means that the caput can turn in or slip out from the acetabulum.

The changed positions between the caput and the acetabulum, due to load, are measured in the points A, B and C. In each point the movement is recorded in two planes. Point A: xy, xz, point B: xy, yz, point C: xy, xz. The measured magnitudes are designated a_1, a_2: b_1, b_2: c_1, c_2 (Fig. 4).

The centre of the caput is designated T (x_0, y_0, z_0). Thus, the initial position coincides with the origin. The translation along the respective axes is calculated accordingly:

$$z_0 = \frac{a_2 + c_2}{2}$$

$$x_0 = b_1 + \frac{c_1 - a_1}{2}$$

$$y_0 = \frac{a_1 + c_1}{2}$$

The rotation of the caput is determined also in components around the respective axes.

$$\overset{\frown}{Z}: \qquad p = \frac{c_1 - a_1}{2}$$

$$\overset{\frown}{X}: \qquad q = b_2 - \frac{a_2 + c_2}{2}$$

$$\overset{\frown}{Y}: \qquad r = a_2 - \frac{a_2 + c_2}{2}$$

p, q, and r are defined as a rotation movement around each axis at the distance R from the centre. They are calculated as distances and bound to the xy, yz and xz- plane through the centre.

For point D the translation along the x and z axes will be:

$$d_1 = b_1 + c_1 - a_1$$
$$d_2 = a_2 + c_2 - b_2$$

Point E is calculated in the respective directions of the axes:

$$x = x_0 - r \qquad y = y_0 + q \qquad z = z_0$$

$$x_E = b_1 + \frac{c_1 - a_1}{2} - a_2 + \frac{a_2 + c_2}{2}$$

$$y_E = \frac{a_1 + c_1}{2} + b_2 - \frac{a_2 + c_2}{2}$$

$$z_E = \frac{a_2 + c_2}{2}$$

The relative movement between the caput and the acetabulum in the given points is obtained by compiling the measured and the calculated coordinates. In points A, B, C and D the movement is calculated in the plane to which the two coordinates belong.

$$S = \sqrt{s_1^2 + s_2^2}$$

In point E the translation will consist of movements in all the coordinate directions.

$$S = \sqrt{x^2 + y^2 + z^2}$$

The movement in each point is obtained as follows:

$$S_A = \sqrt{a_1^2 + a_2^2}$$
$$S_B = \sqrt{b_1^2 + b_2^2}$$
$$S_C = \sqrt{c_1^2 + c_2^2}$$
$$S_D = \sqrt{d_1^2 + d_2^2}$$
$$S_E = \sqrt{x_E^2 + y_E^2 + z_E^2}$$

Thus, comparative figures have been obtained for the movement between the caput and the acetabular surfaces in each measured point. The essential for the futher study is the maximum movement, measured to be $S_{(A-E)\ max.}$ This value is selected and used with the designation S_{max} in the movement loading diagrams. The diagram is obtained by plotting the S_{max} as a function of the load.

Experimental Device

The described calculation method, is based upon certain measured data. These have been obtained by the use of a specially designed experimental device. It consists of a stand on which the specimen is mounted in the desired position. The arthrodesis can be done using the osteosynthetic technique to be tested. The device also has measuring and recording equipment. The measuring component shows the distance deviation between one point on the acetabular edge and the corresponding points on the femoral head. The measuring is done in the earlier defined points, A, B and C and in each of these performed in two planes. One is a joint plane for the three points and consists of the earlier defined xy-plane. The measuring is thus performed along the acetabular edge and in perpendicular planes to this measuring direction, i.e. in points A and C in the xz-plane and in point B in the yz-plane.

Mounting the Specimen

The stand consists of four iron corner columns which are mounted in a cement foundation and at the top joined by a sturdy metal plate (Hirsch, 1951). Between the columns displaceable beams are placed in the vertical plane. On these beams a thick wooden board is fitted with sturdy screw joints. The board is adjustable. The pelvic specimen is fixed to the board with three sturdy through bolts (Figs 5 and 6).

A swivel arm is fitted at right angles to each column of the stand. Between these arms there is a cross-beam with a pulley in which the load-wire runs. The load can be applied to affect the desired directions: flexion, abduction, extension and adduction. On the swivel arms, fitted to the columns, there is a supporting arm system which carries the mechanical unit and the extensometers. This system is designed to allow adjustment of the extensometers.

Application of the Load

The load is applied to the femur in the horizontal plane (Fig. 7). The point of application is set at a fixed distance from the upper edge of the caput to a point on the femur. The distance is measured by means of a

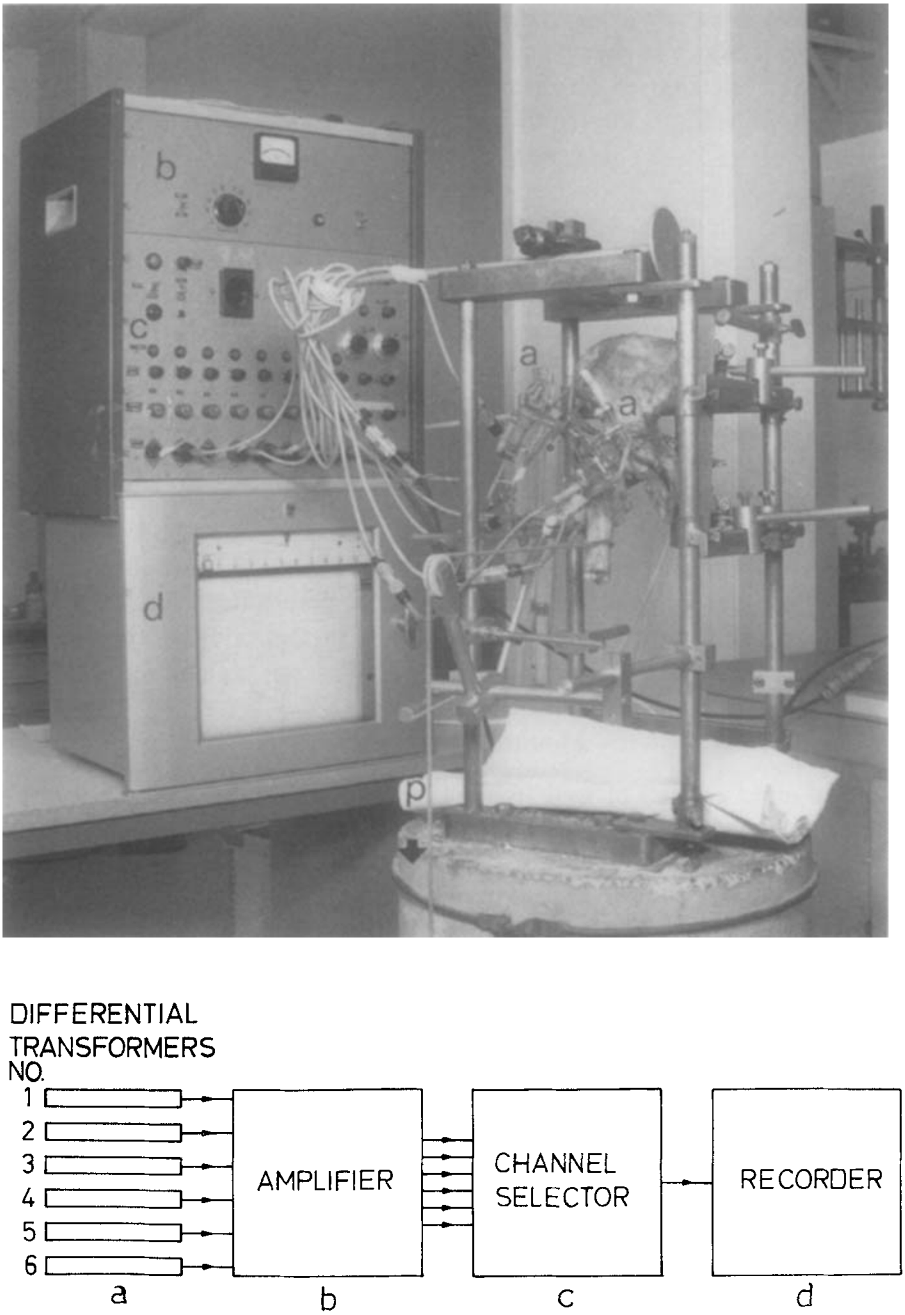


Fig. 5. Photo and diagram showing experimental device. Letters on diagram correspond to letters on photo.

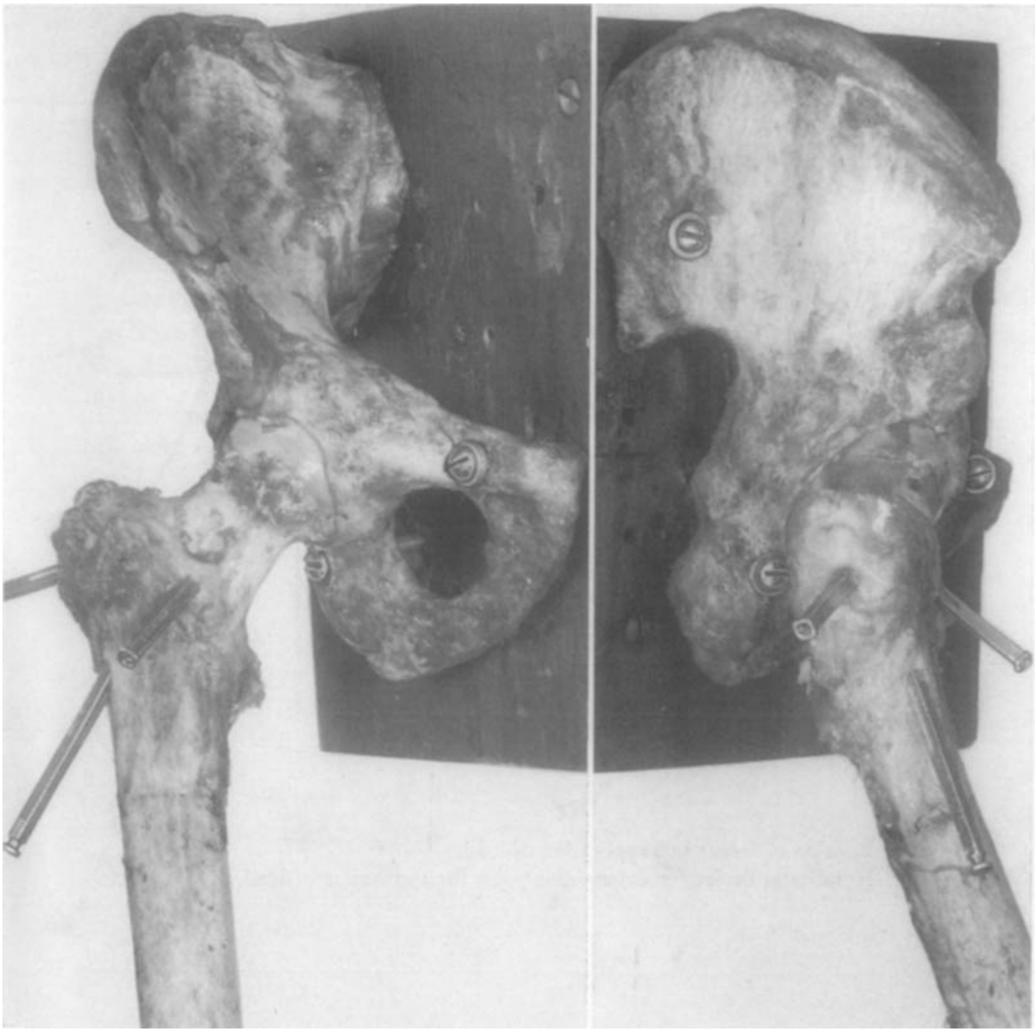


Fig. 6. Specimen fitted to wooden board. Fixation of hip with three partly inserted Nyström nails. Frontal and lateral views.

specially designed measuring plate of transparent plastic. In the upper edge of the plate, there is a hole through which a pin slides perpendicularly to the plate. The plate is held in a vertical position. The point of the pin is directed towards the upper edge of the caput. The lower edge of the plate will then indicate the point at which the loading wire should be applied. The leverage has thus been kept constant.

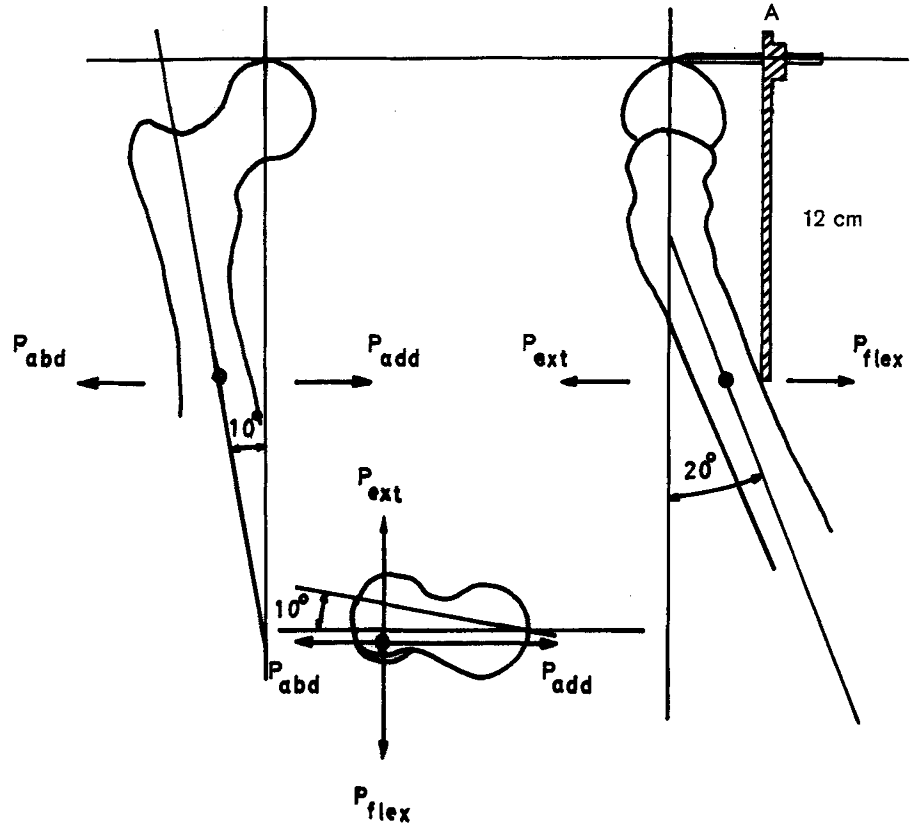


Fig. 7. Position of femur and application of load.
A indicates device for determining point for application of load.

Position of Specimen

The specimen was adjusted to correspond to the pelvis of an individual in a standing position. As it was impossible to obtain specimens consisting of the entire pelvis and both femurs, the individual variations could not be considered. Instead certain fixed angles and distances were decisive for the adjustment of the pelvic specimen as well as the joint:

the angle between the horizontal plane and a line from the promontorium through the upper end of the symphysis — 60 degrees

the angle between the sagittal plane through the symphysis and a sight line between the upper end of the symphysis and the anterior part of the sacro-iliac joint — 30 degrees

the angle between the horizontal plane and a sight line in the frontal plane from the upper end of the symphysis to the anterior superior iliac spine	35 degrees
the acetabular angle according to Sharp (1961)	32—38 degrees
the transverse diameter 13.5 cm	
the angle between the longitudinal axis of the femur and	
the sagittal plane	10 degrees
the frontal plane	20 degrees
anteversion of the collum	12 degrees

(Data from Rauber-Kopsch 1952, Weinreich 1959, Herbert 1960, Backman 1957, S:t Claire-Strange 1965).

The frontal plane of the specimen has been adjusted parallel to one of the sides of the stand.

Measuring and Recording Equipment

Calipers

To measure the movement between the acetabulum and the femoral head, six calipers have been used (Fig. 8). The ratio of these is 1:1 and thus the movement between the measuring tips corresponds to the movement occurring in the gauge which is placed between the opposite ends of the caliper. All the joints of the measuring devices are fitted with ball bearings. The calipers are assembled in pairs with a slightly elastic coupling and fitted in a specially designed frame. They are placed at right angles to each other. The leg of one of the calipers is soldered to the leg of the other using a thin sheet of metal. At the angle of this sheet of metal there is a common tip. This permits slight angular motion between the calipers. The free leg of the feeler gauge is cylindrical and its tip is fitted to a spring-loaded piston which is movable in this cylinder. This is to secure a reliable contact with the specimen (Fig. 9).

The joint measuring tip makes contact with a measuring point on the acetabulum. This consists of a sheet of metal, which is screwed to the pelvis and has a free end protruding from the acetabular edge. The free end is bent towards the surface of the caput so that the measuring tips will lie almost in the same plane. The sheet of metal is covered with a thin layer of plastic to prevent the caliper from sliding against the metal. The free measuring tip is pressed against the surface of the caput.

An elastic band, stretched between the frame and the specimen, guarantees a continuous slight pressure between the measuring tips and the base.

Displacement Gauges

The transducer used is a differential transformer, manufactured by Svensk Elektronikkonsult (AB Detektor) Göteborg. It is identical with that described by Rolander (1966).

The transformer consists of windings on a teflon bobbin inside which there is a movable soft iron core with a brass shaft and a measuring pointer of antimagnetic stainless steel. The length of the gauge is 40 mm with an external diameter of 8 mm. The transducer is wound as a balanced bridge and because of the electrical design it is possible to calibrate against a constant precision resistance. The linear deviation within the measuring

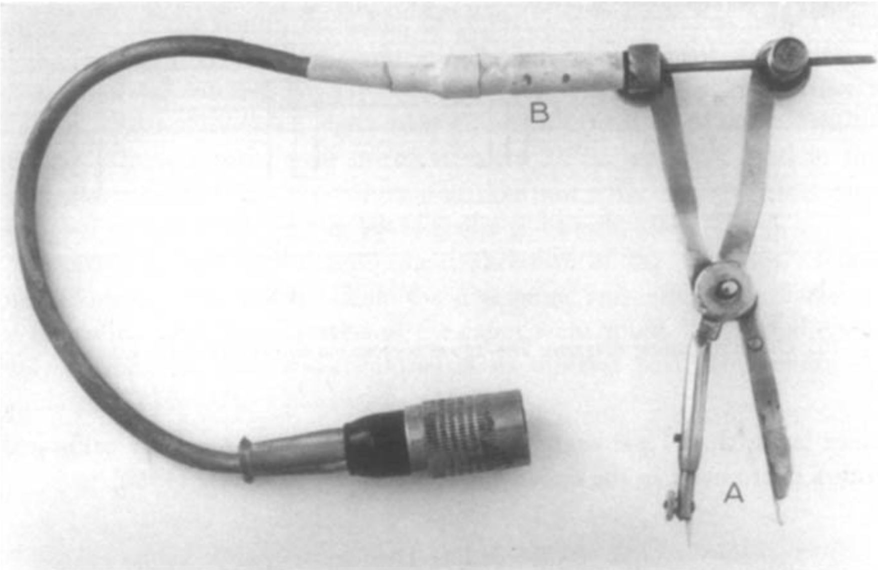


Fig. 8. A. Caliper. B. Displacement gauge.

Fig. 9. **Detail** of calipers contacting the caput and measuring points of the acetabulum.

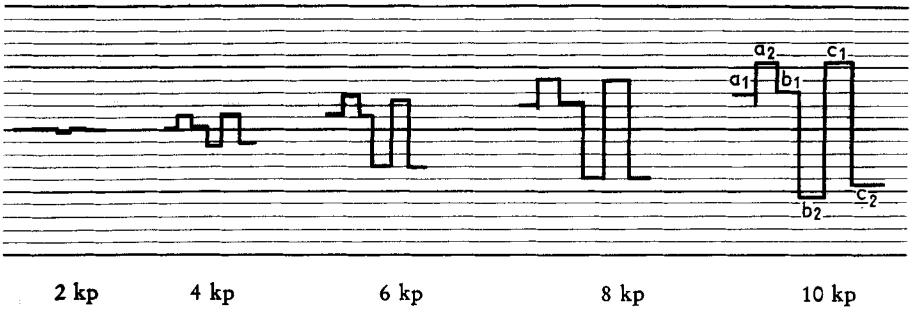


Fig. 10. Original loading diagram. The letters correspond to the respective gauges.

range is less than 1 per cent. The transducer has been regularly calibrated with a micrometer in the apparatus, designed by Rolander (1966).

Recording Device

The six transducers are connected to a specially designed switch monitor (AB Svenska Philips och Svensk Elektronikkonsult, Göteborg). Each transducer is manually connected in turn to a carrier frequency system (Philips BF2). Each channel has its own unit for balancing and zero-setting, an amplifier and a calibration resistance. The carrier frequency system is connected to a one-channel potentiometer recorder (Philips PR 2210 A 21). These devices have been described by Rolander (1966), (Fig. 5).

After connecting each channel the recording paper is fed manually once a stabilized position is obtained. Recording of each channel takes 2—3 seconds, and for all six transducers 15 seconds. Each loading and recording period thus requires 30 seconds. The aim is to maintain this time constant in view of the visco-elastic properties of the bone. Besides the magnitude and the speed of the loading, the degree of deformation is dependent on the loading time (Sedlin, 1965).

The sensitivity of the extensometer is adjusted so that a change in distance of 1 mm between the measuring tips corresponds to 20 scale lines on the recorder. The measuring error is 0.25 per cent at full scale deflection (full scale deflection = ± 2.5 mm). The width of the recording paper is 250 mm (Fig. 10).

Material

The specimens were obtained at routine autopsies at the Pathological Institute of the University Hospital and in exceptional cases at other hospitals in Göteborg. They consisted of the right half of the pelvis and the upper part of the femur, including the intact hip joint and at least 15 cm of the femoral shaft. Only macroscopically normal specimens were selected from cases without any general disease of the skeleton. All specimens were x-rayed, and no abnormal signs were observed except slight osteoarthritic changes. The specimens were stored at minus 30 degrees C, packed in airtight plastic bags. This way of storing does not affect the physical properties (Frankel, 1960; Sedlin, 1965; Sedlin & Hirsch, 1965).

In order to assess the magnitudinal variation of the specimen, certain measurements were taken. Thus, the maximum and minimum diameters of the collum and the diameters of the caput were noted. Furthermore, the body of the iliac bone was measured at its thinnest part. The results are tabulated (Table III).

TABLE II

The study group

Subject number	Autopsy number	Age (years)	Sex	Main cause of death
1–22	These specimens were used for developing the methodology and for preleminary experiments			
23	I.928	54	F	Pyelonephritis chron.
24	I.980	88	F	Emboliae pulm.
25	I.991	45	F	Carcinoma colli uteri, insuff. cordis.
26	I.992	49	M	Circulatory failure
27	I.898	50	M	Uremia
28	I.940	65	M	Carcinoma of the lung
29	I.919	64	F	Information missing
30	I.936	56	F	Cerebral hemorrhage
31	I.1001	66	F	Cerebral tumor
32	I.981	79	M	Bronchopneumonia
33	I.949	68	M	Cardiac failure
34	I.967	74	M	Respiratory failure
35	II.173	54	M	Bronchial carcinoma
36	I.923	64	M	Myocardial infarction
37	I.932	53	F	Uremia
38	I.736	75	F	Myocardial infarction
39	I.443	24	M	Bronchopneumonia
40	I.933	70	M	Cardiac failure
41	I.930	60	F	Cirrhosis
42	II.213	52	M	Carcinoma of the stomach
43	I.1047	59	F	Cardiac failure
44	I.1039	82	F	Cardiac failure, bronchopneumonia
45	I.1032	64	F	Uremia
46	II.225	82	F	Gastrointestinal bleeding
47	I.1109	52	M	Cardiac failure
48	I.1103	59	F	Leukemia
49	I.1089	68	F	Myocardial infarction
50	I.1091	36	F	Fracture of the skull contusio cerebri
51	II.212	85	F	Pulmonary embolism
52	I.1042	71	M	Cardiac failure
53	II.201	87	M	Myocardial infarction
54	L.91	85	M	Gastrointestinal bleeding
55	I.1164	81	F	Pulmonary oedema
56	I.1158	55	F	Carcinoma colli uteri
57	II.248	69	M	Pulmonary embolism
58	I.1172	82	F	Ciculatory failure, diabetes mellitus
59	I.1173	64	M	Pulmonary embolism
60	II.256	88	F	Myocardial infarction
61	L.95	75	M	Pulmonary embolism
62	I.1231	72	F	Circulatory failure
63	II.252	84	F	Circulatory failure, carcinoma pancreatis
64	I.1242	79	M	Pulmonary oedema, carcinoma prostatatae

Subject number	Autopsy number	Age (years)	Sex	Main cause of death
65	L.97	85	F	Circulatory failure, bronchopneumonia
66	II.244	69	M	Circulatory failure
67	I.1248	78	F	Cerebral hemorrhage, circulatory failure
68	I.1246	91	F	Cerebral hemorrhage
69	II.266	56	M	Carcinoma of the stomach
70	II.245	47	F	Malignant lymphogranuloma
71	L.92	68	F	Circulatory failure, bronchopneumonia
72	I.1247	78	M	Pulmonary embolism
73	I.1179	83	M	Gastrointestinal bleeding
74	I.1302	71	M	Circulatory failure, tbc pulm.
75	I.1292	62	F	Pulmonary embolism
76	II.280	50	M	Gastrointestinal bleeding, pulmonary embolism
77	I.1317	53	F	Respiratory failure, malignant tumor
78	L.100	62	M	Sarcoma
79	L.103	86	F	Circulatory failure
80	I.994	81	M	Myocardial infarction
81	L.82	59	M	Subdural bleeding
82	L.83	69	M	Circulatory failure, bronchopneumonia
83	L.83	69	M	Circulatory failure, bronchopneumonia
84	L.77	87	M	Bronchopneumonia
85	L.77	87	M	Bronchopneumonia
86	I.1181	63	M	Myocardial infarction
87	I.1188	55	M	Carcinoma of the hepar
88	L.102	88	F	Bronchopneumonia
89	I.1292	73	F	Cerebral hemorrhage
90	I.1296	55	F	Uremia, pneumonia
91	I.1335	72	M	Malignant tumor
92	I.1332	71	M	Cerebral malacia
93	I.1326	51	F	Cerebral hemorrhage
94	II.307	83	F	Circulatory failure
95	I.937	62	F	Myocardial infarction
96	I.1334	73	M	Myocardial infarction
97	L.103	78	F	Pulmonary embolism
98	I.1346	89	F	Circulatory failure
99	I.1423	77	M	Bronchopneumonia
100	I.1335	87	F	Uremia, cerebral oedema
101	I.1337	67	F	Carcinoma of the uterus
102	L.107	64	M	Circulatory failure
103	I.1326	53	F	Uremia
104	I.1425	80	F	Pulmonary embolism
105	II.333	58	F	Cardiac failure
106	I.1450	76	M	Cardiac failure
107	I.1432	76	M	Pneumonia, carcinoma of the stomach
108	II.11	62	M	Malignant melanoma
109	I.1422	81	F	Pericarditis
110	I.938	63	M	Malignant tumor
111	I.11	72	F	Ciculatory failure, intestinal gangrene
112	I.213	67	M	Cardiac failure

Statistical Analysis

The statistical analysis is an assessment of the tested osteosynthetic methods with regard to the measured value S_{max}. This value has been measured under four types of loading; flexion, abduction, extension and adduction. The study was performed on a number of specimens designated No. 23—112 (Table III). No values were, however, obtained for specimens No. 43 and No. 46, because of damaged specimens.

The magnitude of the load varied between 2 and 20 kp. It was not constant for all specimens, but depended on the magnitude of the measured displacement.

In 11 cases more than one loading series was carried out with the same osteosynthetic method. On statistical analysis of these cases the values from the original experiment were used.

The following conditions complicate a statistical analysis of the present material where the intention is to elucidate the differences in the efficiency of the methods:

1. There are great variations in the physical properties of the individual specimens.
2. A non-measurable weakening may occur in the specimen after testing one method of osteosynthesis. This has an impairing effect on the conditions obtained during investigation of a subsequent method.
3. Certain experiments have been performed with different load intervals and also with different maximum loads. It is impossible to concentrate the measured values obtained for the different loading directions into one adequate expression.

An attempt has been made to overcome these difficulties by statistically analysing the material in two different ways with subsequent comparison of the results.

Sign Test

The series of experiments, in which two or more methods were tested on the same specimen, was studied using the so-called sign test.

The measured values for the respective loading directions, found at the same load for two different methods on the same specimen were recorded. One of the methods was used as a reference and the sign of the difference

TABLE III

Experiments

Number of specimens	Method	Diameter of the acetabulum mm	Width of femoral neck min. mm	Width of femoral neck max. mm	Mim. width of the body of ilium mm	Angle between nail and femoral shaft degrees	Nailing depth mm
23	Sv. J.	45	26	32		145	24
24	Sv. J.	40	22	30		145	36
25	Sv. J.	45	27	39	22	145	20
26	Sv. J.	50	28	40	30	145	18
27	Sv. J.	51	31	40	30	145	21
28	Sv. J.	52	31	39	32	140	34
29	Sv. J.	50	30	40	30	150	32
30	Axer	55	30	40	28	130	25
31	Axer	46	25	33	24	135	14
32	Axer	54	30	38	25	130	14
33	3pfix, N	47	23	30	24		
34	3pflx, N	50	25	32			
35	3pfix, N	50	27	37	24		
36	Axer	50	30	38		130	17
37	Axer	50	25	36		130	11
38	Axer	53	29	43		135	17
39	Sv. J.	44	26	32	18	150	18
40	Sv. J.	53	32	37		150	34
41	3pfix, N	50	27	32	23	145	30
42	Sv. J.	50	29	43	26	145	38
43	Sv. J.	45	28	31		150	43
44	Sv. J.	48	26	32	26	145	40
45	3pfix, N	46	26	34	23		
46					26		
47	Sv. J.	48	30	37		145	30
48	Sv. J.	45	26	32		150	47
49	Sv. J.	44	26	31		153	45
50	Sv. J.	46	26	30		152	49
51	Sv. J.	45	26	30		152	54
52	Sv. J.	49	30	34		143	34
53	3pfix, N Sv. J.	49	25	34	25	147	47
54	3pfix, N	50	26	34	23		
55	3pfix, N	47	26	32	22		
56	Sv. J. 3pfix, N	45	24	32	22	150	20
57	Sv. J. 3pfix, N	54	30	38	28	150	33
58	3pfix, N	43	23	31	25	150	31
58	3pfix, N Sv. J.	43	23	31	25	150	31
59	3pfix, N Sv. J.	52	28	36	25	145	40
60	3pfix, N Sv. J. Sv. J. + plate	51	29	35	31	140	53

Sv. J. = Sven Johanson three-flanged nail.
N = Nyström nail.
E = Experimental nail.

Number of specimens	Method	Diameter of the acetabulum mm	Width of femoral neck min. mm	max. mm	Min. width of the body of ilium mm	Angle between nail and femoral shaft degrees	Nailing depth mm
61	3pfix, N	49	29	34	28	135	67
	Sv. J.						
	Sv. J. + N						
	Sv. J. + Plate						
62	3pfix, N	45	25	30		140	29
	Sv. J.						
	Sv. J. + N						
	Sv. J. + Plate						
63	3pfix, N	44	24	33	26	150	60
	Sv. J.						
	So. J. + N pos. III						
	Sv. J. + N pos. II						
	Sv. J. + Plate						
64	3pfix, N	50	26	36	25	140	66
	Sv. J.						
	Sv. J. + N pos. II						
	Sv. J. + N pos. III						
	Sv. J. + Plate						
65	Fox	48	28	37	24	140	19
	3pfix, N						
66	3pfix, N	47	25	33	25	135	11
	Fox						
67	3pfix, N	44	25	32	23	145	49
	Sv. J.						
	Sv. J. + N						
	Sv. J. + Plate						
68	3pfix, N	43	24	30	23	130	14
	Fox						
69	3pfix, N	55	32	36	27	140	46
	Sv. J.						
	Sv. J. + N pos. II						
	Sv. J. + N pos. III						
	Sv. J. + Plate						
70	3pfix, N	43	27	33	22		
71	3pfix, N	46	25	31	23	130	16
	Fox						
72	3pfix, N	53	29	40	25	148	46
	Sv. J.						
	Sv. J. + N pos. II						
	Sv. J. + N pos. III						
	Sv. J. + Plate						
	Fox					135	11
73	3pfix, screws	60	33	42	30	140	32
	3pfix, Sv. J. mod.						
74	3 pfix, screws	52	34	38	24	135	23
	3pfix, N						
	3P. Sv. J. mod.						
	Sv. J. + N						

Number of specimens	Method	Diameter of the acetabulum mm	Width of femoral neck min. mm	Width of femoral neck max. mm	Min. width of the body of ilium mm	Angle between and and femoral shaft degrees	Nailing depth mm
75	3pfix, screws	44	26	30	22	140	17
	3pfix, N						
	3pfix, Sv. J. mod.						
	Sv. J. + N						
	Sv. J.						
76	Fox	49	30	35	26	135	20
	3pfix, Sv. J. mod.					135	32
77	3pfix, screws	50	29	33	24	140	27
	3pfix, N						
	3pfix, Sv. J. mod.						
78	3pfix, screws	47	27	32	24	145	57
	3pfix, (rep)						
	3pfix, Sv. J. mod.						
79	Mc L.	53	30	37	31	150	52
	Mc L.						
	Mc L. osteotomy						
	Mc L. + N						
	Mc L. + N						
80	Axer	50	29	35	21	145	50
	Sv. J.						
	Sv. J. + N						
81	Axer	49	29	37	22	135	22
	Sv. J. + N						
82	Sv. J. mod.	54	35	40	19	140	40
83	Sv. J.	54	32	38		140	30
84	E	50	27	36		135	46
85	Sv. J.	49	29	34		135	45
86	3pfix, N	55	32	39		125	17
	Mc Kee						
87	3pfix, N	51	31	36		135	30
	Mc Kee						
88	3pfix, N	42	26	32		145	26
	Mc Kee						
89	3pfix, N	45	26	32		135	22
	3pfix, N mod.						
	Mc Kee						
90	3pfix, N	42	28	32		140	41
	3pfix, N mod.						
	Mc Kee						
91	3pfix, screw	50	29	35			
	3pfix, N						
	3pfix, N mod.						
92	3pfix, screw	50	26	35			
	3pfix, N						
	3pfix, N mod.						
93	3pfix, screw	48	26	31			
	3pfix, N						
	3pfix, N mod.						
94	3pfix, screw	49	26	35		140	25
	3pfix, N						

Number of specimens	Method	Diameter of the acetabulum mm	Width of femoral neck min. mm	Width of femoral neck max. mm	Min. width of the body of ilium mm	Angle between nail and femoral shaft degrees	Nailing depth mm
94	3pfix, N mod. Mc Kee						
95	3pfix, N 3pfix, N mod. E + N	45	26	32		140	29
96	3pfix, screw 3pfix, N 3pfix, N mod. Niebauer	50	26	33		130	12
97	Niebauer 3pfix, N 3pfix, N mod.	48	28	37		130	16
98	Niebauer 3pfix, N 3pfix, N mod.	45	26	32		125	15
99	3pfix, N E + N	50	28	35		145	45
100	3pfix, N E + N	43	26	31		145	46
101	3pfix, N E + N	48	27	35		145	40
102	3pfix, N E + N	50	27	34		145	44
103	3pfix, N E + N	41	22	28		150	40
104	3pfix, N E + N	47	26	32		145	36
105	3pfix, N E + N	44	24	28		140	34
106	3pfix, N E + N	53	29	35		140	35
107	3pfix, N E + N	50	29	36		145	49
108	3pfix, N E + N A. O.	52	30	41			38
109	3pfix, N A. O.	46	25	32			
110, r	3pfix, N E + N	48	26	32		145	45
110, l	3pfix, N Sv. J. + N	49	28	32		140	40
111, r	3pfix, N Sv. J. + N	44	24	32		150	40
111, l	3pfix, N E + N	40	20	26		150	45
112	A. O.						

between the measured values for this and the other method was determined. In this way a series of + and — signs was obtained for various pairs of methods.

On the assumption that the methods are equally good from the point of view of stability the number of + and — signs ought to be roughly the same. If the number of the type of sign (+ or —) that occurs least falls below a certain limit, the assumption is rejected and the difference is said to be significantly positive or negative, depending on the distribution of the signs (Brownlee, 1965). An analysis of this type requires comparison of at least six observations (Table IV). This is the reason why comparisons could not be made in certain experiments, despite the fact that two methods were employed on the same specimen. One method can have given such poor stability that the required number of observations could not be made. In spite of the fact that this first method was inferior to that with which it was compared, it was not possible to ascertain this difference by the present method of analysis.

Table X gives a survey of the results of the sign test. It should be emphasized that this is a matter of isolated comparisons in pairs. The test was performed on a 5 per cent level. The designation Sv. J. refers to cases where the depth of the insertion of the three-flanged nail exceeded 30 mm.

Descriptive Calculations

The following calculation was performed in an attempt to obtain a full assessment of the series. For each method the mean values of S_{max}, for loads of 6, 8 and 10 kp was calculated for the loading directions investigated. These mean values were ranked within each loading direction and for each load. For each direction and load a rank sum was then calculated, and finally a total rank sum for each method. From this total sum of ranks a mean rank sum was obtained by dividing by 12 (3 loads, 4 loading directions), (Table XII).

In the ranking procedure the method with the lowest mean value was ranked 1, that with the next lowest mean value 2 and so on. If the mean value happened to be identical they both received a ranking number equal to the mean value of those ranking numbers they would have received had they been slightly different.

The mean rank sum can be said to provide a quantitative measure for a given fixation type with the following reservations:

1. Variations in the physical properties of the specimens have been disregarded. These variations could be rather large as is partly illustrated by the standard deviations, calculated for the three-flanged nail and three-point-nail fixation (Table V). The standard deviation is in these

TABLE IV.

Rejection limits for sign test. Test level 5 per cent.

N	$2\alpha = 0{,}05$	N	$2\alpha = 0{,}05$	N	$2\alpha = 0{,}05$	N	$2\alpha = 0{,}05$	N	$2\alpha = 0{,}05$
	x_l x_r		x_l x_r		x_l x_r		x_l x_r		x_l x_r
0	—								
1	—	21	5—16	41	13—28	61	22—39	81	31—50
2	—	22	5—17	42	14—28	62	22—40	82	31—51
3	—	23	6—17	43	14—29	63	23—40	83	32—51
4	—	24	6—18	44	15—29	64	23—41	84	32—52
5	—	25	7—18	45	15—30	65	24—41	85	32—53
6	0— 6	26	7—19	46	15—31	66	24—42	86	33—53
7	0— 7	27	7—20	47	16—31	67	25—42	87	33—54
8	0— 8	28	8—20	48	16—32	68	25—43	88	34—54
9	1— 8	29	8—21	49	17—32	69	25—44	89	34—55
10	1— 9	30	9—21	50	17—23	70	26—44	90	35—55
11	1—10	31	9—22	51	18—33	71	26—45	91	35—56
12	2—10	32	9—23	52	18—34	72	27—45	92	36—56
13	2—11	33	10—23	53	18—35	73	27—46	93	36—57
14	2—12	34	10—24	54	19—35	74	28—46	94	37—57
15	3—12	35	11—24	55	19—36	75	28—47	95	37—58
16	3—13	36	11—25	56	20—36	76	28—48	96	37—59
17	4—13	37	12—25	57	20—37	77	29—48	97	38—59
18	4—14	38	12—26	58	21—37	78	29—49	98	38—60
19	4—15	39	12—27	59	21—38	79	30—49	99	39—60
20	5—15	40	13—27	60	21—39	80	30—50	100	39—61

cases calculated from the expression $\sqrt{\frac{\sum (X-\bar{X})^2}{n}}$ where x is the deflection in the direction and load concerned, $\bar{x}$ is the mean value of all x, and n the number of observations, i.e. the number of specimens where observations were made for the different directions and loads. The table reveals high standard deviations for the three-flanged nail and lower ones for the three-point fixation. The high values probably depend on the specimen factor*) which includes in particular the variation of the physical properties of the material. Also of importance are mechanical changes occurring in connection with the osteosynthesis itself. The latter occur to a greater extent in osteosynthesis with the three-flanged nail than with the considerably thinner N-nails. In addition, by using three nails a smoothing effect is obtained, in other words, the importance of the specimen factor is greater when only one nail is used.

*) Cf. page 58

TABLE V.

Standard deviation of S_{max} for 3pfix N and Sv.J.

3pfix N

Loading kp	6	8	10	12	14
Flexion	6,4	9,6	15,5	20,4	15,7
Abduction	5,0	7,9	13,2	18,3	28,3
Adduction	10,5	17,4	23,1	29,2	37,4
Extension	12,4	18,4	23,2	24,9	22,8

Sv. J.

Loading kp	6	8	10	12	14
Flexion	23,6	17,4	13,3	18,9	24,0
Abduction	10,6	17,7	28,8	41,1	27,6
Adduction	21,2	30,4	38,2	45,1	43,7
Extension	16,1	24,9	30,3	33,4	26,4

2. The fact that different numbers of observations have been used in calculating the different mean values has been disregarded.
   The mean values within a certain direction of movement should of course increase with heavier loads. It can be seen from the tables of the mean values for the different methods, that this is not always the case, however. This depends on the fact that the weak specimens have been gradually excluded as the load has increased and thus not contributed to the results at higher loads (cf. Table XI).

Experimental Study

For the following osteosynthetic procedures, the previously described testing technique was employed.

A. Nail Reinforcements

1. Three-flanged nail according to Sven Johansson
2. Three-flanged nail + one Nyström nail
   a. Nyström nail in lateral-medial direction (pos. II; Fig. 24)
   b. Nyström nail in an anterio-posterior direction (pos. III)
3. Three Nyström nails
   a. Three of standard dimension
   b. Two of standard dimension + one coarser nail (pos. I)
4. Three-flanged nail + plate according to Alvik
5. Four-flanged experimental nail + lateral-medial Nyström nail (pos. II)

B. Screw Reinforcement

Three trans-articular screws

C. Compression Methods

1. Compression nail according to Axer
2. Compression nail according to Fox
3. Compression nail according to Niebauer
4. Compression screw according to Mac Kee
5. Compression plate according to AO

Initially only one osteosynthetic method was performed on each specimen. However, the specimens varied considerably with respect to size and resistance. (These factors have in the following been denominated the *specimen factor).* Because of this variation the experimental series would have been too extensive to ensure a statistically significant result for all the methods to be tested.

By using several osteosynthetic methods on the same specimens, the specimen factor can be considerably reduced. Thus, direct comparisons between the various osteosynthetic methods can be made.

This creates the disadvantage of the first osteosynthetic procedure affecting the specimen in such a way that the conditions for the following ones will be impaired.

To master this problem certain rules have been set. The method requiring the smaller amount of bone was tried before the one engaging a greater amount, i.e. osteosynthesis with thinner nails was performed before using the coarser ones.

When it was not quite clear which method caused the least damage, the succession of the methods was varied. The method seeming to be the most inferior at the preliminary experiments was tried as the first method when the next series of experiments was carried out. The best conditions for testing were thus given the assumed inferior method.

The loading level, reached at each experiment, depended on the degree of deformation. The intention was to evade remaining deformation. The load was increased stepwise by 2 kp, and normally the load was augmented to a moment of 120 kpcm before unloading. The degree of remaining deformation after unloading was also recorded. The loadings were always done in the same succession; flexion, abduction, extension, adduction.

N.B. The following abbreviations will from now on be used:

Three-flanged Sven Johansson nail = Sv. J.-nail

Nyström nail = N-nail.

Stabilization with Three-Flanged-Nail

Theoretical Analysis

Stabilization in arthrodesis of the hip with a three-flanged nail has perhaps been the most common method. Special attention has therefore been paid to this method. It is referred to in technical literature as "the simple nail reinforcement" and due to its simple mechanical design, it can be analysed theoretically to a certain extent. The purpose of this is to elucidate guiding principles for experimental application.

This kind of analysis is complicated by the number of variable factors in the composition of the bone. The shape of the skeleton is complicated, and the bone is inhomogeneous, with wide variations in the material properties. These factors cannot be represented mathematically. Simplifications and assumptions must be made.

In the analysis, a three-flanged nail of the Sv. J. type has been selected.

Assumptions

The calculations are carried out using the mechanical model "beam on elastic foundation". The deflection curve of beams on spring supports can be represented by means of a fourth degree differential equation. In order to calculate the shape of the curve in a special case, the existing boundary conditions are included in the general equation. After solving the equation, the deflection is obtained as a function of parameters, depending only on the properties of the beam — and the support. The following assumptions are made:

1. The bone material obeys Hook's law
2. The deflection of the material is transmitted in a finite area of the bone.

The spring constant of the bone can then be calculated. On the basis of these calculations, the deflection of a nail in bone material can be determined for various degrees of loading, as well as the effect of the varying nail and bone properties.

The nail penetrates two cortical layers which surround an area of spongy bone. The material is inhomogeneous and has varying physical properties in each layer. Between these layers, there is no sharp boundary. The elastic resistance of the spongy bone is of little importance when considering tensile and compressive stresses. On the other hand, the cortical bone has marked physical properties(Rauber, 1876; Evans, 1957; Sedlin, 1965). Because of these conditions, calculations were carried out for two extreme cases, the bone material of which was assumed to be:

1. Solid cortical bone (infinite homogeneous elasticity)
2. Two cortical layers with a hollow intermediate space (stepwise elasticity).

Case 1. On the basis of assumption 1, the model shown in Fig. 11 is used to calculate the deflection curve. In this case the deflection caused will obey the following differential equation:

$$\underline{\text{DE:}} \quad \frac{d^4y}{dx^4} + 4\,n^4y = 0$$

$$\text{where } \frac{C}{EI} = 4\,n^4$$

C = spring constant of elastic support
EI = bending resistance of nail

Case 2. On the basis of assumption 2 above, the model shown in Fig. 12 is used to calculate the deflection curve.

The loading case defined according to this figure, with the load and moment applied to the end point, is conveniently treated in parts according to Fig. 13.

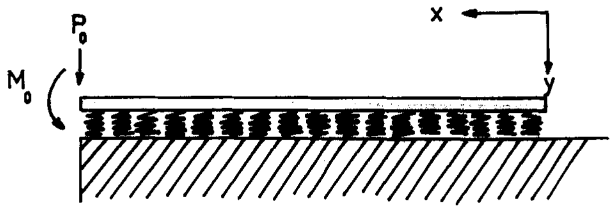


Fig. 11. Model according to Case 1. (Homogeneous cortical bone).

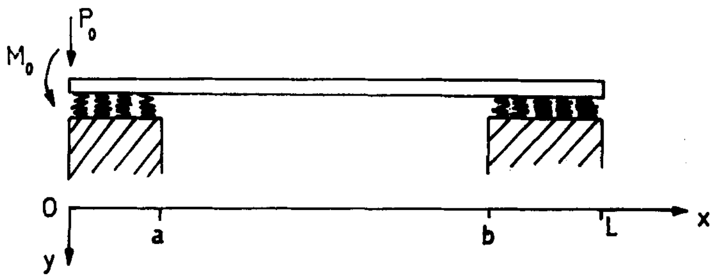


Fig. 12. Model according to Case 2. (Two cortical layers with hollow intermediate space).

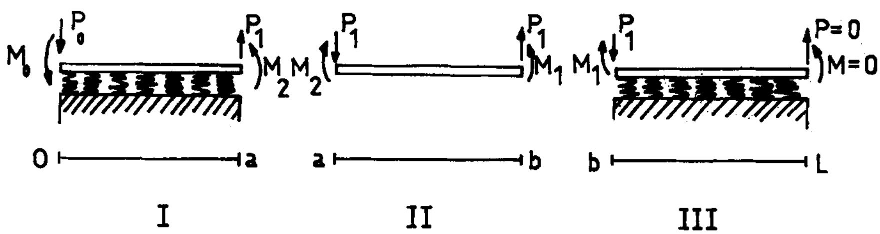


Fig. 13. Case 2 divided into three parts.

Calculations

Equations for each partial loading case are obtained by superposition of the elementary cases for concentrated force and moment according to Hetényi: "Beams on elastic foundation". By constructing boundary conditions, the true deflection curve can be calculated. When the form of the curve has been obtained, interest is concentrated on the most critical factor for the bone material, i.e. the point of maximum deflection.

Maximum deflection is obtained in the actual loading cases at that point where the force and moment are concentrated, i.e. at the external edge of the bone.

Formulae are devised for calculation of the edge deflection as a function of the following parameters:

1. Modulus of elasticity of the bone
2. Spring constant of the bone
3. Moment of inertia of the nail
4. Modulus of elasticity of the nail.

1. The modulus of elasticity, E_b for cortical bone, varies within wide limits and is strongly dependent on the type of loading (Sedlin, 1965). For these approximate calculations, a mean value between the moduli of elasticity for tension and for compression has been used, viz. $E_b = 1075$ kp/mm².

2. The spring constant (C) is calculated according to a special model: $C = k \cdot E_b$, where k is a constant. The value of the constant varies with certain shape factors and has been calculated to lie within the range $2.0 > k > 1.6$. To calculate the deflection of the edge in the acetabulum the value $k = 1.75$ is used.

3. The three-flanged nail of the Sv. J.-type used for calculations and experiments has a moment of inertia of 140 mm⁴.

4. The nail is made of stainless steel with a modulus of elasticity $E_s = 21.000$ kp/mm².

The Influence of Nailing Depth on Deflection of Edge

Assuming, according to Case 1 (solid cortical bone) the deflection of the edge is calculated for a given force and moment as a function of the length (= L) of the part of the nail which is inserted into the material. The result of these calculations shows that when a certain depth has been reached, only a very slight improvement will be achieved by increasing the depth. Thus, an improvement of only 5 per cent will be obtained if L is increased from 22 mm to infinite depth. With decreasing nailing depth the deflection of the edge will increase rapidly (Fig. 14).

Assuming, according to Case 2 (two cortical layers with a hollow intermediate space) the deflection of the edge is calculated as a function of the thickness of the cortical layers and of the distance between them.

According to the principle of superposition complete calculations can be carried out for force and moment separately and the results superimposed in the final calculations.

In order to obtain an unambiguously defined quantity as a result, the separate deflections are related to the deflection obtained using infinite homogeneous elasticity. This involves defining the quotients:

for the force $R^P = \dfrac{\delta_0{}^P}{\delta^P{}_{0\,(\infty)}} = \dfrac{\delta_0{}^P}{\dfrac{P_0}{2n^3 \cdot EI}}$

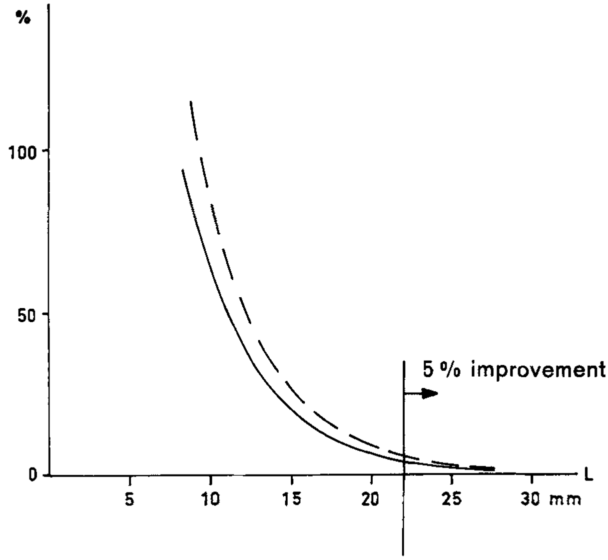


Fig. 14. — — — — — — R^P ————— R^M Improvement in percentage (diminished edge deflection) with increasing nailing depth according to Case 1.

for the moment $R^M = \dfrac{\delta_0{}^M}{\delta^M{}_{0\,(\infty)}} = \dfrac{\delta_0{}^M}{\dfrac{M_0}{2n^2 \cdot EI}}$

Calculations are performed assuming constant parameters, the values of which are discussed above.

$E_b = 1075$ kp/mm²
$C = 1.75 \times E_b = 1880$ kp/mm²
$n = 0.1125$

The results are tabulated in Table VI. The curve for a cortical layer thickness, a = 2.5 mm, is selected as a basis and the quotients relating the other curves to this basis curve are formed. The table of force values shows that the quotients of the variables (b—a) are almost the same for each curve. This implies that only the exact form of the basis curve is reported together with a comparison curve for the quotients as a function of a-values, (Fig. 15).

The table of values of moment shows that a corresponding relation does not exist. For the different a-values separate curves are plotted (Fig 16). To obtain the intermediate a-values interpolation has to be made.

Under the assumption that the bone obeys Hooke's law, the values R^P and R^M are calculated from the curves of force and moment quotients. These are converted to a coefficient, which constitutes the direction coef-

TABLE VI.

Quotients R^P and R^M at some different values for a and b—a measured in mm.

$E_b = 1075$, $C = 1880$, $E_s = 21000$ $I_s = 140$

R^P

b—a	$a_1 = 0,8$	$a_2 = 1,0$	$a_3 = 1,5$	$a_4 = 2,0$	$a_5 = 2,5$	$\frac{R^Pa_1}{R^Pa_5}$	$\frac{R^Pa_2}{R^Pa_5}$	$\frac{R^Pa_3}{R^Pa_5}$	$\frac{R^Pa_4}{R^Pa_5}$
0									
2,5	6,937	5,802	4,161	3,292	2,743	2,55	2,12	1,52	1,20
5	6,356	5,223	3,692	2,907	2,425	2,62	2,15	1,52	1,20
10	5,981	4,865	3,372	2,622	2,171	2,76	2,24	1,55	1,21
20	5,778	4,667	3,187	2,452	2,016	2,87	2,32	1,58	1,22
40	5,674	4,566	3,095	2,370	1,947	2,91	2,35	1,59	1,22
80	5,626	4,521	3,062	2,355	1,952	2,88	2,32	1,57	1,21
120	5,614	4,512	3,065	2,373	1,989	2,82	2,27	1,54	1,19
					Mean value	2,77	2,25	1,55	1,21

R^M

b—a	$a_1 = 0,8$	$a_2 = 1,0$	$a_3 = 1,5$	$a_4 = 2,0$	$a_5 = 2,5$	$\frac{R^Ma_1}{R^Ma_5}$	$\frac{R^Ma_2}{R^Ma_5}$	$\frac{R^Ma_3}{R^Ya_5}$	$\frac{R^Ma_4}{R^Ma_5}$
0									
2,5	24,587	19,737	12,875	9,249	7,031	3,49	2,80	1,83	1,31
5	11,731	9,578	6,581	4,994	4,001	2,94	2,40	1,65	1,25
10	5,545	4,538	3,181	2,494	2,082	2,66	2,18	1,53	1,20
20	2,700	2,221	1,601	1,313	1,161	2,33	1,91	1,38	1,13
40	1,416	1,204	0,964	0,891	0,884	1,60	1,36	1,09	1,01
80	0,902	0,847	0,856	0,946	1,064	0,85	0,79	0,80	0,89
120	0,825	0,845	0,990	1,183	1,386	0,60	0,61	0,71	0,85

ficient in the equation which represents the deflection as a function of the force P_0.

$$\delta_0 = \delta_0{}^P + \delta_0{}^M$$

$$\delta_0{}^P = \frac{R^P}{2n^3 \cdot EI} \times P_0$$

$$\delta_0{}^M = \frac{R^M}{2n^2 \cdot EI} \times M_0$$

M_0 is converted to $M_0 = L \times P_0$

from which is obtained $\delta_0 = (K_0{}^P + K_0{}^M) \times P_0$

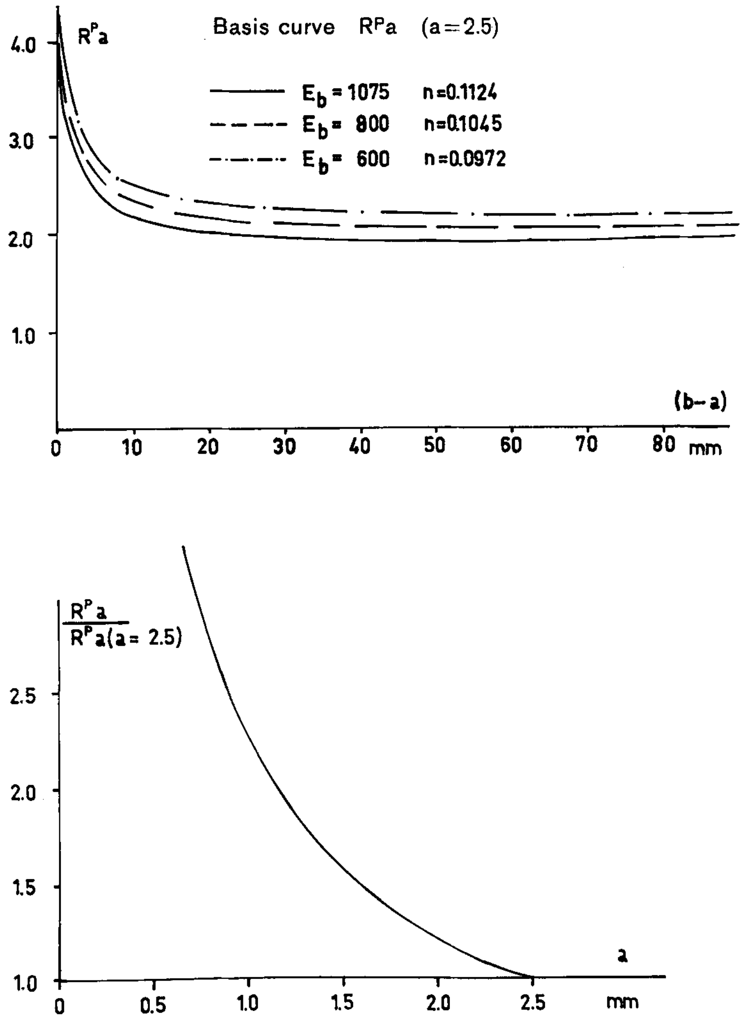


Fig. 15. a) Basis curve for R^p and cortical layer, a = 2,5 mm.
b) Comparison curve for the quotients as a function of a-values.

The influence on the edge-deflection of a variation of the modulus of elasticity is shown in Diagrams 15 and 16. It is here seen that the values of R^p are increased by approximately 7 per cent when changing n from 0.1124 to 0.1045. The R^p-values are increased by approximately 15 per cent when changing n from 0.1124 to 0.0972. These changes of the n-value correspond to a change of the elastic modulus for cortical bone in the range of 1075—600 kp/mm^2.

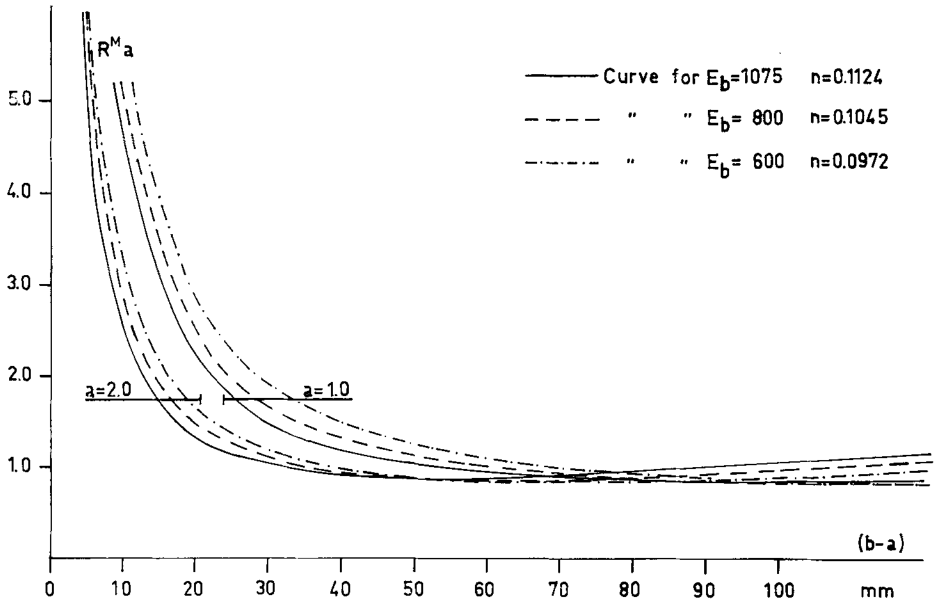


Fig. 16. Edge deflection as a function of bone layer-thickness and distance between the layers, for three different values of modulus of elasticity of bone. The two cortical layers are assumed to be of equal thickness and are designated *a* mm.

Conclusions

From the tables and diagrams showing the quotients R^P and R^M the following special relationship can be derived:

1. For each individual value of the distance between the cortical layers (b—a) the quotients become smaller with increasing cortical thickness. This implies that areas with thick cortical layers should be singled out for nailing.

2. As regards the influence of the forces it is found that with an increased distance (b—a) from 20 mm to the distance giving R^P minimum, an improvement of less than 5 per cent is obtained.

The effect of the moment is altered, however, to a greater extent; the thinner the cortical layer, the greater is the change. The percentage improvement that can be obtained by increasing the distance b—a from 20 mm to the distance which gives R^M minimum has been calculated in Table VII. The conclusion can be drawn that the nail should be inserted in such a direction that a large distance is obtained between the cortical surfaces, at least 20 mm. The thinner the cortical layer, the larger the distance must be.

TABLE VII.

Percentage improvement that can be obtained by increasing the distance $(b-a)$ from 20 mm to the distance which gives R^M min. has been tabulated below as a function of the given parameters:

Parameters	Cortical thickness mm	R^M min at $(b-a)$	Obtainable improvement $\frac{RM_{20} - RM_{min}}{RM_{20}}$ per cent
$E_b = 1075$	$a = 1{,}0$	90	60
$n = 0{,}1124$	$a = 1{,}5$	60	50
	$a = 2{,}0$	50	34
	$a = 2{,}5$	37	24
$E_b = 800$	$a = 1{,}0$	105	68
$n = 0{,}1045$	$a = 1{,}5$	75	54
	$a = 2{,}0$	55	42
	$a = 2{,}5$	50	31
$E_b = 600$	$a = 1{,}0$	120	74
$n = 0{,}0972$	$a = 1{,}5$	85	60
	$a = 2{,}0$	65	50
	$a = 2{,}5$	58	39

Preliminary Experiments with Three-Flanged Nail

A series of experiments was performed with the three-flanged nail in order to find out the correlation between the theoretically calculated and the experimentally found values of the deflection of the edge, and to determine the relation of the deflection to the nailing depth as carried into practice.

The deflection of the edge was measured when the nail was subjected to bending stress, inserted at different positions and depths into the acetabulum. Furthermore, experiments were carried out with the nail subjected to torsional stress. The latter experiments were repeated with the nail driven through the femoral neck and head.

The specimen, consisting of half of the pelvis, was attached to the stand, described previously. After preboring, an Sv. J.-nail was inserted into the desired direction and depth through the acetabulum.

Through a bore of the acetabular edge a metal tube was fitted with its orifice placed next to the edge of the bone above the nail (Fig. 17). A metal pin was introduced into the tube to contact the nail. When the nail was loaded, the movement occurring at the edge of the bone was transmitted by the metal pin. The load was applied at right angles to the

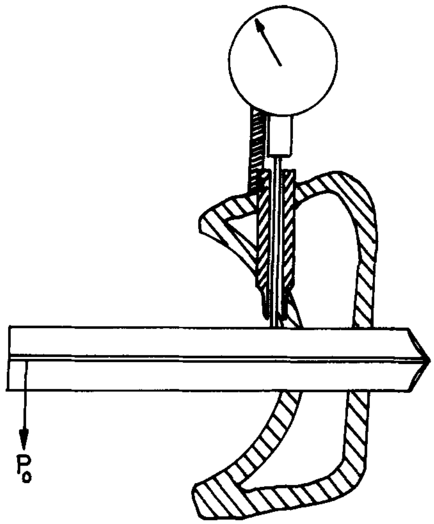


Fig. 17. Experimental device for determining edge deflection caused by bending stress on three-flanged nail. Nail inserted through two cortical layers. Dial indicator attached to bone.

longitudinal axis of the nail. The movement of the pin was read on a dial indicator. The entire measuring device was attached to the bone and, consequently, the error in measurement due to the elasticity of the attachment device was eliminated. Subsequently, the specimen was sawn through in the direction of the nail, so that the thickness of the cortical layers concerned, and the length of the nail tunnel could be measured. On the basis of these values, theoretical calculations were made on the direction coefficient of the deflection curve. The latter was then put into relation to that measured at the experiment.

The theoretically calculated and experimentally measured values of the direction coefficient of the deflection curve at varying nail depths and different cortical thicknesses, are presented in Table VIII.

The theoretical values of the direction coefficient are generally lower than the experimental ones. The reason is that the bone material sometimes in practice deviates in a negative direction as compared to that of an ideal case, accepted in theory.

When hammering in the three-flanged nail, small cortical fissures, originating from the flanges, regularly occur. This means that the connecting factor of the bone material will be inferior around the nail. In comparison with the ideal case, as assumed in the theoretical analysis, the deviation will be negative.

TABLE VIII.

Direction coefficient (K) of deflection curve.
Experimental and theoretical values. a, b and L measured in mm.

I_S = 140 mm^4 Test number	1	2	3	4
a	3,0	1,5	1,4	1,5
b−a	12	20	75	75
L−b	0,8	1,9	3,6	3,5
$K_{measured}$	$3{,}0 \cdot 10^{-3}$	$4{,}28 \cdot 10^{-3}$	$2{,}85 \cdot 10^{-3}$	$2{,}10 \cdot 10^{-3}$
$K_{theor.}$ (n_1=0,1125)	$0{,}95 \cdot 10^{-3}$	$1{,}27 \cdot 10^{-3}$	$0{,}89 \cdot 10^{-3}$	$0{,}87 \cdot 10^{-3}$
$K_{theor.}$ (n_4=0,0845)	$2{,}80 \cdot 10^{-3}$	$3{,}83 \cdot 10^{-3}$	$2{,}28 \cdot 10^{-3}$	$2{,}14 \cdot 10^{-3}$

In cases where the nail penetrated a posterior cortical layer, extensive fractures sometimes occurred. This affected the securing and also had a negative effect on the measured values.

For the theoretical calculations a fixed value, which more or less can deviate from the value of the individual specimen, was also applied to the modulus of elasticity.

Temperature, humidity, loading speed, and so on, are all factors affecting the elastic modulus (Sedlin, 1965; Sedlin & Hirsch, 1966; Hirsch & da Silva, 1967). The conditions existing at the experiments may justify the use of values for elastic moduli which are in the lower range of those used for the theoretical calculations, or even lower.

The influence of various material factors can be represented in the mechanical model by a variation of the n-value. Table VIII shows the influence on the direction coefficient for a variation of the modulus of elasticity of cortical bone and of the "elastic coupling" in the material. Thus the spring constant ($C = k \cdot Eb$) varies in the range of 600—1880 kp/mm^2. All these factors are included in the parameter "n".

The parameters "n" and Is (the moment of inertia of the nail) are essential for the values of the coefficient of direction. Thus "n" is found in the second and the third potency, through which even small changes will have a comparatively large effect on the result.

Fig. 18 presents the deflection of edge at various depths of nail insertion. The nail has been directed towards the body of the iliac bone and its point has not penetrated any part of the internal cortex. The diagrams show that the deflection of edge becomes much improved when the nailing

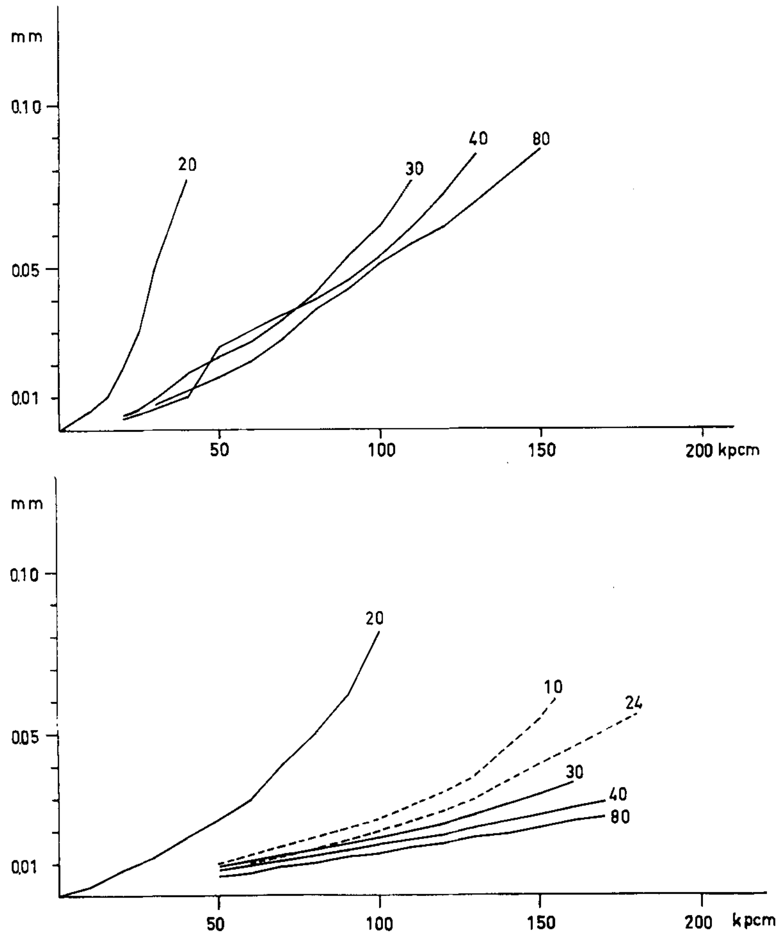


Fig. 18. Edge deflection caused by bending stress on three-flanged nail. — — — — — — — through two cortical layers. ————————— into body of iliac bone. Figures on curves designate nailing depth in mm.

depth is increased from 20 to 30 mm. A nailing depth exceeding 40 mm will only give slight improvement.

Experiments with Torsion Load

Experimental Device

The forces, to which the nail has the least resistance, act around the longitudinal axis of the nail.

A special torque transmission device was designed (Fig. 19) in order to find out the relation between nailing depth and deflection caused by torque.

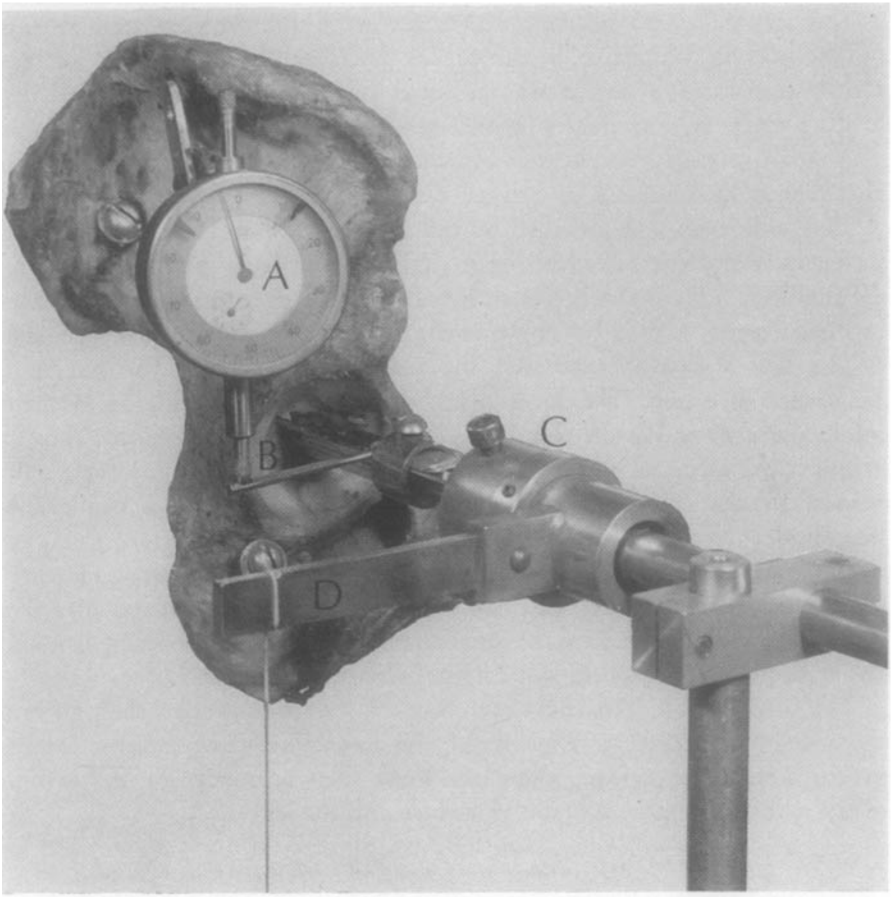


Fig. 19. Experimental device for determining deflection caused by torque on three-flanged nail. A = dial indicator B = lever pin transmitting movement to dial C = torque transmission device D = loading lever arm.

The device consists of a shaft, at one end mounted with a sleeve by means of a ball bearing. For transmitting the torque to the nail, three screws are fitted in the sleeve. A lever is welded to the sleeve.

The three-flanged nail was hammered into the desired depth of the mounted specimen. The sleeve of the torque transmission device was slipped over the head of the nail and their longitudinal axes were centered to each other. The shaft of the torque transmission device was fitted to the iron stand to prevent any bending moments. The screws in the sleeve head were tightened to grip the space between the flanges of the nail.

The specimen was placed so that the nail and the longitudinal axis of the torque transmission device lay horizontally. The lever of the torque transmission device was adjusted to lie horizontally as well. By loading the lever, a gradually increasing torque was applied.

A small metal lever pin was attached to the nail perpendicularly and also placed horizontally at a fixed distance from the acetabular surface. A dial indicator was attached to the specimen by a metal rod so that its measuring point rested at right angles to the lever pin. By attaching the dial indicator to the specimen it was possible to evade potential errors in measurement caused by movements in the attachment of the specimen.

The dial indicator registered the movements of the lever pin in a tangential direction. The lever pin thus described a circular movement while the dial indicator recorded changes in the set direction. Thus, a systematical error in measurement was introduced which, however, with respect to the effective range, was considered to be of a negligeable magnitude.

The lever arm also described a circular movement. This error in measurement is also systematical and can be neglected in the utilized effective range. The effect caused by the circular movements of the loading arm and the lever pin, furthermore, will counterbalance each other.

The distance between the attachment of the lever pin on the nail and the acetabular surface was measured. For measurement of the true torsion in the acetabular surface, allowance must then be made for the torsion of the nail between the acetabular surface and the lever.

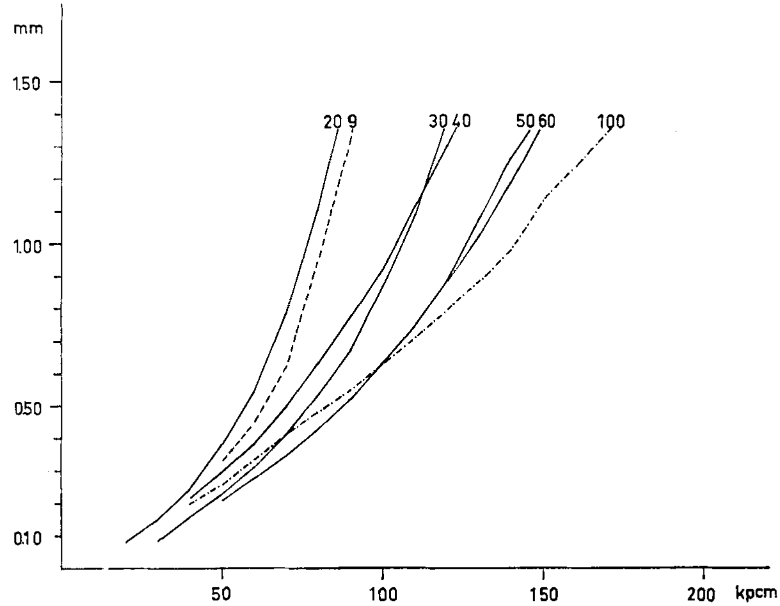
Measurement of Torsion of Nail

For determining the natural torsion of the nail the described torque transmission device was used. One end of the nail was fixed to a screw vice, and the other end to the torque transmission device. Two points of the nail were fitted with levers which each affected their dial indicator. A gradually increasing torque was applied and each indicator read. The natural torsion of the nail was thus determined to $14._{16}$ per 0.1 kpm and per 10 mm of the nail. With satisfying accuracy, the correction value 14 per 0.1 kpm and per 10 mm of the nail was used.

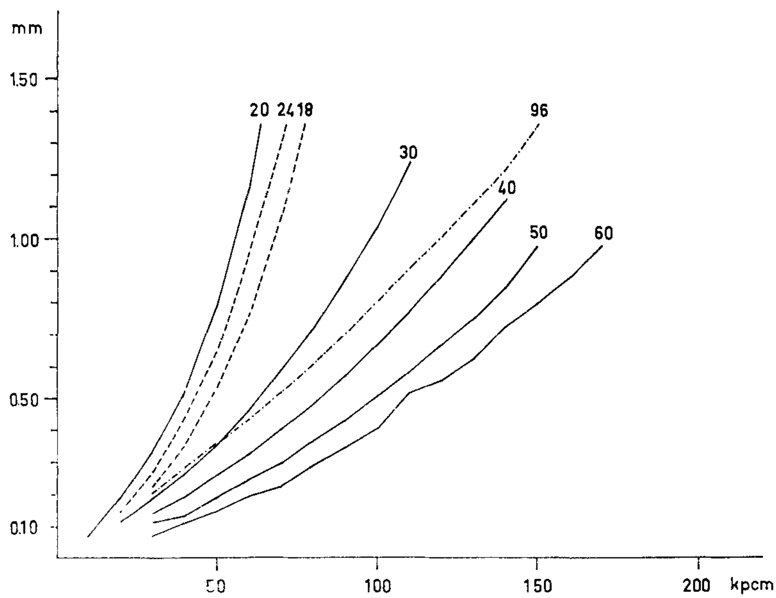
Torsion Experiments in Acetabulum

The described method was used for a series of experiments. In conformity with the bending stress, there was a pronounced reduction of deflection of the edge when the nailing depth exceeded 20 mm. The value is, however, slightly higher in connection with torque as compared to bending stress. In reality a nailing depth of 4—5 cm should be attempted.

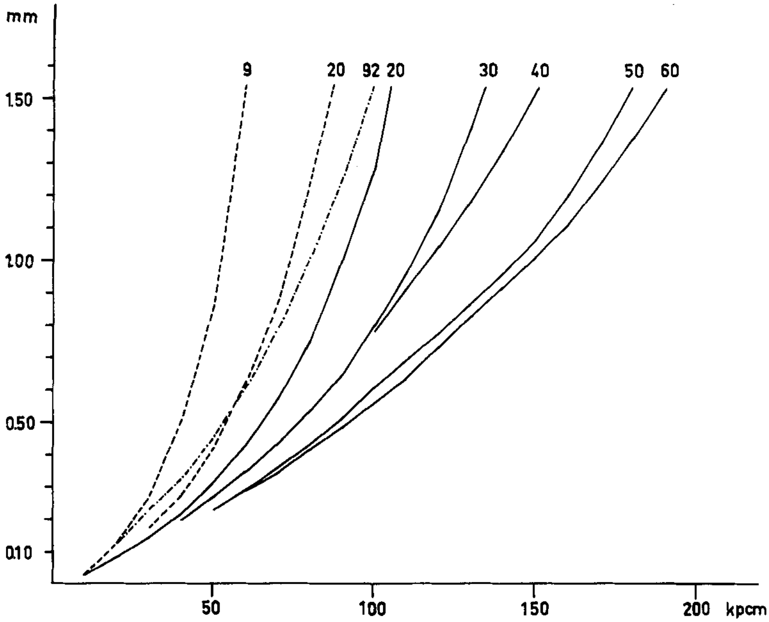
Fig. 20 a, b, c. Edge deflection caused by torque on three-flanged nail. — — — — — — — through two cortical layers. ——————— into body of iliac bone. —.—.—.—.—.—.— through femoral neck and head. Figures on curves designate nailing depth in mm.



a)



b)



c)

Fig. 20 presents examples of deflection curves obtained at these experiments.

The diagrams also include curves which were obtained with the nail in positions where it penetrated the posterior cortex. The thickness of bone then varied from 9 to 24 mm. The curves are at the same level as the one showing a nailing depth of 20 mm. Thus, penetration of the posterior cortex does not necessarily mean improvement of the stabilization. This presents an uncertain factor depending on how the cortical surface is fractured when introducing the nail.

Torsion Experiments in Neck and Head of Femur

The method described was also used for torsion experiments with the nail, introduced just below the greater trochanter, up through the femoral neck and head. The nail was inserted between 90 and 105 mm through the bone.

The nail tunnel was carefully prepared before inserting the nail. First a bore was drilled, corresponding to the core of the nail. The preparation continued using a three-flanged die. At the insertion of the nail the caput rested in a hemispherical metal cup or else in the acetabulum which thus offered adequate resistance. Despite this, fractures of the cortical surfaces were regularly noted. The torque was applied to the nail from the caput side.

Curves of deflection are marked in the diagrams which were obtained at the experiments of the pelvis. The curves show that the resistance is about the same as for the greater depth on the pelvic side.

Conclusions

The theoretical analysis and the experiments performed show that if a single nail is selected as an osteosynthetic technique, certain points should be carefully considered. As regards the nail it should have a great moment of inertia and shape properties which will give a minimum of fissures when penetrating the material. This also implies that the cortical layer must not be fractured when penetrated. As regards the edge deflection, the nailing depth should theoretically amount to a minimum of 22 mm. The cortical layers should be as thick as possible.

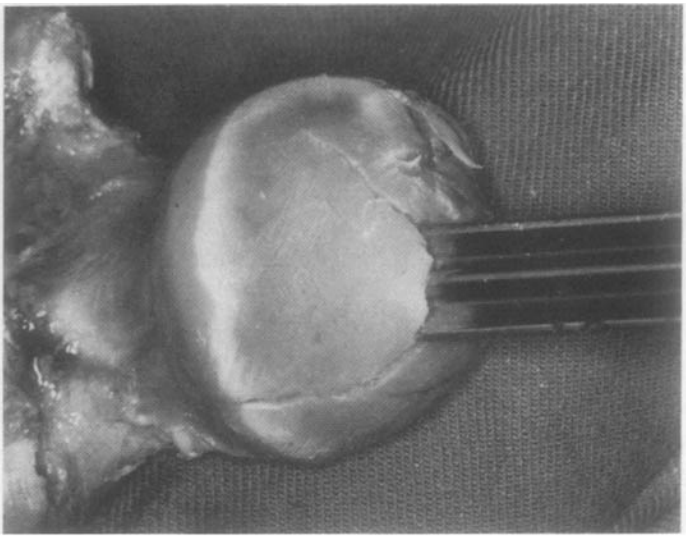
The experiments have shown that there is a limit value for the nailing depth which exceeds 30 mm for bending stress and slightly higher for torsinal stress. Thus, the nailing depth should be at least 40 mm. The securing will then not be less than that on the femoral side.

This demand in reality means that only one direction of nailing is possible, i.e. when the nail reaches into the body of the iliac bone. Only then can sufficient depth be achieved. Furthermore, in this direction a suitably dimensioned nail will be fixed between two cortical layers. This means that to the greater part it will rest in bone with cortical resistance properties. Finally, with this direction there is no risk of fractures in the internal cortical layer.

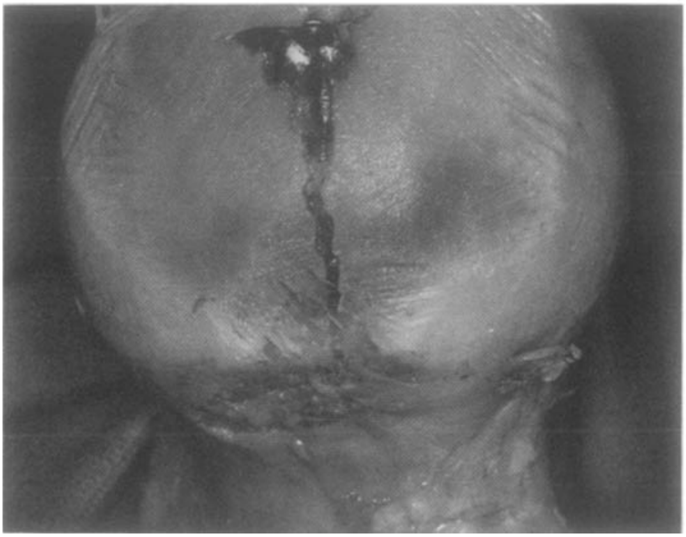
Traumatic Effect of Three-Flanged Nail

Nailing with a three-flanged nail has revealed that there are great risks of fracturing the caput. The nailing has been done carefully to cause as small a trauma as possible. The caput rested in the acetabulum, the preboring was done with great care, and the nail tunnel was prepared with a die.

With the nail well centered into the collum and the caput, the risk of fractures seemed small, provided that the tip did not reach or penetrate the cortex of the caput. If this occurred, fractures would regularly originate from the edges of the flanges. If the nail went obliquely through the caput the risk of fractures increased. This type of fracture usually appears as a



a.



b.

Fig. 21. Traumatic effect of three-flanged nail on femoral head.
a) Detachment of triangular fragment.
b) Fissure.

fissure in the caput from a flange of the nail towards the periphery, or else as a released and elevated triangular bone fragment. This may happen even if the nail has not penetrated the cortex. The tendency is more pronounced in a caput of a sclerotic type (Fig. 21).

These fractures are not visible on the radiographs, partly because they are concealed by the opacity of the nail, partly because they are not superimposed on normal radiographs.

Arthrodesis with Three-Flanged Nail

Arthrodesis was carried out in 35 specimens using the three-flanged nail for the osteosynthesis. In five cases no measuring values could be obtained for statistical analysis, because of undue complications with the specimens.

The preliminary experiments and the theoretical analysis of the three-flanged nail reinforcement, suggested a minimum nailing depth of 30 mm and a desired nailing depth of 40 mm. For the sake of relating these results to measurings on completed arthrodeses, a series of 7 specimens was tested, in which the nailing depth was less than 30 mm. (Mean nailing depth 24.4 ± 3.9 mm.) In the further experiments the nailing depth was at least 30 mm with a mean depth of 44 mm (± 10.4 mm).

When comparing these two depths, the result is inferior with the more shallow depth, the mean value for the deflection being considerably higher as also the mean rank (Tables XI and XII).

This confirms the results of the preliminary experiments.

For the comparative experiments, the greater nailing depth was used except for specimen No. 75, which accordingly was excluded from the statistical analyses of the series.

In using the sign test, the values are significantly inferior for all the loading directions as compared to three-point fixation with N-nails. The mean values of deflection are higher than for three-point fixation and in ranking, the mean rank places the method in a middle group (Tables X, XI and XII).

In order to find out if any loading direction was inferior as compared to the others, the four loading directions within each specimen and on levels 6, 8 and 10 kp were subjected to ranking (Table IX). Loading in extension gives the highest total ranking sum while the other loading directions are about equal. In placing the loading directions in pairs according to the plane at which the movement takes place, i.e. the frontal and the sagittal planes, the fixation preventing movements in the sagittal plane will be inferior (flexion-extension). The movement will then act about an axis which will coincide with the longitudinal axis of the nail. In the minimum nailing depths (<30 mm), however, the movements of the individual specimens in abduction and adduction often appear to be greater than in flexion-extension.

In order to reach into the body of the iliac bone, which is necessary to obtain the desired nailing depth, the nail must be inserted 2—3 cm

TABLE IX.

Sum of ranks of the four directions of loading at the Sv.J.nail

Kp.	Flx.	Abd.	Ext.	Add.
6	49	46	74	51
8	46	45,5	73	55,5
10	50	45	71	54

below the greater trochanter, close to the anterior side of the femur at an angle of between 140 and 150 degrees (mean value 146° ±4.6). The nail penetrates the posterior upper lateral quadrant of the femoral head. Thus, it will pass the longitudinal axis of the femoral neck under an acute angle both in the frontal and the transversal planes. As a rule, it will lie very close to the posterior cortex of the neck, near the caput, which often results in longitudinal fractures.

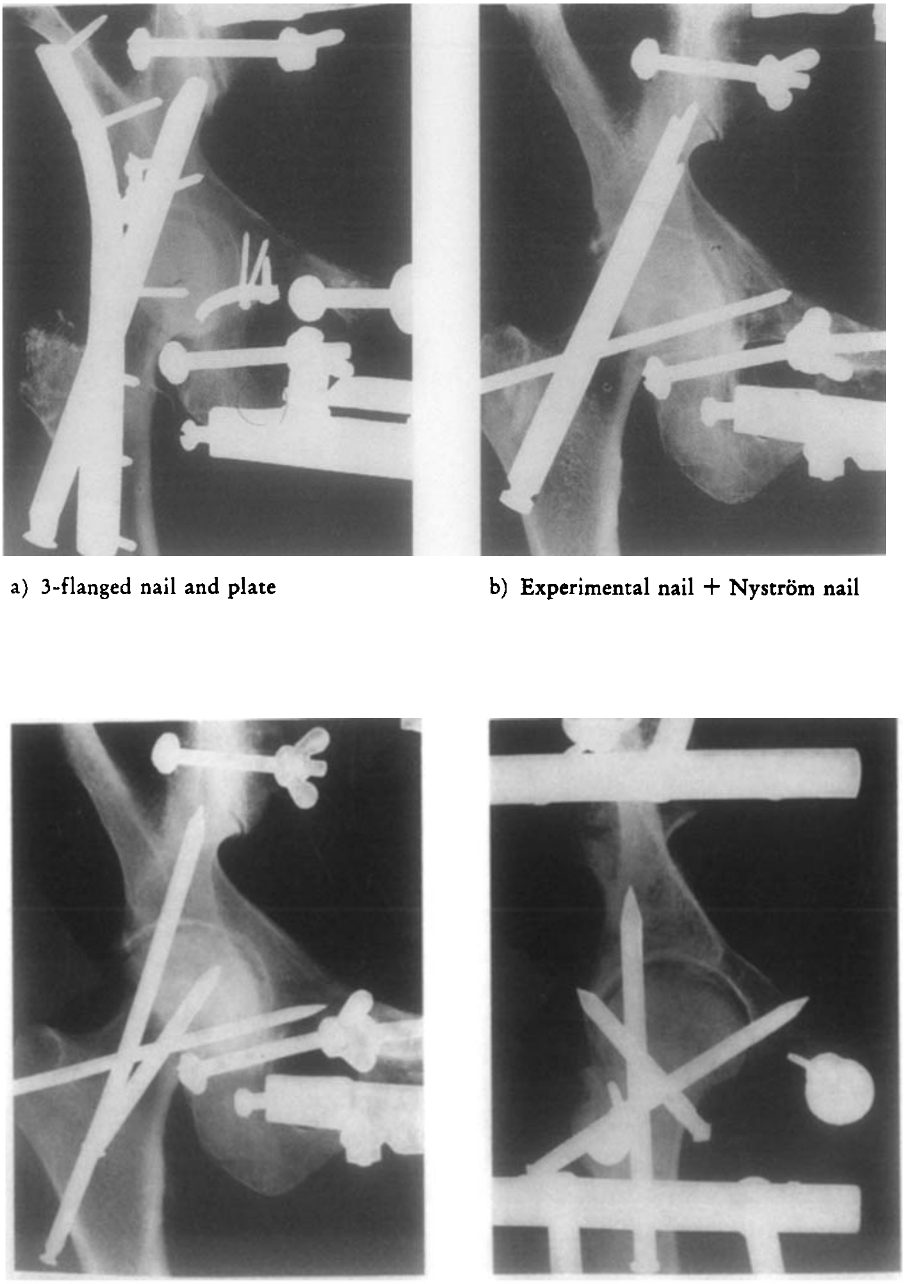
The described position of the nail implies a slightly flexed position of the arthrodesis, a mean position between abduction and adduction and also a mean position for rotation. If the hip is flexed more, the insertion of the nail can be less anterior. In abduction and outward rotation there is an increased risk of the nail not running all the way through the bone of the collum-caput. From the point of view of nail-position, the ideal position for arthrodesis is flexion, inward rotation and adduction. The nail will then lie optimally centered in the bone. From the clinical point of view, this is an impossible position.

Three-Flanged Nail and Plate

Osteosynthesis with nail and plate was performed according to Alvik (1961), (Fig. 22 a). The difficulty with the method is to obtain a good fit and satisfactory contact of the plate to the bone. The plate should cover the part from the ilium across the joint to the front side of the proximal femur. It is attached to the bone with several screws. A comparatively good fit of the plate is obtained by bending it properly. This may, increase the risk of corrosion (Venable & Stuck, 1948).

This technique was tried on 8 specimens. A comparison has been made, with the three-point fixation, with the three-flanged nail only and, finally, with a three-flanged nail together with a lateral-medial inserted N-nail. In the sign test the three-flanged nail and plate showed significantly reduced movement for flexion-extension as compared with both the three-point fixation and the simple three-flanged nail (Table X). On the other hand, there was no significant difference between these methods as regards mobility with load in the abduction-adduction direction. As compared with the three-flanged nail and an N-nail, there was no significant differ-

Fig. 22. Radiographs of various types of tested appliances.

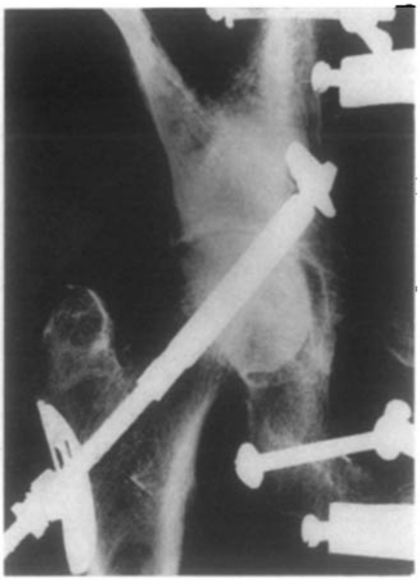


a) 3-flanged nail and plate

b) Experimental nail + Nyström nail

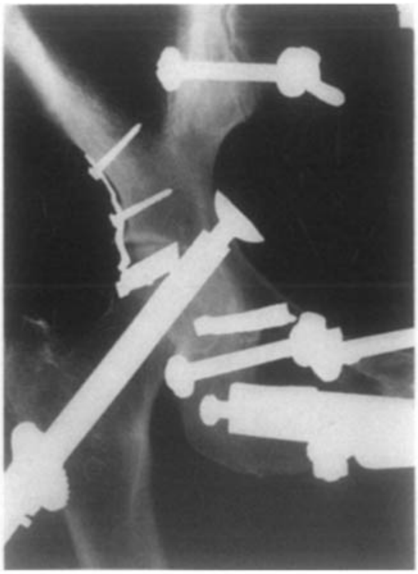
c) 3pfix Nyström nails. Frontal view.

d) Oblique view



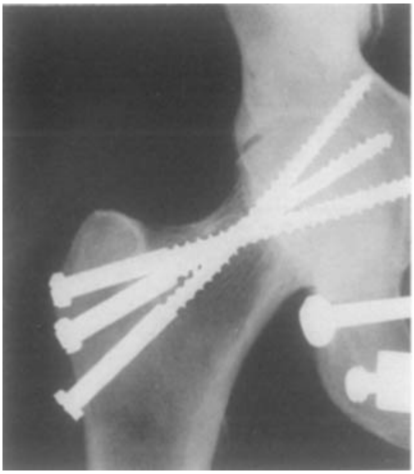
e) Axer nail

f) Fox nail



g) Niebauer nail

h) Mc Kee lag-screw



i) 3pfix screws

j) AO compression plate

ence in flexion and adduction. In abduction loading, there was greater mobility, while in extension loading, the mobility was reduced. The mean values of deflection in 6, 8 and 10 kp were low (Table XI). In analysis, ranking placed the method in the best group with respect to stability (Table XII). Thus, it offers good stability but the application is rather difficult.

Three-Flanged Nail and N-nail

The experiments with the three-flanged nail resulted in great mobility when loading in the flexion-extension direction. The three-flanged nail will only have one point of fixation. The special shape of the cross-section improves the resistance to bending and torsion stress as compared to a circular shape. Despite this, the fixation with the three-flanged nail could perhaps be improved by fixing an additional point in the contact surface between the caput and the acetabulum. This point should then be at a distance as far as possible from the three-flanged nail. Thus, the specific load in the bores will be reduced and more so the play in the acting point of the force, actually the movement between the surfaces will decrease (Fig. 23).

On the basis of the shape of the pelvis, there are consequently two possible positions for the complementary nail, viz. positions II and III (Fig. 24).

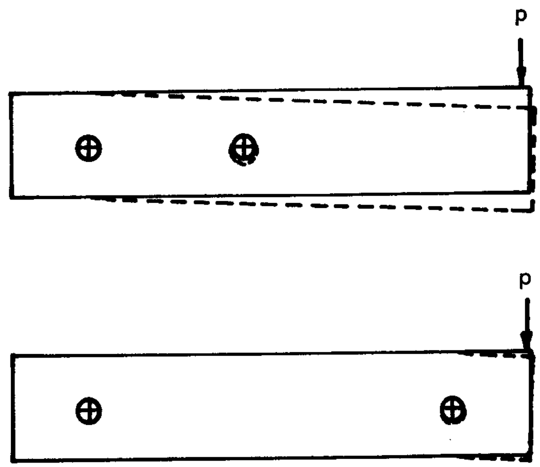


Fig. 23. Deflection in short and long distances between points of fixation.

The dimensions of the upper femoral end and of the three-flanged nail prevent the use of a complementary nail of the same dimensions. The large moment of inertia of the three-flanged nail also makes this unnecessary. Instead a nail of a thinner dimension is selected which can easily be placed inside the bone without affecting the large three-flanged nail. The two nails will penetrate the proximal femur about 10 cm. This will cause the nails to be well connected to each other. There is no additional advantage in letting the thinner nail run through a hole in the coarser one, as in Witt's double nail. A disadvantage, with this arrangement is that the direction of the thin nail is set. Consequently, it may be impossible to select a position which will give the best securing on the pelvic side.

Using an N-nail in positions II and III, a series of comparative experiments was carried out to establish the most suitable position for the nail. These experiments were made on 4 specimens. An N-nail, placed in position II (lateral-medial position) gave a significantly better result than a nail in position III (main direction anterio-posterial) (Table X). The first position was selected for the subsequent experiments.

The technique was tried in a total number of 12 specimens. In comparison with the three-point fixation there is no significant difference in any loading direction. As opposed to this, there are significantly better values in all the loading directions as compared with the simple three-flanged nail (Table X). In ranking, this technique was placed in the best group from the point of view of stability with a mean rank below 4 (Table XII).

Thus, it was found that simply by completing a three-flanged nail with

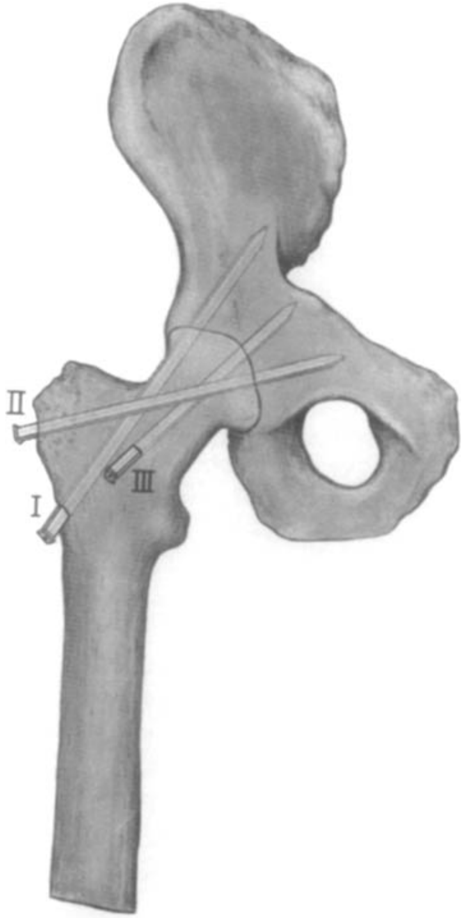


Fig. 24. I, II, III show the respective positions of nail, referred to in text.

an N-nail, inserted from the greater trochanter and transversally directed into the acetabular part of the pubic bone, the stabilization was considerably improved. The clinical procedure is also simple, due to television roentgen, and does not magnify the incision.

Three-Point Fixation with Nails

In an earlier investigation (Graziati & Kalén, 1965; Kalén 1965) a better result of stabilization was reported for arthrodesis of the hip by employing three thin nails of the N-type as compared to fixation with a three-flanged nail. The N-nail type was found to be superior to the three-point fixation with Steimann pins. The difference can be explained by the circular cross-section of the latter type.

The aim with fixation of this type is that each nail should lock the movement which occurs in a plane perpendicular to the longitudinal axis of the nail. The ideal is to place, if possible, the nails at an angle of 90 degrees. The maximum distance between each point of fixation in the spherical surface between the caput and the acetabulum is then obtained. The anatomical conditions are of a kind that the parts of the pelvis which offer the greatest nailing depth are placed so that their longitudinal axes will intersect each other at an angle of less than 90 degrees. On the femoral side, two of these directions will allow the nail to be inserted into the bone at a depth of between 8 and 10 cm; the third alternative, of no less than 6 cm (Figs. 24, 6).

The outlined technique is in good accordance with the technological principle which expresses that for stabilization of a piece of material the points of fixation should be placed as far from each other as possible.

The thin nails of the N-type have a diameter of 4 mm with a square cross-section and slightly concave sides. Due to this dimension, a very small portion of the bone material is involved, and the technique has therefore been considered suitable to use as a reference method when evaluating the other techniques of osteosynthesis.

The position of the nails in three-point fixation is as follows: one nail is placed in the same position as for fixation with a three-flanged nail, i.e. into the body of the iliac bone (No. I, Fig. 24). A second nail is directed from the posterior part of the greater trochanter transversally and medially into the acetabular part of the pubic bone (No. II). The third nail is introduced slightly below the centre of, and inside, the intertrochanteric line. It takes a posterior course, slightly medial and cranial into the spine of the ischium (No. III).

At the experimentally performed arthrodesis the insertion of nails in the described directions does not involve any difficulties. The small dimensions of the nails and their position will prevent them from contacting each other.

In clinical surgery there is no difficulty in placing nails Nos. I and II. Instead, nail No. III, which is directed to the spina of the ischium, may involve a certain risk of nerve and vascular injury if the tip is uncontrollably hammered through the cortex of this area.

When introducing the nails into the femur the cortex has always been prebored with a suitably dimensioned drill. This is essential in positions I and III as these nails penetrate the cortex under an acute angle. The cortical layer into which nail No. I is inserted is furthermore, rather dense.

When compiling the experiments with the sign test, a significantly improved fixation is found for all the load directions as compared to fixation with a three-flanged nail (Table X). The same result is found in comparison with three-point fixation with screws and with compression techniques. As compared to a three-flanged nail plus a lateral-medial directed N-nail, there is no significant difference. In comparison with a three-flanged nail and plate there is no significant difference in the load directions adduction-abduction, but negatively in flexion-extension.

When compiling the method with the descriptive calculations, there are low mean values for the deflection at 6, 8 and 10 kp. The ranking places the method in the best group with a mean rank of 3.50 (Tables XI, XII).

Variations of Three-Points Fixation with Nails

Osteosynthesis with three nails was varied by substituting the N-nail in position I for a nail of a larger dimension. An N-nail of a 6 mm dimension was tested and also a triangular nail, in principle a three-flanged nail without flanges, the latter having a maximum diameter of 8 mm.

On comparison between the different types of nail and the conventional ones used for fixation, there is a significant difference in favour of a nail of the latter type in position I. However, no significant difference could be found when the usual N-nail in position I was replaced by a slightly coarser nail of the same type.

It should be pointed out that the coarser nails were inserted into the same tunnel as the thin N-nail first introduced and then the specimen was re-tested. This will impair the conditions of the latter nails which to a certain extent explains the indemonstrable difference between the N-nail of 4 and 6 mm dimensions.

Three-Point Fixation with Screws

Osteosynthesis was performed according to Merle d'Aubigné (1964) with the nails in the positions, recommended by him. The length of the screws was between 12 and 14 cm. The root diameter was 3.6 mm and the diameter over the threads 6 mm. The technique was carried out on ten specimens as comparative experiments (Fig. 22 i).

This technique was always performed first, in order to ensure the best conditions for the screws. As a second technique the three-point fixation with nails was performed. The results show significantly inferior values for the fixation with three screws in all loading directions. The descriptive calculations show a mean rank sum which ranges within higher values (Tables X, XII).

The advantage of the screw reinforcement as compared to that of the nail is that the screw is much more resistant to loading in axial direction. However, the bending resistance of a screw is less than that of a nail of the same dimension and further its resistance to torsional forces is lower. In the present case the stress to which the osteosynthetic material is subjected, will mainly be in the form of bending and torsional stress. The property of the screw to bring about compression by prestress is here of less interest.

The load and muscular force, always cause compression. As the technique with nails gives better stabilization and is easy to apply, there is actually no reason to use screws instead.

Compression Methods

Four different methods for osteosynthesis with compression have been tried. In three of these, viz. the methods according to Axer, Fox and Niebauer, the same procedure, in principle, is utilized.

A nail is directed from the greater trochanter through the femoral neck and head, penetrating the acetabulum so that the tip will reach the true pelvis. It is secured with a locking device. A nut which is screwed on to the threaded end will then cause compression against the cortex of the femur. The femoral part will thus be pressed along the nail and there will be compression between the joint surfaces.

The fourth method, according to Mac Kee consists of a coarse screw which is inserted into the acetabular roof.

These methods have been tried on a total of 23 specimens. The cartilage was carefully removed from the joint surfaces involved as, when employing the methods of compression, an increased friction between the surfaces could be of importance for the efficiency of the fixation.

Compression Nail according to Axer

The osteosynthetic material consists of a short three-flanged nail, a threaded pin which is screwed into the head of the nail, a locking device which is mounted over the tip of the nail and locking it against the cortical surface of the true pelvis. Furthermore, the outer end of the threaded pin is fitted with a plate of special design which rests against the femoral cortex. A spring to maintain the compression force, a locking washer and a nut, finally, complete the device (Figs. 22 e; 25 a).

With osteosynthesis of this type, there is a risk that the threads of the pin may catch in the plate which rests against the femoral cortex. It is necessary to take care that this does not happen as, otherwise, the compression in the arthrodesis will not be that intended.

The method has been tested in 8 specimens, 2 of which were comparative experiments with a three-flanged nail and one transverse N-nail. The stabilization was not satisfactory with this technique. Already light loads caused considerable deflection. The sign test of this technique resulted in significantly inferior values as compared to stabilization with a three-flanged nail and one N-nail, despite the fact that the compression method was carried out first. The range of the mean values of deflection is also high. In the statistical analysis of the technique, the ranking procedure gave the highest average ranking value (Tables X, XI, XII).

Compression Nail according to Fox

The osteosynthetic material consists of a nail with a square cross-section and concave sides. The tip is designed to cause gradual scooping of the nail tunnel. There is also a locking washer to secure the tip of the nail inside the pelvis. It is coarser, of a more simple design and easier to apply than the Axer nail. In this technique a plate is also fitted across the head of the nail. The plate is fixed to the femoral shaft with through-screws. When the end nut is tightened, the compression is transmitted via this plate to the femoral portion. No helical spring is used (Figs. 22 f; 25 b).

The method has been tested on 6 specimens, all comparative experiments, with three-point fixation.

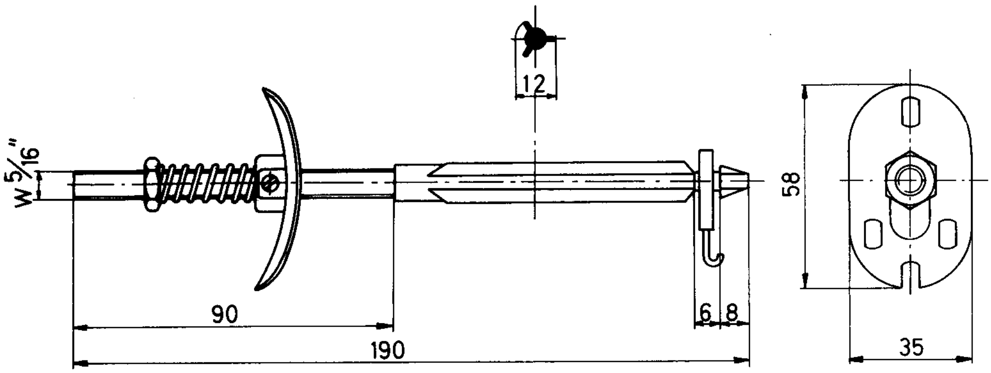
In the sign test, there is a significantly higher deflection value with this method as compared to the three-point fixation. However, the mean value of the deflection at 6, 8 and 10 kp loads ranges lower than the values obtained for the Axer technique. The explanation is probably that the dimensions and design are more correct (Tables X, XI).

At the ranking procedure there is a comparatively high mean rank sum which places the method in the group of less satisfactory (Table XII).

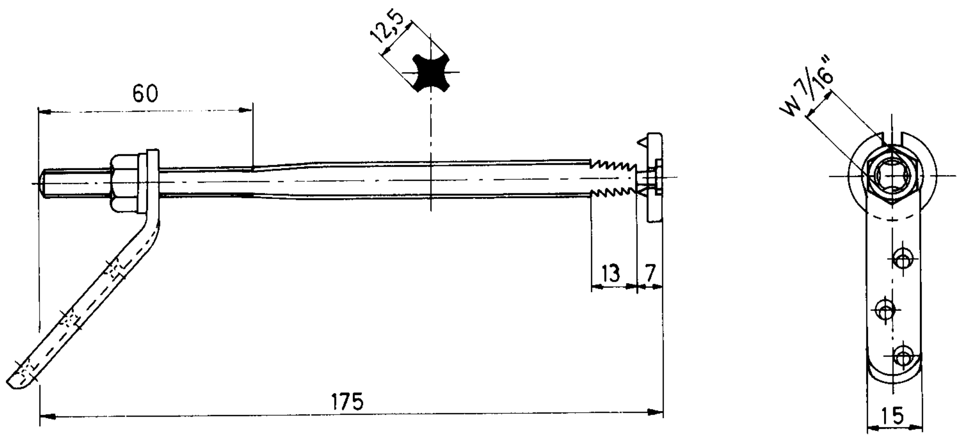
Compression Nail according to Niebauer

The nail is three-flanged and has a slightly coarser dimension than the Axer nail. The locking washer on the inside of the pelvis also differs. The compression is brought about with a nut via a sleeve mounted on the head of the nail (Figs. 22 g; 25 c).

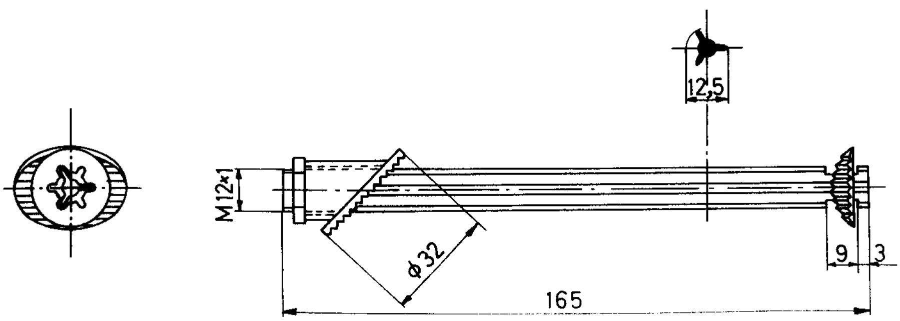
The method was only tested in 3 specimens. In one of these the stabilization only allowed a load of 4 kp in two directions. The stabilizing effect is clearly inferior as compared to the three-point fixation. Niebauer also recommends a complementary screw from the upper edge of the acetabulum through the caput in a caudal direction. The technique, at present does not seem to be in clinical practice.



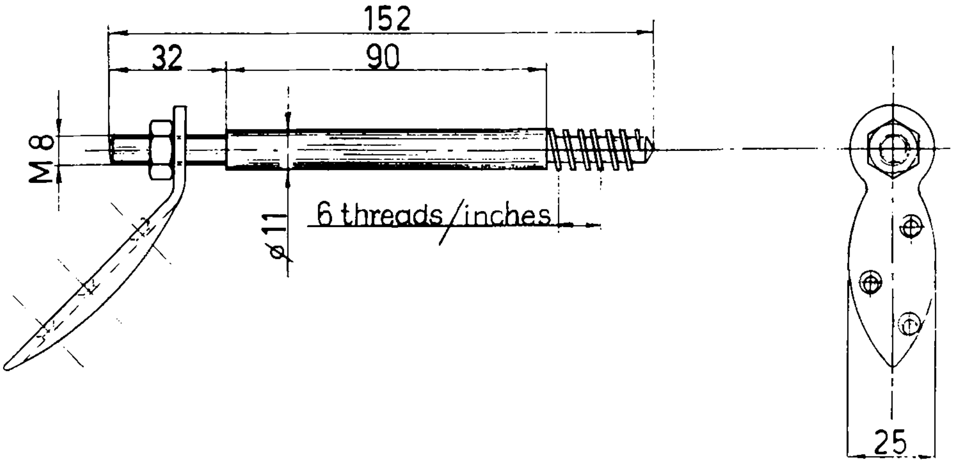
a) Compression nail according to Axer.



b) Compression nail according to Fox.



c) Compression nail according to Niebauer.



d) Compression screw according to Mc Kee.

Fig. 25 a—d. Construction drawings of tested compression devices. The measurements are expressed in millimeters.

Compression Screw according to Mac Kee

The screw is inserted through the collum/caput and screwed into the acetabular roof, reaching a depth of 2.5 cm. Only the part on the acetabular side is threaded with wide threads, while the part of the screw in the femoral portion is smooth, cylindrical. Also here there will be compression by means of a nut fitted on to the threaded outer end of the nail.

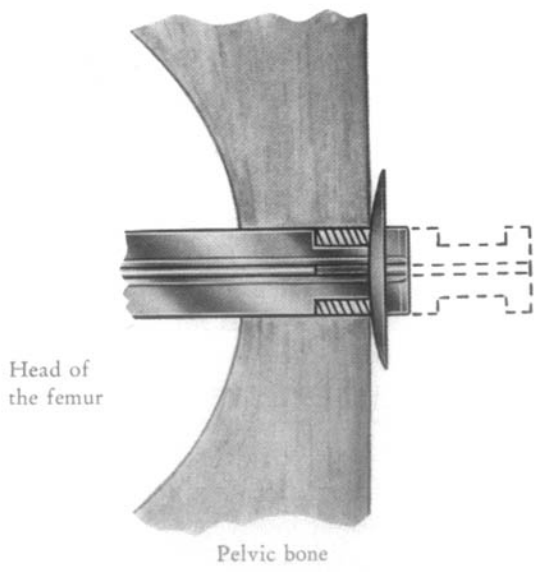
The method was tried in 6 cases as comparative experiments to the three-point fixation. Two of these, however, had to be excluded as sufficient fixation for minimum loads could not be obtained. Only in one case were all four loading directions recorded, with 4, 6 and 8 kp respectively (Figs. 22 h; 25 d).

At the sign test the values of deflection were significantly higher as compared with the three-point fixation (Table X). The mean values obtainable for the deflection were high (Table XI). Due to the low number of observation, ranking could not be calculated for loads of 6, 8 and 10 kp. As the stabilization in these experiments was poor, there was no reason to increase the series. The poor stabilization depended on insufficient securing to the acetabulum, a short portion of the screw inserted into spongy bone, and on the circular section of the screw. The first condition is the reason for an inferior preventive effect of the movement in abduction and adduction loading, the latter refers to the flexion-extension loading.

In loading, where the movement will occur close to the longitudinal axis of the screw, i.e. mainly flexion-extension, the counteracting force will only be the friction force between the joint surface (primarily increased through compression) and friction between the screw threads and the bone in the acetabulum.

Summary

In summary, none of the tested methods of compression with nail or screw offered stabilization to a degree which could be expected. Stabilization with compression should theoretically give a better result than without. The reason of this not being the case may depend on the quality of the utilized bone on the pelvic side. The average thickness of the bone layer, penetrated on the pelvic side, was for the Axer nail 17 mm with a variation ranging between 11 and 25 mm, and for the Fox nail, 16 mm with a variation between 11 and 20 mm. As the nails in a small area inside the locking plate lack flanges, a few additional millimeters are lost because the nail is pulled back at the compression (Fig. 26). The cortical layer of the pelvis is thin within the area concerned, and not of the quality which, for instance, is found on the femoral side where the nail is inserted. Thus, the bone cannot always resist the great stress concentration which will occur. Especially the curved locking plate used for the Niebauer nail causes impression in the underlying bone when subjected to compression. It should also be pointed out that the joint surfaces around the nail, which are compressed against each other are not plane but spherical with a sometimes varying



Figs. 26. No bone contact of compression nail in shaded-in patches.

TABLE X.

Result of Sign test

	3pfix N	3pfix N mod.	Sv. J.	Sv. J.+N position II	3pfix screws
3pfix N mod.	0 0 0 0				
Sv. J.	+ + + +				
3pfix (Sv. J. mod.)	0 — — —				— — — —
3pfix. screws	+ + + +	+ + + +			
Sv. J.+ N position II	0 0 0 0		— — — —		
Sv. J.+ N position III				+ + + +	
Sv. J. + plate	— 0 0 —		— 0 0 —	0 + 0 —	
Axer nail				+ + + +	
Fox nail	+ + + +				
Mc Kee screw	+ + + +				

+ means that the line-method gives significantly higher values of S_{max} than the column-method.

— means that the line-method gives significantly lower values of S_{max} than the column-method.

0 means that there is no significant difference.

As regards the loading directions the signs are set as follows:

Flexion Abduction

Extension Adduction.

radius. This means that the force intended to be transmitted between these surfaces will be concentrated within a rather small area around the nail.

The position of the nail means that the longitudinal axis will lie close to that of the collum. Loading in flexion and extension will then mainly appear as torsion stress. From the femoral side it will be transmitted to the pelvic side, partly by friction between the joint surfaces, partly via the

TABLE XI.

Mean values for S_{max}

3pfix N

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	9.94	6.28	10.80	15.83	(49, 50, 49, 50)
8	14.92	12.36	18.65	23.68	(49, 50, 49, 50)
10	21.32	20.37	26.75	29.94	(47, 49, 49, 47)

3pfix N mod.

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	12.77	14.77	16.44	20.44	(9, 9, 9, 9)
8	20.66	24.88	26.55	29.22	(9, 9, 9, 9)
10	24.00	36.43	32.00	39.86	(7, 7, 7, 7)

3pfix (Sv. J. mod.)

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	7.17	2.50	4.50	8.83	(6, 6, 6, 6)
8	11.33	4.33	6.33	12.83	(6, 6, 6, 6)
10	15.83	6.17	8.33	18.50	(6, 6, 6, 6)

3pfix screws

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	30.89	36.89	27.44	38.20	(9, 9, 9, 10)
8	31.14	30.71	42.00	41.75	(7, 7, 7, 8)
10	46.50	46.67	71.50	52.28	(6, 6, 6, 7)

Sv. J. (Depth of insertion $>$ 30 mm)

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	20.89	13.47	22.84	26.47	(19, 19, 19, 19)
8	24.61	21.68	34.05	40.63	(18, 19, 19, 11)
10	26.87	32.58	45.16	44.50	(16, 18, 19, 16)

Sv. J. (Depth of insertion $<$ 30 mm)

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	41.86	66.67	93.25	112.20	(7, 6, 4, 5)
8	77.00	113.50	92.67	132.00	(7, 6, 3, 4)
10	63.20	167.00	105.67	101.00	(5, 4, 3, 3)

Sv. J. + N (position II)

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	11.25	9.25	14.92	17.25	(12, 12, 12, 12)
8	13.36	16.67	23.17	24.25	(11, 12, 12, 12)
10	18.36	19.40	32.40	21.00	(11, 10, 10, 10)

Sv. J. + N (position III)

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	11.25	16.25	14.50	17.00	(4, 4, 4, 4)
8	17.75	24.50	23.00	25.50	(4, 4, 4, 4)
10	17.33	21.00	32.75	20.00	(3, 3, 4, 3)

Sv. J. + plate

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	6.25	12.63	25.00	6.25	(8, 8, 8, 8)
8	11.63	20.50	35.75	10.00	(8, 8, 8, 8)
10	16.38	31.13	23.14	14.50	(8, 8, 7, 8)

Exp. nail + N (position II)

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	7.5	6.5	6.3	10.1	(10, 10, 10, 10)
8	13.1	10.7	10.9	14.6	(10, 10, 10, 10)
10	16.9	14.9	15.9	20.3	(10, 10, 10, 10)

Fox Nail

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	21.83	26.83	26.33	26.33	(6, 6, 6, 5)
8	33.80	46.67	27.20	49.00	(5, 6, 5, 5)
10	38.75	34.67	40.40	52.50	(4, 3, 5, 2)

Axer Nail

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	68.25	123.25	128.28	121.37	(8, 8, 7, 8)
8	73.83	99.33	140.50	125.33	(6, 6, 6, 6)
10	111.25	138.40	115.40	158.00	(4, 5, 5, 5)

Mc Kee screw

Loading Kp	Flx	Abd	Add	Ext	No. of obs.
6	80.75	107.33	185.00	100.75	(4, 3, 3, 4)
8	47.00	—	—	—	(3, –, –, –)

TABLE XII.

Ranks of methods

Method	Sum of ranks over directions			Sum of ranks over loadings				Total sum of ranks	Mean rank
	6 kp	8 kp	10 kp	Flx.	Abd.	Add.	Ext.		
3pfix N	10	13	19	13	8	9	12	42	3.50
3pfix N mod.	24	27	27	21	22	16	19	78	6.50
3pfix Sv. J. mod.	6	5	5	4	3	3	6	16	1.33
3pfix screw	40	36	39	29	28	30	28	115	9.58
Sv. J. > 30 mm	29	29	32	24	17	24	25	90	7.50
Sv. J. < 30 mm	44	47	45	34	35	33	34	136	11.33
Sv. J. + N pos. II	16.5	14	17	11.5	9	15	12	47.5	3.96
Sv. J. + N pos. III	18.5	21	18	13.5	18	14	12	57.5	4.79
Sv. J. + plate	14	16	12	5	14	20	3	42	3.50
Axer nail	48	45	47	35	34	36	35	140	11.67
Fox nail	34	36	35	28	25	24	28	105	8.75

flanges of the nail to the external cortical surface of the pelvis and its spongy bone. Finally, the torsion stress may be transmitted via the stop plate to the internal cortex. This is especially pronounced in using the Fox and Niebauer nails while, contrary to this, the locking plate in Axer's technique allows the nail to turn freely.

In all the experiments these compression methods were inferior to the reference method. In analysis, the ranking procedure revealed that the compression methods do not offer better stabilization than an adequately fitted three-flanged nail.

Arthrodesis with Compression Fixation according to AO

Arthrodesis was performed by the use of the technique, described by Müller in the AO-Bulletin, September 1967. With this technique the osteotomy of the pelvis is made horizontally at the level of the upper acetabular edge and releasing a segment of the upper part of the caput. The caput is displaced medially so that its planed upper surface will contact the bone surface of the ilium medial to the acetabulum. Part of the greater trochanter is removed by saw and then a specially designed cross-plate is screwed on to the outside of the ilium so that the plate will contact the proximal femoral end laterally. Compression is applied by using AO's compression device and then screwing the plate to the femoral shaft (Fig. 22 j).

As the caput and the acetabulum are not kept intact when this technique is used, the earlier measuring technique was not applicable. Thus, comparative experiments could not be executed either. The measurings were performed with three measuring calipers, fitted according to Fig. 27.

Due to pelvic osteotomy the pelvis could not be fixed in the same way as in earlier experiments. The ilium was instead fixed by means of polyester. The osteosynthesis leaves the entire ischio-pubic portion of the acetabulum unstabilized.

Measurings were performed in three cases. In all the cases there was a certain amount of mobility in all the four tested load directions. The lowest reading was obtained for adduction load, which was expected, as there will then be a force component in a direction which will increase the compression.

Digrams, (Fig. 28), exemplify the recorded movement in the three transducers with increasing load in the four tested load directions. Thus, a total movement as S_{max} is not reported as in earlier diagrams. No relevant comparison with these values can consequently be made. It has merely been established that the method will not give rigid fixation.

Certain fixed factors may thus be involved. The design of the plate

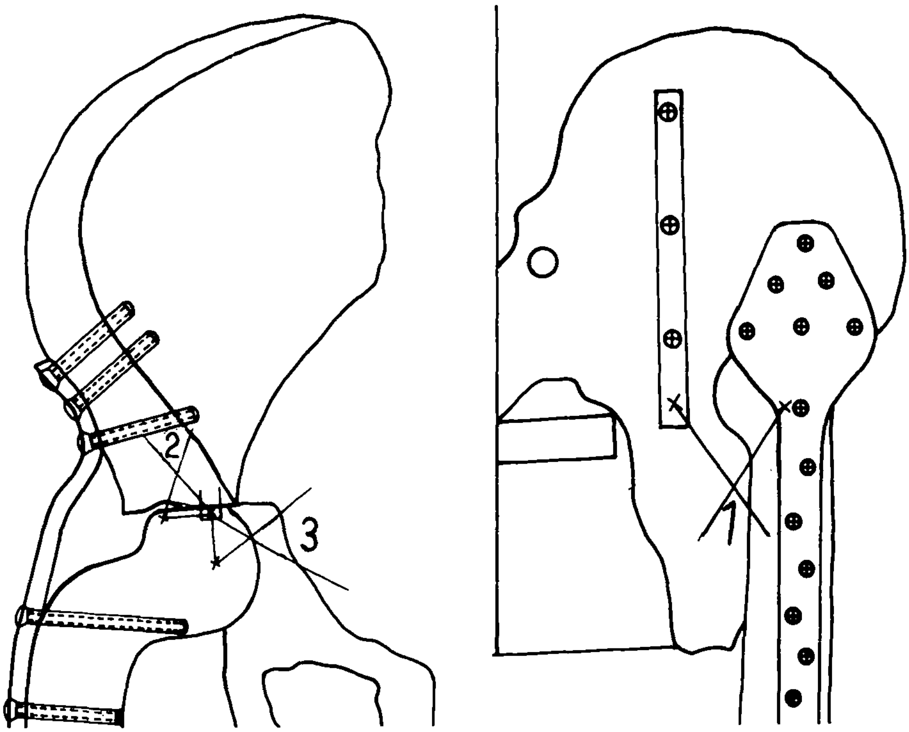


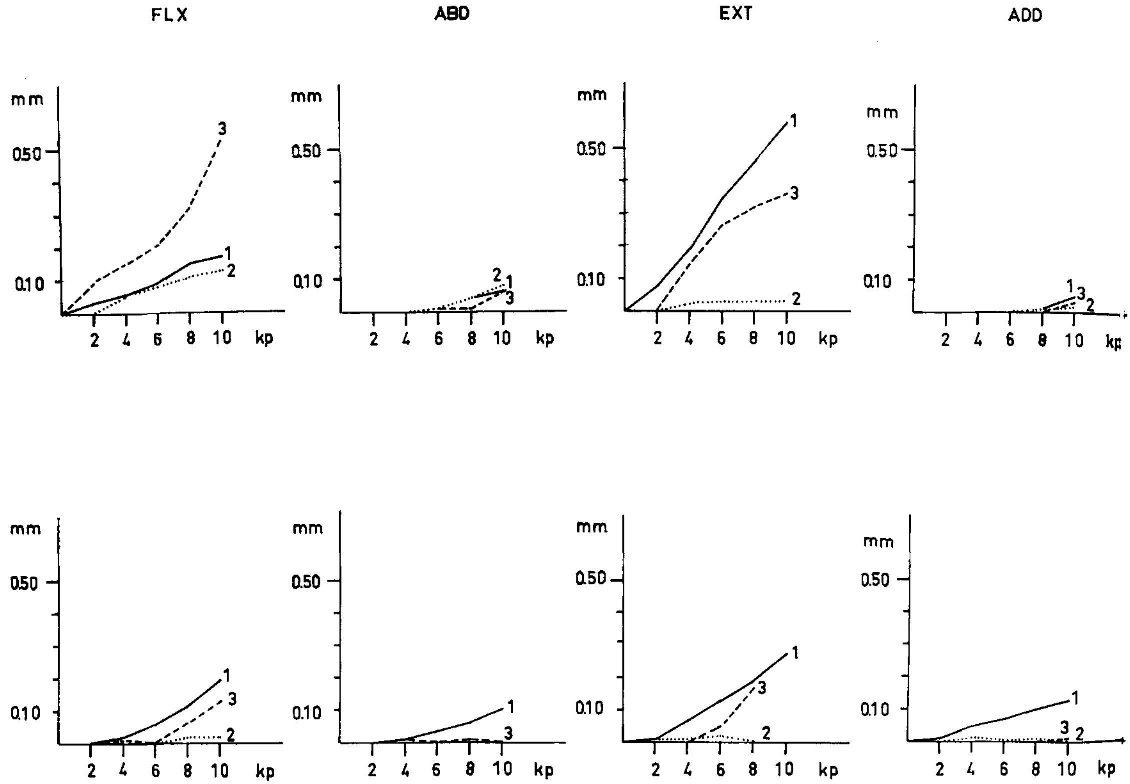
Fig. 27. Position of displacement gauges when testing AO compression plate.

does not always allow the plate at the attachment to the ilium to be fitted in close contact to he bone. The bone to which it is screwed is of a thin dimension and has lower resistance properties than, for instance, the sturdy cortex of the femoral shaft. De Palma (1962) complained of the difficulty in obtaining a satisfactory attachment for screws in this region, and instead recommended through bolts. The applied compression may partly compensate the inferior attachment but, for example, in abduction load the compression force will be reduced between the contact surfaces in general and in extension-flexion load within certain areas.

As regards the contact surfaces, the ilium will after osteotomy, offer a very narrow bone area for contact with the surface of the caput. The caput will thus balance on this narrow bone surface when compression is applied. The contact surface of the ilium can be increased by placing the osteotomy on a more proximal level, but as this is done, the contact surface of the caput will be reduced accordingly.

The bone surfaces which are to be compressed will also lie at a great distance from the plate which causes compression.

Finally, the osteotomy, performed dorsally to the acetabulum will leave



Figs. 28. AO compression plate. Experiments 109 and 112. The diagrams show displacement in gauges in positions according to Fig. 27.

large, open spongy bone surfaces which are not utilized for compression, but clinically will be the source of extensive bleeding.

Nail Design

The experiments which were performed on the basis of the theoretical analysis of the three-flanged nail, show slightly higher values for the edge-deflection than the theoretical values.

The reason is mainly the impaired resistance, resulting from the fractured bone connected with the insertion of the nail. The properties of the nail, furthermore, are also decisive for the result. The moment of inertia of the nail is an important factor. It should be as large as possible. The dimensions of the nail should be such that it will remove as little as possible of the bone material. Finally, the anatomical shape of the bone areas concerned is a factor to consider when dimensioning the nail.

Besides a form factor, the properties of the nail are determined by a material factor, namely the physical properties. Due to the demands made on the corrosive resistance, the selection in reality is limited: stainless steel, vitallium, titanium. For the experimental nail stainless steel was selected.

The moment of inertia of the nail completely depends on the form factor. It is defined for the perpendicular cross between the axes as follows:

Moment of inertia with respect to x-axis $$I_x = \int_A y^2 \cdot dA.$$

With respect to y-axis $$I_y = \int_A x^2 \cdot dA.$$

The designed nail will, according to the dimensions in Fig. 29 receive a moment of inertia amounting to 350 mm^4 (compare the Sv. J.-nail 140 mm^4).

A cross-section which gives a large moment of inertia in certain directions is the H-form. It has been utilized previously for nail designs by Frankel (1960) and Laing & O'Donell (1961). This section, however, causes difficulties in shaping the tip as the aim is to create as small a nailing-in resistance as possible. Furthermore, it may also involve a chiselling effect in the bone.

To obtain equal resistance of the nail in various directions, it is necessary that its properties be uniform and, therefore, the design should be quite symmetrical, if possible. The moment of inertia will then be constant in all the directions. A four-flanged section is consequently preferable. The solid bone lying between the flanges will diminish by an increased number of flanges. An optimal relation between the number of flanges and the dimensions of the intermediate bone area should be attempted.

By finishing each flange with a circular segment instead of a pointed angle the moment of inertia will increase and at the same time, the chipping effect will be reduced.

Due to the shape of the bone in that particular area a nail dimensioned 12 mm was selected. It is slightly smaller than the conventional Sv. J.-nail.

To reduce the risk of fissures occurring along the flanges of the nail at the insertion, the tip of the nail also has a special design. The nail has been extended from its middle to a circular tip in order to fit in a bore of the same dimension. The tip of the flanges have been pulled back in relation to each other so that they will each rest against the bone surface. This means that a plane through the tips of the flanges will be at an angle of 145 degrees against the longitudinal axis of the nail. This will prevent the nail from sliding along the cortical surface. Furthermore, the tip of each flange is shaped as a cross-ground edge directed slightly towards the centre of

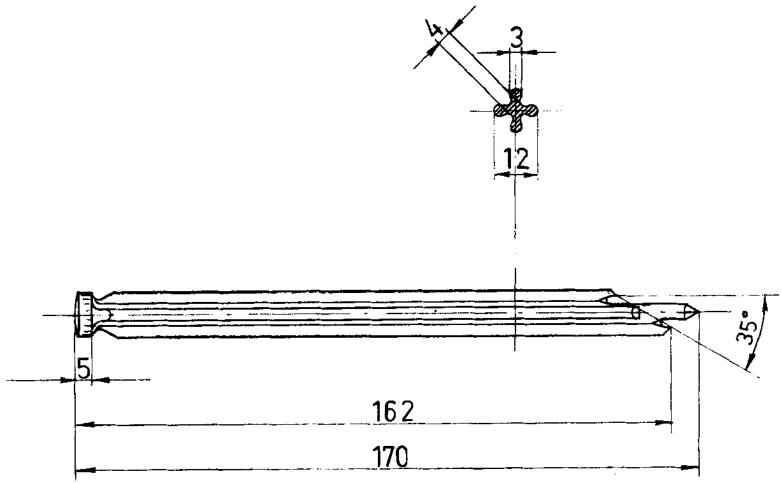


Fig. 29. Construction drawing of experimental nail. The measurements are expressed in mm.

the nail. When the nail is inserted, this edge will chisel out small fragments of bone. Inside this edge at an angle of 90 degrees, the flange itself is ground to an edge. At the insertion small fragments of bone will be chiselled out and guided into the groove between the external coarser edge of the flanges and the centre of the nail. They will accumulate here and definitely improve the securing of the nail.

Testing of Experimental Nail

The earlier investigations showed that the three-flanged nail combined with a thin transversal nail gave a very good primary fixation. Thus, there was no signficant difference as compared to the three-point fixation with thin nails. The purpose of the new-designed experimental nail was to replace it for the three-flanged nail used in this method of stabilization. Bearing in mind the disadvantages of the three-flanged nail, the efficiency of the nail joint should gain.

So that any difference between the experimental nail and the three-flanged nail could be determined in practice, it would have been advantageous to compare measurements with both nails tested on the same specimen. As both nails, however, do not differ much with respect to dimension, and the position of both nails should be in good accordance, an experiment of that type would not be just. The nail, tried first, will actually give such a loss of bone substance that the securing conditions for the following nail will be very poor.

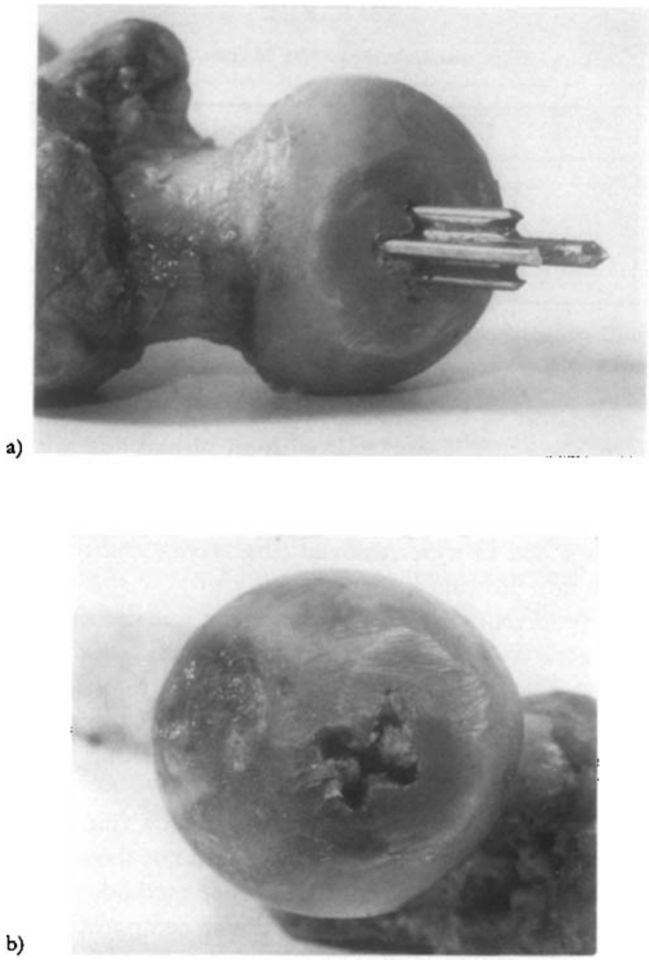


Fig. 30. Experimental nail. a) note no traumatic effect.
b) after removal of nail.

(Compare Fig. 21)

In order to create as equal conditions as possible, it was decided that each nail would be tested on the right-left sides of the same specimen. Four of these experiments were performed. It was found, however, that the specimen factor by no means was eliminated by this. Furthermore, there were

TABLE XIII.

Sign test 3pfix N — E + N (pos. II).

Loading direction	Numbers of observations 3pfix N > E + N	Total number of observations	Significance
Flx	31	41	yes
Abd	18	41	no
Add	16	39	no
Ext	35	47	yes

difficulties in obtaining whole pelvic specimens to the required extent.

As direct comparative experiments could not be carried out, a series was tested using the experimental nail with an N-nail and with the three-point fixation as a reference method. This series includes ten specimens. On each specimen osteosynthesis was first done with three N-nails. Then the nails in positions I and II were removed (Fig. 22 b), and the experimental nail was inserted into position I.

In assessing the measured results and carrying out the sign test, there is a significantly greater mobility with three-point fixation in loading in flexion-extension. On the other hand, there is no significant difference between the tested methods in abduction-adduction loading (Table XIII). The mean values for S_{max} are low, (Table XI) and ranking between certain methods places the method on the top (Table XIV).

In a test series with an Sv. J.-nail combined with a transversal nail and compared to three-point fixation, the sign test did not show any significant difference. By testing against the same reference method, as used here, an indirect comparison can be made. As no direct comparative experiments were carried out, the results cannot be regarded as statistically significant. The results obtained, however, support the opinion that the new-designed nail gives a better result than that of the conventional three-flanged nail.

It can well be explained that an improvement is obtained in flexion-extension in comparison with the three-flanged nail, but that no difference can be demonstrated in abduction-adduction. Loads in the latter directions will cause considerable bending stress to the nail. The moment of inertia of the nail will be of great importance. However, the moment of inertia for both nails is satisfactory in the loads concerned. When loading in flexion-extension, the nail will on the other hand transmit torsional stress. Any fractures of the bone emerging from the flanges will result in an impaired stability.

When performing arthrodesis it was established that the new-designed nail had a reduced traumatic effect in the bone. In no case was there any

TABLE XIV.

Ranks of certain methods

Method	Flexion			Abduction			Adduction			Extension			Sum of ranks
	6kp	8kp	10kp	6kp	8kp	10kp	6kp	8kp	10kp	6kp	8kp	10kp	
E + N	1	1	1	2	1	1	1	1	1	1	1	1	13
3pfix N	2	2	2	1	2	2	2	2	2	2	2	2	23
Sv. J.	3	3	3	3	3	3	3	3	3	3	3	3	36
3pfix screws	4	4	4	4	4	4	4	4	4	4	4	4	48
Compression nails and screw	5	5	5	5	5	5	5	5	5	5	5	5	60

fracture of the caput or the acetabulum which was comparable to that caused by the three-flanged nail (Fig. 30). Subjectively, it also gave a clear impression of penetrating the bone easier. This also means that the risk of diastasis developing in the joint, when the nail is inserted, will be reduced. By inserting the transversal N-nail first, the risk is completely eliminated.

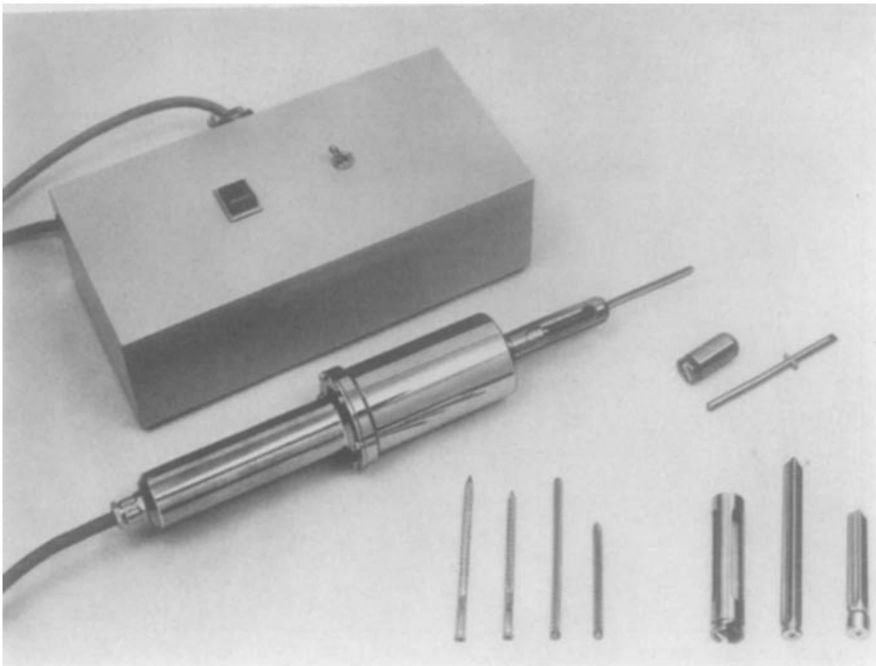
Electro-Mechanic Hammer

During the course of the experiments, it was found that a special tool for insertion of the nails would be of advantage. The reason for this was to get a better control of the force of impact and an even distribution of the required energy. It was hoped that by this the traumatic effect of the nail would be further reduced. In co-operation with the Division of Computer Research, Chalmer's Institute of Technology, University of Göteborg, an electro-mechanic hammer was thus designed and manufactured.

The principle of the design is depicted in Fig. 31. It consists of an electric coil inside which a core of soft iron slides. One end of the core is spring-loaded. When the coil receives an electric impulse, the soft iron core moves into the coil. This results in force of impact. The energy is transmitted to a hammering pin which is designed to grip the head of the nail. The nail is fitted to the pin by means of a sleeve which can be exchanged to fit all the nail dimensions. The sleeve is fitted to the front side of the hammer by means of a bayonet clutch.

A pulse generator, powered from 220 V mains, supplies the coil in the hammer with pulses of suitable frequency and energy. The pulse energy and thus also the force of impact is via a semiconductor-controlled rectifier operated with a pedal. The control unit is equipped with an illuminated main switch and a switch for the pulse frequency selector. The selector can be adjusted to produce 12.5 or 6.25 strokes per second. The hammer also has a switch to alter the force of impact; one position for nailing and one on a lower level for chiselling.

Within each position the force is controlled by means of the pedal. The controlling devices with which the tool is equipped ensures a lenient and rapid insertion of the nail. The tool can also be used for an effective and precise chiselling.



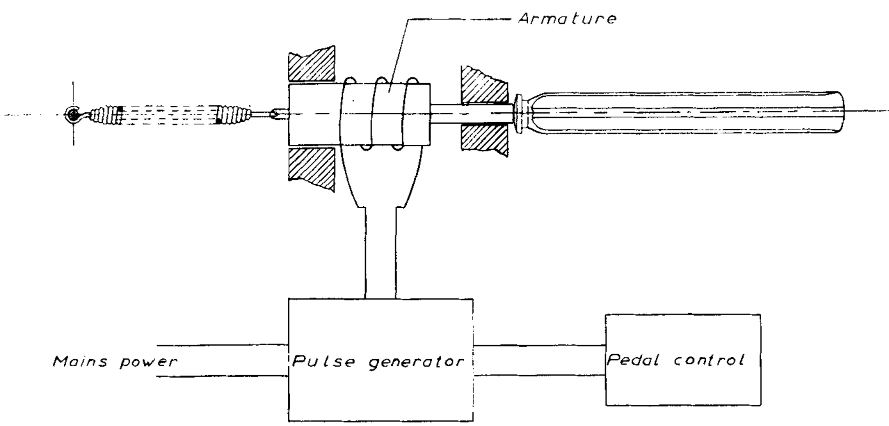
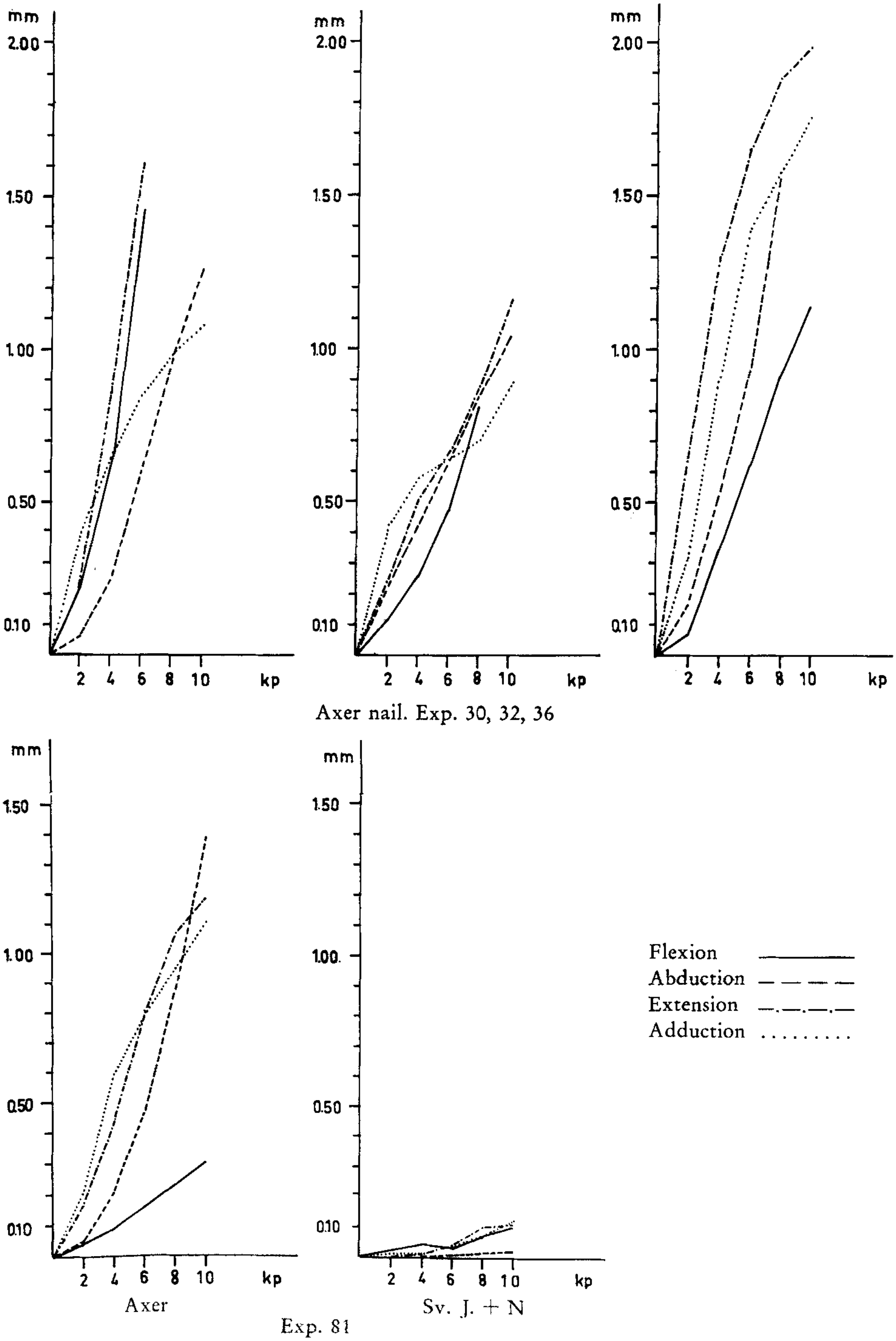
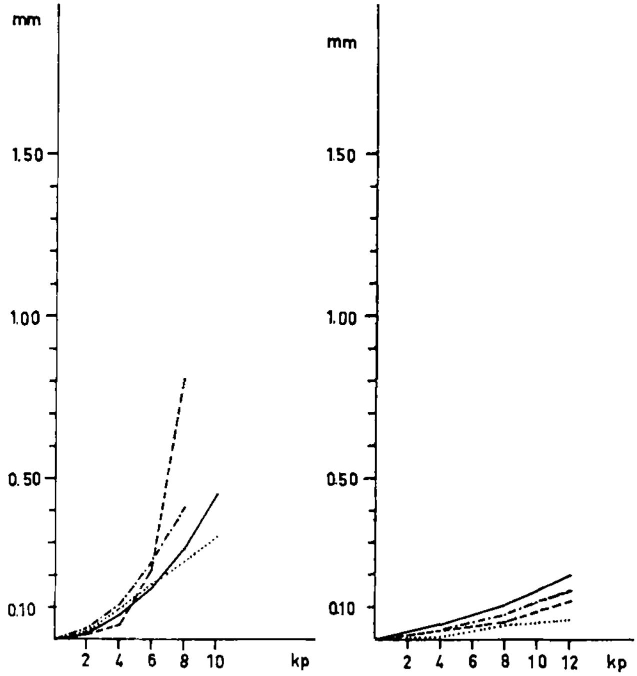


Fig. 31. Photograph and principle sketch of electro-mechanic hammer. On the photograph are seen the pulse generator, the hammer, different sleeves, nails and chisel.

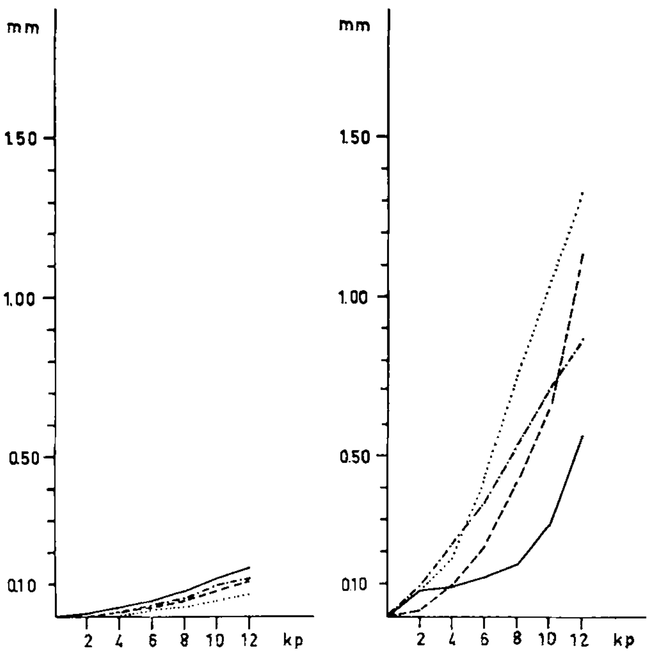
Fig. 32. Examples of Loading Diagrams. (S_{max} in mm as a function of loading).





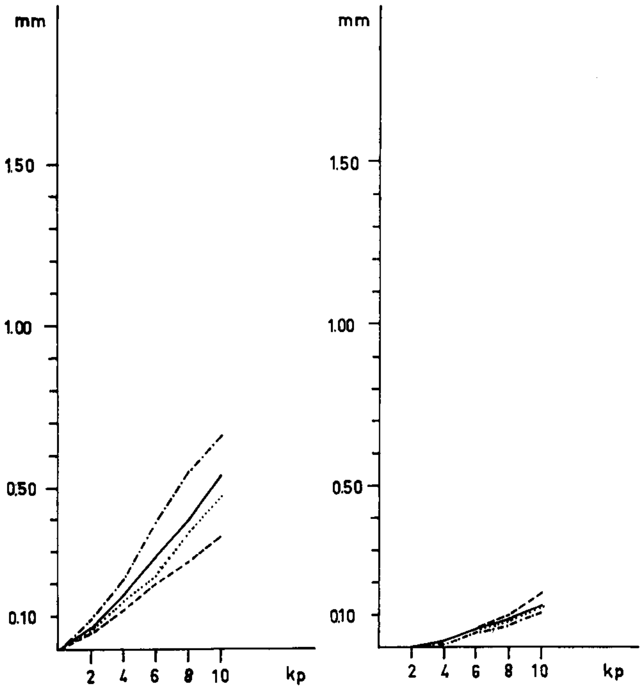
Fox 3pfix N (mod.)

Exp. 76



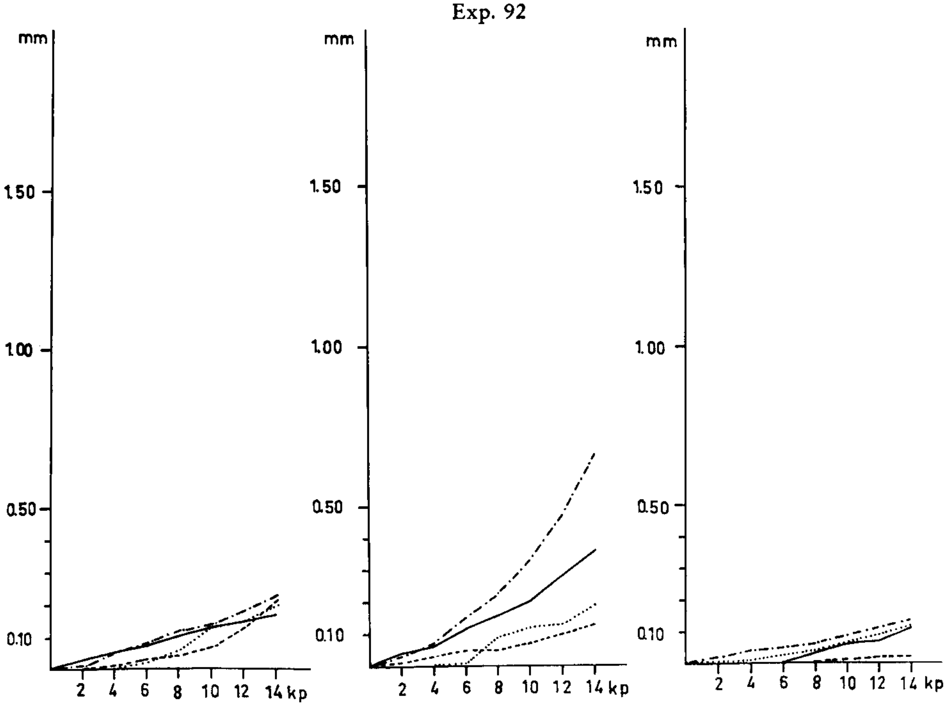
3pfix N Mc Kee

Exp. 87



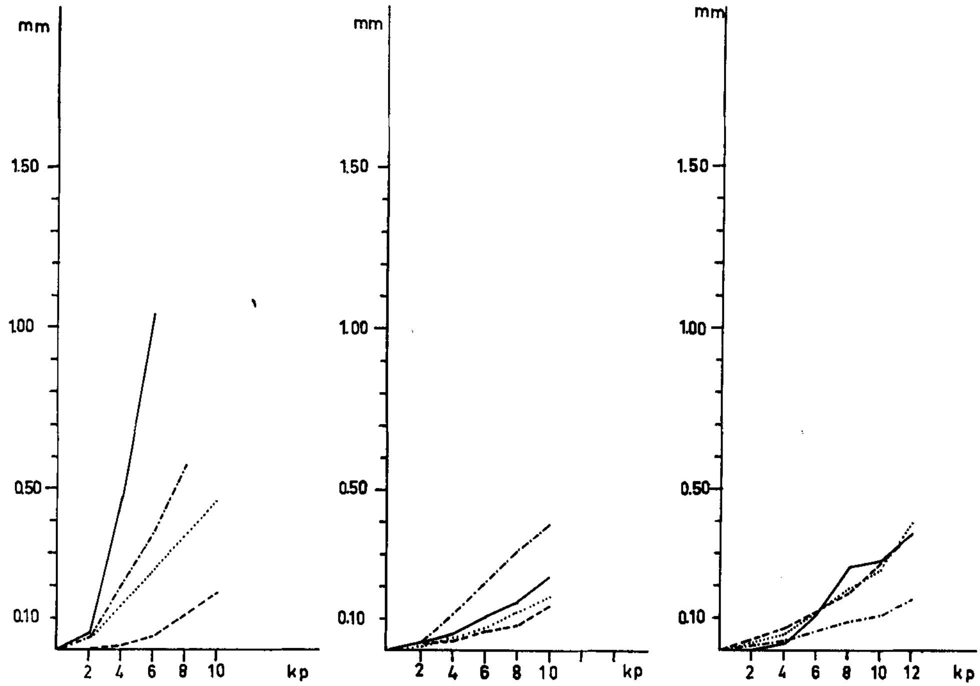
3pfix screws 3pfix N

Exp. 92



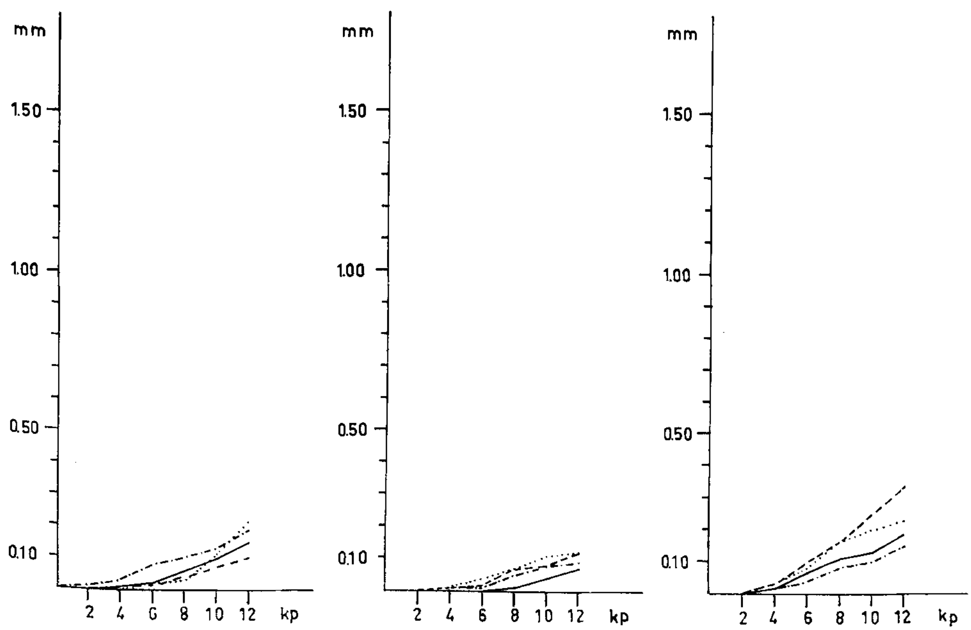
3pfix N Sv. J. Sv. J. + plate

Exp. 60



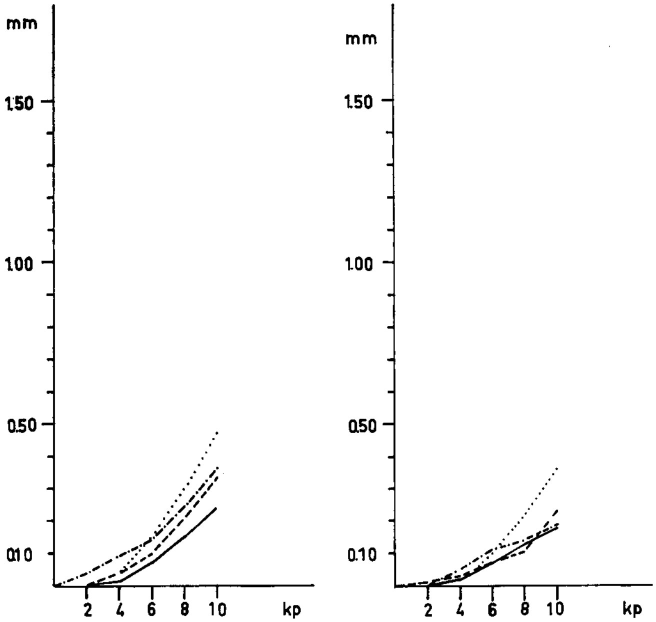
Sv. J. | Sv. J. + N | Sv. J. + plate

Exp. 63



3pfix N | E + N | E

Exp. 102



3pfix N E + N

Exp. 103

General Summary

There are many methods described in the literature dealing with the operative technique of arthrodesis of the hip. Certain problems have been of special interest. The position of the arthrodesis, the contact between the surfaces of the joint, bone grafting, additional subtrochanteric osteotomy and stabilization of the joint during the time of healing. In the latter case, the techniques recommended vary extremely. However, the common opinion seems to be that some kind of osteosynthesis is necessary to obtain a successful result. The attitude towards a plaster hip spica varies depending on how reliable the internal fixation is considered to be. The evaluation of the stability of an osteosynthetic method, is mainly based upon clinical observations.

The opinions are thus not unanimous with respect to the elaboration of osteosynthesis in arthrodesis of the hip. The aim with this study was to establish the extent of stabilization achieved by using various techniques of osteosynthesis and, therefore, experiments were carried out on autopsy specimens.

The simple nail reinforcement, by the use of the three-flanged nail, was given special attention. A theoretical analysis shows that in ideal conditions a minimum nail depth of 3 cm in the pelvis is necessary for satisfactory stabilization. Furthermore, it is essential that the nail be maximally secured to a cortical bone.

The theoretical analysis served as a basis for an experimental study on the three-flanged nail. Thus, the nail was inserted into the acetabulum at varying depths and in different directions. The nail was then subjected to bending moment and torque. The resulting deflection was recorded.

In comparing the values obtained in the theoretical analysis with those in the experimental investigation, the latter values were higher. In cases where the nail was inserted through an internal cortical layer, the analytical and experimental values deviated more than when the nail was placed between the cortical layers. The reasons are too small a nailing depth, and fractures of the internal pelvic cortex. These fractures cause a poorer connection of the bone around the nail. The experiments revealed that a satisfactory result was obtained if the nail was inserted into the body of the iliac bone at a depth of approximately 4 cm. Further depth of the nail only gave an insignificant increase in stabilization. The nail then lay fixed between the cortical surfaces and could be regarded as secured to a bone with cortical resistance properties. In this position, the securing in the pelvis was not inferior to that on the femoral side.

Finally, these experiments also reveal that the three-flanged nail of the conventional type has a great tendency to causing fractures in the areas of bone through which it passes. The greatest risk is the passage through the femoral head, as almost without exception fractures occur. These appear as a fissure in the caput along the flange of the nail which is close to the surface or as a triangular fragment which is released. These lesions are generally not visible on the radiographs due to the opacity of the nail and the conventional projection.

A special measuring technique was elaborated in order to test the immediate stabilization obtained in autopsy specimens with various techniques of osteosynthesis in arthrodesis of the hip. The calculations demand that the movement between the joint surfaces at the acetabular edge should be measured at three points, each in two directions. Special extensometers were designed for this measuring. The arising movement was transmitted by these extensometers to electric impulses which via an amplifier were recorded.

The values obtained were concentrated to one value which represented the maximum movement. The measurings were performed during gradually increased loading of the femur in four directions of mobility; flexion, abduction, extension and adduction. By combining the values obtained for the maximum movement with the respective loads, diagrams were plotted which represent the movement in the arthrodesis as a function of the loading.

In several experimental series the various osteosynthetic methods were tried. For statistical reasons, it was considered justified to perform comparative experiments on the same specimen. As a reference method, osteosynthesis with three Nyström nails (N-nails) was selected. The reason for this was that the N-nail did not damage the bone in such a way that the results of the subsequent osteosyntheses would be affected negatively. The positions of the N-nails were selected on the basis of an earlier investigation. Thus, one nail was inserted from a point below the greater trochanter upwards-backwards into the body of the iliac bone. The other was directed from the upper part of the greater trochanter in a horizontal direction into the acetabular portion of the pubic bone. Finally, the third was introduced from the front of the proximal part of the femur through the collum-caput into the bone area at the spina of the ischium. By applying the nails in these positions, the skeleton can be utilized to a maximum. This means that the nails are placed at a maximum distance from each other, at optimal angles to each other and can be inserted to the greatest depth.

When testing the three-flanged nail a marked impairment of the stability could be found at nail depths below 3 cm. Therefore, in the experiments where the three-flanged nail was compared to the reference method only a greater nailing depth was accepted (mean value 4.4 cm). Even then the reference method was superior.

In order to improve the stabilization with a three-flanged nail, this nail was combined either with an N-nail, or with a plate. Two positions of the N-nail were then compared. An N-nail directed in a lateral-medial direction into the acetabular portion of the pubic bone was superior to one inserted in an anterior-posterior direction into the bone area at the spina of the ischium. At the continued experiments, only the first-mentioned position was therefore utilized. In comparison with the reference method there was no significant difference. The three-flanged nail in combination with a sturdy metal plate which was attached to the iliac bone and the proximal end of the femur also gave results equal to the reference method.

In an experimental series, various types of compression nails were tried. These were directed trans-articularly into the pelvis and secured with a washer. None of the tested methods resulted in the desired stability. They were inferior to the reference method, and even inferior to a three-flanged nail inserted at the recommended depth. The reason of this probably was that the bone layer on the pelvic side, penetrated by the compression nails, did not have the necessary resistance. The bone layer is too thin, generally only about 15 mm, and the cortex on the inside of the pelvis is weak.

A comparison was also made between three-point nail fixation and three-point screw fixation, the result of which was in the negative for the screw. The screw is fit to resist axial tensile stress, but of a corresponding nail dimension has a lower bending resistance and impaired ability to resist torque.

Thus, the results were equal between the reference method, the three-flanged nail and plate, and the three-flanged nail and N-nail. As the latter is easiest to apply, there was reason to attempt improving on it. The disadvantage of the method is connected with the traumatic effect of the nail. The nail, due to its design, causes great resistance at the insertion. This results in diastasis of the joint when the nail penetrates the acetabulum. The bone layers which are passed may be fractured causing an impaired securing of the nail. In an attempt to improve these deficiencies, an experimental nail was designed. By a special design of the tip of the nail and of the flanges, the nail was easier to introduce and at the same time the risk of fissures occuring in the bone was diminished. Due to the design of the tip, the bone particles released at the insertion will be pressed in between the flanges and, as a consequence, the securing will improve. The nail has also a greater moment of inertia than that of the conventional three-flanged nail in spite of its thinner dimension.

In a series of experiments the experimental nail was tried together with a transversal N-nail. The results were significantly improved in the loading directions which mainly cause torque; however, there was no significant difference in the loading directions which mainly cause bending stress as compared to the reference method. The result may be connected with the improved securing of the nail to the bone, which is obtained by eliminating the fractures emerging from the flanges. This improved securing can be expected to bring about a better stabilization with respect to the torque.

An electro-mechanic hammer was designed to futher reduce the risks of fractures when the nail was inserted. The hammer allows an adjustment of both the frequency of the strokes and the force of impact. Consequently, the insertion of the nail can be fully controlled.

Conclusions

An experimental investigation was carried out on autopsy specimens for the assessment of the primary stability in arthrodesis of the hip. The following conclusions can be made:

Osteosynthesis with a trans-articular compression nail or a screw will give poor stabilization.

Osteosynthesis with a three-flanged nail will give a better stabilization, provided that the nailing depth is at least 4 cm into the body of the iliac bone.

Osteosynthesis with three Nyström nails in described positions (three-point fixation), three-flanged nail with a plate, and three-flanged nail with one Nyström nail in a described position will give good stabilization.

Osteosynthesis using three-point fixation with screws will result in an inferior stabilization, as compared to three-point fixation with nails of the corresponding dimensions.

A very good stabilization was obtained with a new-designed experimental nail in combination with one Nyström nail in a described position. These devices offer less difficulties at the application as compared to many others.

References

ABBOTT, L. C. & FISCHER, F. J.: Arthrodesis of hip with special reference to a method of securing ankylosis in massive destruction of the joint. Surg. Gynec. Obstet. 52: 863—871, 1931.

ABBOTT, L. C. & LUCAS, D. B.: Arthrodesis of the hip in wide abduction. J. Bone Jt Surg. 36 A: 1129—1140, 1954.

ABBOTT, L. C. & LUCAS, D. B.: Arthrodesis of the hip. A two-stage method for difficult cases. Surg. Clin. N. Amer. 36: 1035—1050, 1956.

ADAMS, A. O.: A method for the pre-operative determination of the best functional position for an ankylosed hip. Surg. Gynec. Obstet. 52: 261—265, 1931.

ADAMS, J. C.: Ischio-femoral arthrodesis. Livingstone, Edinburgh & London, 1966.

AHLBÄCK, S.-O. & LINDAHL, O.: Hip arthrodesis. The connection between function and position. Acta orthop. scand. 37: 77—87, 1966.

ALBEE, F. H.: Arthritis deformans of the hip; a preliminary report of a new operation. J. Amer. Med. Ass. I, 1977—1980, 1908.

ALBERT, E.: Beiträge zur operativen Chirurgie. 1—2. Urban & Schwarzenberg, Wien, 1878—80.
—Einige Fälle von künstlicher Ankylosenbildung an paralytischen Gliedmassen. Wien med. Presse 23: 725—728, 1882.

ALVIK, I.: Arthrodesis of the hip. A method allowing weightbearing and walking postoperatively. Acta orthop. scand. 32: 451—456, 1962.
—Arthrodesis and arthroplasty of the hip joint. Acta orthop. scand. 33: 253—261, 1963.

ANDERSON, L. D.: Compression plate fixation and the effect of different types of internal fixation on fracture healing. J. Bone Jt Surg. 47 A: 191—208, 1965.

APLEY, A. G. & DENHAM, R. A.: Osteotomy as aid to arthrodesis of the hip. J. Bone Jt Surg. 37 B: 185—190, 1955.

ARRIOLA, F. & ELOSEGUI, J.: Betrachtungen über die chirurgische Behandlung der Arthrosis des Hüftgelenkes. Z. Orthop. 81: 336, 1951.

AXER, A.: Compression arthrodesis of the hip joint. A preliminary report. J. Bone Jt Surg. 43 A: 492—504, 1961.

BACKMAN, S.: The proximal end of the femur. Thesis, Stockholm. Acta radiol. (Stockh.) Suppl. 146, 1957.

BAILEY, E. T. & BURROWS, H. J.: Nail fixation of osteoarthritic hip without exposure of joint. Lancet 236: 980—983, 1939.

BLAUTH, W. & MAU, H.: Erfahrungen mit der Abspreiz-Druckarthrodese des Hüftgelenkes. Z. Orthop. 92: 529—542, 1959/60.

BLOUNT, W. P.: Don't throw away the cane. J. Bone Jt Surg. 38 A: 695—708, 1956.

BOOS, O.: Verriegelungsarthrodese der Hüfte ohne Röntgenkontrolle. Z. Orthop. 97: 533—538, 1963.

BOYTCHEV, B.: L'arthrodèse tunellisante de la hanche. Acta Chir. orthop. Traum. čech. 27: 147—149, 1960.

BRANCIFORTI, S. & LANCIOTTI, G.: L'abbassamento-artrodesi nel trattamento della lussazione congenita inveterata dell'anca. Chir. Organi Mov. 45: 155—166, 1957/58.

BRITTAIN, H. A.: Ischiofemoral arthrodesis. Brit. J. Surg. 29: 93—104, 1941/42.
—Architecture principles in arthrodesis. Livingstone, Edinburgh & London, 1952.

BRODETTI, A.: The blood supply of the femoral neck and head in relation to the damaging effects of nails and screws. J. Bone Jt Surg. 42 B: 794—801, 1960.

BROWNLEE, K. A.: Statistical theory and methodology in science and engineering. 2 ed. Wiley, New York, 1965.

BURNS, B. H.: Fixation of the osteo-arthritic hip by nailing. Lancet 236: 978—980, 1939.

CALVÉ, J.: Sur un nouveau procédé d'arthrodèse-résection de la hanche et d'ostéotomie dans les coxalgies anciennes et arthrites déformantes. Scalpel 85:373 – 375, 1932.

CAMPBELL, W. C.: Internal fixation in fractures of the neck of the femur. Ann. Surg. 105: 939—951, 1937.

CASTAING, J., DOUVION, J. C. & AUTRET, J.: Technique de l'arthrodèse de la hanche avec ostéotomie intertrochantérienne non fixée. Rev. Chir. orthop. 48: 757—763, 1962.

CASUCCIO, C.: L'arthrodesi nella anca dell'artrosi deformante dell'anca. Boll. Sci. med. 118: 252, 1946.

CATTANEO, R.: L'artrodesi dell'anca (con particolare riguardo alla fissazione con innesto osseo). Arch. Ortop. (Milano) 72: 801—817, 1959.

—[Experimental study on the mechanical resistance of various types of bone implants in arthrodesis of the hip.] Arch. Ortop. (Milano) 72: 1114—1123, 1959.

CAUCHOIX, J., MASCHAS, A. & CARLIOZ, H.: L'arthrodèse de la hanche dans le traitement de la coxarthrose. Ann. Chir. 19: 334—344, 1965.

CHAPCHAL, G.: Die Arthrodese des Hüftgelenkes bei der Behandlung der schweren einseitigen Arthrosis deformans. Arch. orthop. Unfall-Chir. 41: 244—245, 1941.

—Die Arthrodese bei der Hüftarthrose. Langenbecks Arch. klin. Chir. 301: 417—420, 1962.

—Orthopädische Chirurgie und Traumatologie der Hüfte. Enke, Stuttgart, 1965.

CHARNLEY, J.: Compression arthrodesis. Livingstone, London & Edinburgh, 1953.

—Stabilisation of the hip by central dislocation. J. Bone Jt Surg. 37B: 514—515, 1955.

CHOLMELEY, J. A.: Femoral osteotomy in extra-articular arthrodesis of the tuberculous hip. J. Bone Jt Surg. 38B: 342—352, 1956.

CIUCCARELLI, C. & MARCHI, F.: L'artrodesi transarticolare con due viti associata ad osteotomia nel trattamento della coxartrosi. Chir. Organi Mov. 51: 273—281, 1962.

COMPERE, E. L. & LEE, J.: The restoration of physiological and anatomical function in old ununited intracapsular fractures of the neck of the femur. J. Bone Jt Surg. 22: 261—277, 1940.

COMPERE, E. L., WALLACE, G. & LEE, J.: Materials for internal fixation of intracapsular fracture of the neck of the femur. Arch. Surg. 44: 327—338, 1942.

COZZOLINO, A.: [Arthrodesis of the hip according to the Delitala method combined with transarticular screws in osteoarthrosis.] Arch. Ortop. (Milano) 73: 442—451, 1960.

CRELLIN, R. Q. & SIMURDA, M. A.: Intertrochanteric osteotomy of the femur for osteo-arthritis of the hip. Brit. J. Surg. 52: 437—439, 1965.

DARAIGNEZ, B. J. E.: De l'arthrodèse. Thesis, Bordeaux, 1891.

DAUBENSPECK, K.: Arthrodesis of the hip joint by means of pressure screw plates. Int. Surg. 45: 678—681, 1966.

DAVIS, J. B.: The muscle-pedicle bone graft in hip fusion. J. Bone Jt Surg. 36A: 790—799, 1954.

DE BEULE, F.: La résection de la hanche suivie de fixation de l'extrémité-supérieure du fémur à la tubérosité ischiatique. J. Chir. (Brux.) 9: 173—176, 1909.

DEBEYRE, J.: In: The surgical treatment of osteoarthritis of the hip (arthroplasty excluded). J. Bone Jt Surg. 40B: 156, 1958.

DECOULX, P., DECOULX, J. & DELBREIL, P.: Une technique d'arthrodèse de la hanche. Indications et résultats. Acta orthop. belg. 31: 770—779, 1965.

DELITALA, F.: Deambulazione ed anchilosi dell'anca; contributo alla fisiopatologia articolare. Chir. Organi Mov. 26: 5—13, 1940.

DEPALMA, A. F., SNEDDEN, H. E. & MCDOWELL, C. L.: Arthrodesis of the hip with intramedullary fixation. Clin. Orthop. 25: 124—140, 1962.

DEYERLE, W. M.: Multiple-pin peripheral fixation in fractures of the neck of the femur: immediate weight-bearing. Clin. Orthop. 39: 135—156, 1965.

DICKSON, J. A. & WILLIEN, L. J.: Arthrodesis of the hip joint in degenerative arthritis. J. Bone Jt Surg. 29: 687—696, 1947.

DICKSON, J. A., WOODRUFF, J. B. & RUDOLPH, J. F.: Coxometer. J. Bone Jt Surg. 33A: 513—516, 1951.

DICKSON, J. A. & HARTMAN, J. T.: Arthrodesis of the hip by the Dickson technique. Results after sixteen years. J. Bone Jt Surg. 47 A: 1070—1072, 1965.

DOLLINGER, J.: Arthrodesen bei der Kinderlähmung. Zbl. Chir. 18: 689—695, 1891.

DWYER, A. F. & CASS, C. A.: Internal fixation in hip arthrodesis. Med. J. Aust. 48: II: 977—979, 1961.

DWYER, A. F.: Experience of a new method of hip arthrodesis. Austr. N. Z. J. Surg. 34: 105—115, 1964.

EHALT, W.: Die Vorteile der operativen Versteifung der Hüfte mit den Dreilammellennagel. Wien. klin. Wschr. 66: 658—659, 1954.

EVANS, F. G.: Stress and strain in bones; their relation to fractures and osteogenesis. Thomas, Springfield, Ill., 1957.

FARKAS, A.: A new operative treatment of tuberculous coxitis in children. J. Bone Jt Surg. 21: 323—333, 1939.

FOX, T. A.: Operative technique for insertion of internal fixation device for arthrodesis of the hip. Zimmer Co, Warsaw, Ind., n.d.

FRANKEL, V. H.: The femoral neck. An experimental study of function, fracture mechanism, and internal fixation. Thesis, Uppsala, 1960.

FRIBERG, S.: On arthrodesis and arthroplasty. Acta med. scand. Suppl. 341: 169—172, 1958.

GALANTE, J. O.: Tensile properties of the human lumbar annulus fibrosus. Thesis, Copenhagen. Acta orthop. scand. Suppl. 100, 1967.

GALLAND, M.: Traitement de la coxalgie et de ses séquelles. In: Congrès de l'Association internationale de thalassothérapie, 6 (Berck, 1931). Rev. Orthop. 18: 614—617, 1931.

GARDINER, T. B.: Nail and graft arthrodesis of the hip. J. Bone Jt Surg. 44 B: 588—594, 1962.

GENOVESI, A.: L'artrodesi trans-articolare dell'anca con vite metallica. Arch. Putti 19: 341—356, 1964.

GERTSCH, R.: Die Arthrodese des Hüftgelenks mit Kreuzplatte und Beckenosteotomie. Helv. chir. Acta 33: 216—221, 1966.

GHORMLEY, R. K.: Use of the anterior superior spine and crest of ilium in surgery of the hip joint. J. Bone Jt Surg. 13: 784—798, 1931.

GIRARD, P. M.: Hip-joint fusion and the shelf operation. J. Bone Jt Surg. 17: 443—449, 1935.

GIRDLESTONE, G. R.: Tuberculosis of bone and joint. Oxford University Press, London, 1940.

GRAHAM, C. E.: Hip arthrodesis — a variant on the Trumble method. Med. J. Aust. 50: II: 955—956, 1963.

GRAZIATI, G. & KALÉN, R.: Stability of osteosynthesis in hip arthrodesis. Acta orthop. scand. 35: 225—233, 1965.

GREENBERG, B. B.: A new method of pelvi-femoral arthrodesis by means of multiple bone grafts. Preliminary report. Bull. Hosp. Jt Dis. (N.Y.) 13: 183—195, 1952.

GUILLEMINET, M., FAYSSE, R. & DESBROSSES, J.: Arthrodèse de la hanche par le procédé de Davis. Lyon chir. 51: 119—122, 1956.

GUTIÉRREZ, A.: Arthrodesis extraarticular isquiotrocantérea. Rev. Cirug. (B. Aires) 14: 193—200, 1935.

HAGGART, G. E.: Degenerative arthritis of the hip joint. Treated by one or two stage arthrodesis with metal fixation (Watson-Jones). J. Amer. med. Ass. 128: 502—506, 1945.

HARMON, P. H., BAKER, D. R. & RENO, J. H.: Experiments on the holding powers of various types of metallic internal fixation for transcervical fractures of the femur. Amer. J. Surg. 76: 515—524, 1948.

HARRIS, R. I.: Arthrodesis for tuberculosis of the hip. J. Bone Jt Surg. 17: 318—323, 1935.

—Arthrodesis of the hip joint. A new and simple operation. Surg. Clin. N. Amer. 23: 1412 1428, 1943.

HASS, J.: Extraartikuläre Ankylosierung der Hüfte. (Verriegelung des Hüftgelenkes). Zbl. Chir. 49: 1466—1467, 1922.

HAW, D. W. M.: A review of fifty-one cases of arthrodesis of the hip. Guy's Hosp. Rep. 113: 6—16, 1964.

HENDERSON, M. S.: Combined intra-articular and extra-articular arthrodesis for tuberculosis of the hip joint. J. Bone Jt Surg. 15: 51—57, 1933.

HENSSGE, J.: Geschlossene Hüftgelenkarthrodese mit Knochendübel und verbundener Doppelschraube. Arch. orthop. Unfall-Chir. 61:26—29, 1967.

HERBERT, J. J.: Etude critique sur les arthrodèses de la hanche. Rev. Chir. orthop. 46:3—14, 1960.

HETÉNYI, M. J.: Beams on elastic foundation. Univ. of Mich. Press, Ann Arbor, Mich., 1958.

HEUSNER: Über Hüftresektion wegen angeborener Luxation. Zbl. Chir. 11:751, 1884.

HIBBS, R. A.: A preliminary report of twenty cases of hip joint tuberculosis treated by an operation devised to eliminate motion by fusing the joint. J. Bone Jt Surg. 8:522—533, 1926.

HIRSCH, C.: Studies on the mechanism of low back pain. Acta orthop. scand. 20:261—274, 1950/51.

HIRSCH, C. & DA SILVA, O.: The dffect of orientation on some mechanical properties of femoral cortical specimens. Acta orthop. scand. 38:45 – 56, 1967.

HIRSCH, C. & GOLDIE, I.: Osteotomia en la artrosis deformante de la cadera. Rev. Ortop. Traum. lat.-amer. 12:175—180, 1967.

—Osteotomy in osteo-arthritis of the hip joint. Acta orthop. scand. 1968. In press.

HOWARD, R. C.: V-arthrodesis of the hip. J. Bone Jt Surg. 32B:282, 1950.

HÖBLER, W.: Die Hüftarthrodese und ihre Problematik. Arch. orthop. Unfall-Chir. 56:370—377, 1964.

JONES, J. B., DRISCOLL, A. J., Jr. & HALLOCK, H.: Ischiofemoral arthrodesis of the hip. J. Bone Jt Surg. 38A:1117—1125, 1956.

KALÉN, R.: Undersökning av stabiliteten hos osteosynteser vid höftledsartrodes. Nord. Med. 74: 1119—1120, 1965.

KARLÉN, A.: A clinical study on arthrodesis for arthritis deformans of the hip joint. Thesis, Stockholm. Acta chir. scand. Suppl. 96, 1944.

KEMPF, I., TSOUKAS, S., COPIN, G. & BUCK, P.: Arthrodèses de hanche par clou trans-articulaire. Etude de 43 cas. Strasbourg méd. N. S. 15:464—470, 1964.

KEY, J. A.: The treatment of the tuberculosis of the hip. J. Miss. med. Ass. 23:388—396, 1926.

KING, T.: In: Advantages of adduction deformity and internal fixation in ischio-femoral arthrodesis for tuberculosis of the hip joint in the adult. J. Bone Jt Surg. 34B:506, 1952.

KIRKALDY-WILLIS, W. H. & MBUTHIA, A. S.: Abduction arthrodesis of the hip. J. Bone Jt Surg. 34B:433—439, 1952.

KIRKALDY-WILLIS, W. H., CHAUDHRI, M. R. & ANDERSON, R. J. D.: Arthrodesis of the hip with staple fixation. J. Bone Jt Surg. 40A:114—120, 1958.

KIRSCH, R.: Die Spaneinpflanzung bei chronischen Arthritiden (ausser Tuberkulose). Ergebn. Chir. Orthop. 32:227—260, 1939.

KONFORTI, B.: [Bio-mechanical considerations on arthrodesis of the hip joint.] Khirurgiya (Sofiya) 15:213—215, 1962.

KÜNTSCHER, G.: Die Technik der „geschlossenen" Hüftarthrodese. Chirurg. 24:404—410, 1953.

—In: Aussprache zu Lechten: Erfahrungen mit der intraartikulären Hüftarthrodese nach Küntscher. Verh. dtsch. orthop. Ges. 44:111—112, 1956.

LAGRANGE: Résection orthopédique de la hanche pour luxation pathologique. Bull. Soc. Chirurgie, Paris 132, 1892. Ref.: Karlén, A.: Acta chir. scand. Suppl. 96, 1944.

LAING, P. G. & O'DONNELL, J. M.: The engineering design of hip nails and the development of the H-beam nail. Surg. Gynec. Obstet. 112:567—576, 1961.

LAMPUGNANI, C.: La decapitazione del femore nella lussazione congenita dell'anca; studio pratico di ortopedia chirurgica antisettica. G. Accad. Med. Torino 33:538—551, 1885.

LANCIOTTI, G.: Osservazioni clinico-statistiche sulle artrodesi dell'anca. Chir. Organi Mov. 45: 482—501, 1957/58.

LANGE, M.: Orthopädisch-chirurgische Operationslehre. Springer, München, 1951.

—Arthrodesis of the hip. Review of a series of more than five hundred cases. J. int. Coll. Surg. 29:638—643, 1958.

LANGENSKIÖLD, A. & LAURENT, L. E.: Compression arthrodesis of the hip joint by the method of Axer. A preliminary report. Acta orthop. scand. 38:359—367, 1967.

LAPRAS, A.: L'arthrodèse iliofémorale avec entretoise ischiofémorale. Ann. Chir. 19:1411—1415, 1965.

LECHTEN: Erfahrungen mit der intraartikulären Hüftarthrodese nach Küntscher. Verh. dtsch. orthop. Ges. 44:96—98, 1956.

LENOBLE, J. C.: Les arthrodèses de hanche. Gaz. méd. Fr. 72:1643—1656, 1965.

LINDAHL, O.: Determination of hip adduction, especially in arthrodesis. Acta orthop. scand. 36:280—293, 1965.

—Hip-joint arthrodesis: to find the best position. Acta orthop. scand. 37:317—327, 1966.

LINDSTRÖM, N.: Partial intra-plus juxtaarticular arthrodesis with simultaneous nailing according to Watson-Jones. Acta orthop. scand. 26:255—269, 1956/57.

LINTON, P.: On the different types of intracapsular fractures of the femoral neck. Acta chir. scand. Suppl. 86, 1944.

LIPSCOMB, P. R. & MCCASLIN, F. E., Jr.: Arthrodesis of the hip. Review of 371 cases. J. Bone Jt Surg. 43A:923—938, 1961.

MCKEE, G. K.: Arthrodesis of the hip with a lag-screw. J. Bone Jt Surg. 39B:477—486, 1957.

MARAGLIANO, D.: Esiti definitivi della remineralizzazione chirurgica nelle coxiti tubercolari. Arch. Ortop. (Milano) 35:31, 1919.

—Nuovi punti di appoggio chirurgico nelle lussazione vere da coxite. Chir. Organi Mov. 5:225, 1921.

MATHIEU, P.: L'arthrodèse de la hanche. Technique et resultats d'un procédé extra-articulaire. Bull. Soc. nat. Chir. 53:1241—1246, 1927.

MAY, V. R., Jr. & MAUCK, W.: Intra-articular hip fusion with the intramedullary nail. Clin. Orthop. 25:113—123, 1962.

MAYER, L.: Critique of Brittain operation for fusion of hip. Bull. Hosp. Jt Dis. (N. Y.)9:4—8, 1948.

MAYR, H.: Probleme und Erfahrungen an 200 Arthrodesen bei chronischen unspezifischen Hüfterkrankungen. Z. Orthop. 84:189—206, 1953/54.

MERLE D'AUBIGNÉ, R. & CHABROL, J.: Les arthrodèses de la hanche par enclouage. Résultats. Indications. Techniques. Rev. Chir. (Paris) 71:293—326, 1952.

MERLE D'AUBIGNÉ, R., RAMADIER, J. O. & POSTEL, M.: Hip: Arthrodesis. In: Surgery of arthritis, Ed. R. A. Milch. Williams & Wilkins, Baltimore, 1964:214—240.

MERLE D'AUBIGNÉ, R. & DEBURGE, A.: Technique actuelle d'arthrodèse de hanche. Presse méd. 73:2749—2751, 1965.

MORRIS, J. B.: Charnley compression arthrodesis of the hip. J. Bone Jt Surg. 48B:260—279, 1966.

MORTENS, J. & JENSEN, E.: Charnley stabilisation of the hip. J. Bone Jt Surg. 42B:466—475, 1960.

MÜLLER, M.: Ostéosynthèse externe de compression pour arthrodèses et ostéotomies. In: Réunion des orthopédistes suisses, S:t Gall, 1953. Rev. Chir. orthop. 39:531, 1953.

—Hip Surgery. AO-Bulletin 1967: Sept.

NIEBAUER, J. J. & KING, D.: Arthrodesis of the hip produced by internal fixation. J. Bone Jt Surg. 28:103—112, 1946.

NIXON, J. E., MERLINO, A. F. & DEAKINS, J. S.: Arthrodesis of the hip. Experience with adjunctive high femoral osteotomy. Penn. med. J. 65:795—799, 1962.

NOVÉ-JOSSERAND, G.: Les nouvelles applications de l'arthrodèse de la hanche. Paris méd. 12: 63—68, 1922.

NYSTRÖM, G.: Osteosynthesis of medival fractures of the femoral neck with the aid of three nails ("multiple nailing"). Acta chir. scand. 91:449—471, 1944.

ONJI, Y., KURATA, Y. & KIDO, H.: A new method of hip fusion using an intramedullary nail. A preliminary report. J. Bone Jt Surg. 47B:690—693, 1965.

OSTAPCHUK, A. D.: [Compression arthrodesis of the hip joint.] Ortop. Travm. Protez. 25:1:59 —61, 1964.

PIATKOWSKY, S.: [Theoretical and practical value of hip arthrodesis by means of 2 Smith-Petersen nails.] Chir. Narzad. Ruchu 24:589—592, 1959.

PIGGOT, J.: Charnley stabilisation of the hip. J. Bone Jt Surg. 42B:476—479, 1960.

PUTTI, V.: Indirizzo e metodica nella cura delle fratture del collo del femore. Chir. Organi Mov. 23:399—429, 1938.

RADULESCU, A. D.: Nouveau procéde de verrouillage de la hanche arthrosique douloureuse. Rev. Chir. orthop. 49:623—624, 1963.

RAUBER, A.: Elasticität und Festigkeit der Knochen. Anatomisch-physiologische Studie. Engelmann, Leipzig, 1876.

RAUBER, [A.] & KOPSCH, [F.]: Lehrbuch und Atlas der Anatomie des Menschen. 18. Aufl. 1, Leipzig, 1952.

RESINA, J.: Modification de l'arthrodèse ischio-fémorale. Rev. Chir. orthop. 40: 514—520, 1954.

ROAF, R.: Arthrodesis of the hip. Brit. J. clin. Pract. 15: 739—746, 1961.

ROERSCH: In: Nové-Josserand, G.: Les nouvelles applications de l'arthrodèse de la hanche. Paris méd. 12: 63—68, 1922.

ROLANDER, S. D.: Motion of the lumbar spine with special reference to the stabilizing effect of posterior fusion. Thesis, Göteborg. Acta orthop. scand. Suppl. 90, 1966.

ROSBOROUGH, D. & STILES, P. J.: Non-union after intertrochanteric osteotomy with internal fixation for osteoarthritis of the hip. J. Bone Jt Surg. 49B: 462—474, 1967.

RÜTT, A.: Gefahren der Marknagelung und der Hüftarthrodese mit Kirschnerdrähten. Verh. dtsch. orthop. Ges. 46: 526—527, 1958.

RYDELL, N. W.: Forces acting on the femoral head-prosthesis. Thesis, Göteborg. Acta orthop. scand. Suppl. 88, 1966.

SCHINDLER, H.-S.: Beitrag zur Arthrodese des Hüftgelenkes. Z. Orthop. 90: 487—493, 1958.

SCHUMM, H. C.: Extra-articular immobilization of the hip joint. Surg. Gynec. Obstet. 48: 112—115, 1929.

SCHUMPELICK, W.: Die stabilere Osteosynthese des medialen Schenkelhalsbruches mit der verbundenen Doppelschraube. Chirurg 26: 131—135, 1955.

SCOTT, P. J.: Non-union of oblique displacement intertrochanteric osteotomy for osteoarthritis of the hip. J. Bone Jt Surg. 49B: 475—487, 1967.

SEDLIN, E. D.: A rheological model for cortical bone. Acta orthop. scand. Suppl. 83, 1965.

SEDLIN, E. D. & HIRSCH, C.: Factors affecting the determination of the physical properties of femoral cortical bone. Acta orthop. scand. 37: 29—48, 1966.

SHARP, I. K.: Acetabular dysplasia. The acetabular angle. J. Bone Jt Surg. 43B: 268—272, 1961.

SICARD, A. & GERHARD, Y.: [Technics and results of a procedure for arthrodesis of the hip combining grafting and nailing.] Ann. Chir. 14: 1149—1155, 1960.

SMITH, A. DEF. & BAAB, O. D.: A technique for arthrodesis of the hip joint. J. Bone Jt Surg. 31A: 727—733, 1949.

SORRELL, E.: Arthrodèse extra-articulaire pour coxalgie en évolution chez un adulte. Bull. Soc. nat. Chir. 56: 101—102, 1930.

SPEED, K.: Hip joint fusion. Surgery 1: 740—747, 1937.

STINCHFIELD, F. E. & CAVALLARO, W. U.: Arthrodesis of the hip joint. A follow-up study. J. Bone Jt Surg. 32A: 48—57, 1950.

STONE, M. M.: Arthrodesis of the hip. J. Bone Jt Surg. 38A: 1346—1352, 1956.

STRANGE, F. G. ST.CLAIR: The hip. Heinemann, London, 1965.

TEINTURIER, P.: Arthrodèse de la hanche. Lambeau pédiculé trochantérien avec vissage ischio-fémoral. Rev. Chir. orthop. 52: 645—649, 1966.

THOMPSON, F. R.: Combined hip fusion and subtrochanteric osteotomy allowing early ambulation. J. Bone Jt Surg. 38A: 13—22, 1956.
—Arthrodesis of the hip in osteoarthritis of the hip. Acad. Med. New Jersey Bull. 7: 327—343, 1961.
—The role of hip fusion in osteoarthritis. Clin. Orthop. 31: 24—30, 1963.

TRUMBLE, H. C.: A method of fixation of the hip joint by means of an extraarticular bone graft. Aust. N. Z. J. Surg. 1: 413—420, 1931/32.

TSOUKAS, S., ABOUSSOUAN, G. S. & GONZALO-VIVAR, F.: Considérations sur les arthrodèses de hanche. Rev. méd. Moy. Or. 21: 414—420, 1964.

UNANDER-SCHARIN, L.: A compression instrument for use in hip joint arthrodesis with nailing. Acta orthop. scand. 36: 314—316, 1965.

Van NES: L'arthrodèse de la hanche pour arthrite déformante. Rev. Orthop. 26: 771, 1939.

VENABLE, C. S. & STUCK, W. G.: Results of recent studies and experiments concerning metals used in the internal fixation of fractures. J. Bone Jt Surg. 30A: 247—250, 1948.

VERHEUGEN, P. & NAVARRE, M.: La place de l'arthrodèse dans la chirurgie des coxarthroses. J. belge Méd. phys. Rhum. 19: 25—32, 1964.

VESELY, D. G.: Ischiofemoral arthrodesis. An end-result study of forty-four cases. J. Bone Jt Surg. 43A: 363—378, 1961.

VIERNSTEIN, K.: Erfahrungen bei Hüftarthrodesen. Verh. dtsch. orthop. Ges. 44: 93—95, 1956.

VOGL, A.: Die „transkolläre" Arthrodese des Hüftgelenkes. Zbl. Chir. 75: 197—199, 1950.

WATSON-JONES, R.: Inadequate immobilization and non-union of fractures. Brit. med. J. I: 936—939, 1934.

—Arthrodesis of the osteoarthritic hip. J. Amer. med. Ass. 110: 278—280, 1938.

WATSON-JONES, R. & ROBINSON, W. C.: Arthrodesis of the osteoarthritic hip joint. J. Bone Jt Surg. 38B: 353—377, 1956.

WEINREICH, M.: Zur Statik der Hüftarthrodese. Verh. dtsch.orthop. Ges. 47: 509—515, 1959.

WEISS, J. W., MÜNZENBERG, K. J.: Ergebnisse der Hüftgelenksarthrodese nach Küntscher. Arch. orthop. Unfall-Chir. 54: 74—89, 1962.

WILKINSON, M. C.: Intertrochanteric osteotomy for the treatment of tuberculosis of the hip. Proc. roy. Soc. Med. 40: 238—241, 1946/47.

WILLIAMS, P.: Arthrodesis of the hip. Aust. N. Z. J. Surg. 32: 139—144, 1962.

WILSON, J. C.: Operative fixation of tuberculos hips in children. J. Bone Jt Surg. 15: 22—47, 1933.

WITT, A. N.: Zur Problematik der Hüftversteifung. Z. Orthop. 80: 559—564, 1950/51.

von WINIWARTER, A.: Lehrbuch der chirurgischen Operationen und der chirurgischen Verbände. Enke, Stuttgart 1895.

ZANOLI, R.: L'artrodesi "a ponte levatoio" nella cura della tuberculosi dell'anca. Arch. Med. Chir. 2: 3—25, 1933.