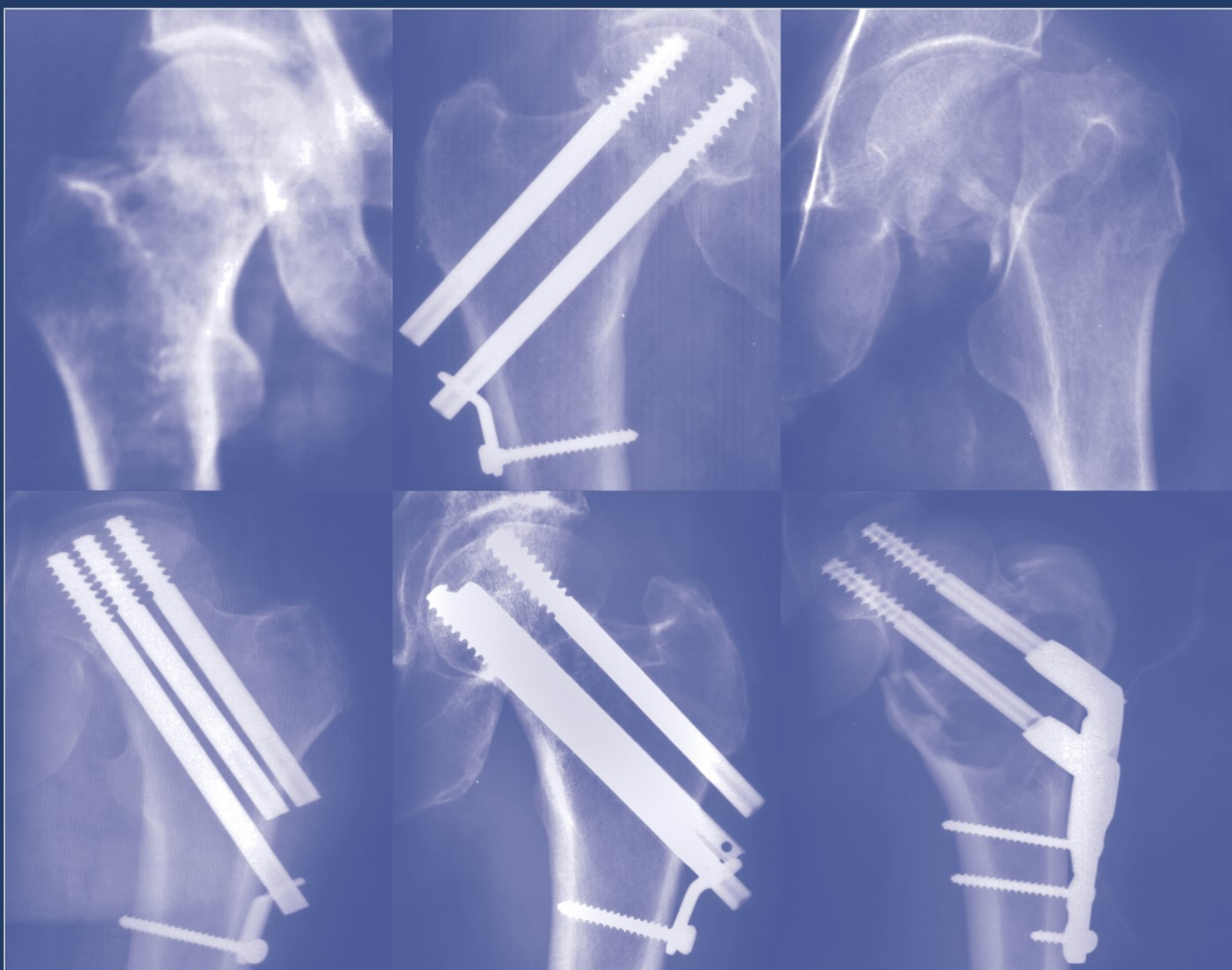
manninger, bosch, cserháti, fekete, kazár (eds.)

internal fixation of femoral neck fractures

an atlas



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Cover Pictures

Upper row (from left to right)

Garden-I fracture: slight displacement in valgus (Fig. 213a, reversed reproduction);
Recommended procedure for the stabilization of undisplaced (Garden-I and -II) and typical displaced (Garden-III and -IV) neck fractures: percutaneous fixation with two cannulated screws, the caudal fracture is attached to a 2 mm two-hole plate (Fig. 155i);
Displaced Garden-IV fracture with an avulsed fragments (Fig. 87a).

Lower row (from left to right)

Recommended procedures for the stabilization of atypical displaced (Garden-III and -IV) femoral neck fractures (comminuted fractures, base of neck, vertical, severely porotic, pathologic fractures) clinically applied techniques to increase stability.
Percutaneous fixation with three cannulated screws (Fig. 163c, reversed reproduction);
Percutaneous fixation with two cannulated screws. The plate inserted into the longitudinal slit of the caudal screw (flanged screw) increases the rotational stability (Fig. 138g);
Exposure of the lateral femoral cortex, anchorage of the screws with two angle-stable DCD (Dynamic-Collo-Diaphyseal) plates. This is currently our most stable variant (Fig. 228b).

Jenő Manninger
Ulrich Bosch
Péter Cserháti
Károly Fekete
György Kazár † (Eds.)

Internal fixation of femoral neck fractures

An atlas

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CONTENTS

PREFACE TO THE ENGLISH EDITION

Hip fractures constitute one of the most resource consuming diagnoses in health care. With an increasing amount of elderly in the population WHO has prognosticated an almost five fold increase from 1.7 million hip fractures in the year 1990 to 6.3 million in 2050. With age the osteoporosis becomes more abundant, and at the same times the tendency of the elderly to fall. Preventive measures against both osteoporosis and falls are necessary to stop the continuous increase of fragility fractures in the elderly. Hip fractures are the most resource consuming of all these fractures, all need surgery. With increasing number of hip fractures, and the frail constitution of the patients who often have other concomitant diseases, which impair mobilisation and rehabilitation, it is necessary to have surgical methods that are specifically suited for the fracture type. Too extensive surgery may impair the situation of the patient, whereas insufficient surgery endangers the early weight bearing and walking training.

The work of Professor Manninger and his team at the National Institute of Traumatology in Budapest has extensively broadened the knowledge in the healing of femoral neck fractures. The well selected use of osteosynthesis versus arthroplasty is the utmost optimised goal for the treatment of this challenging fracture. During more than half a century Professor Manninger and his team in Budapest have investigated the different factors of importance for successful healing of femoral neck fractures. Especially the blood circulation to the femoral head has been the focus for this extensive research. Based on a large number of venographies Manninger and his team could very clearly show that the disturbed blood circulation in the displaced femoral neck fractures was of major importance for the development of pseudarthrosis and femoral head necrosis. They could also show that the anatomic reduction of the fracture restored the venous drainage from the femoral head, and thereby decreased the risk of a healing complication. Through their research and large amount of patients at the National Institute of Traumatology Manninger et collaborators could investigate and show the importance of early surgery with osteosynthesis in femoral neck fractures. If patients were operated later than six hours after the fracture had occurred, the healing complications, pseudarthrosis and later femoral head necrosis, increased significantly.

The osteosynthesis technique developed by Manninger et his team has combined stability in the fracture system with the mini-invasive approach of semi-percutaneous osteosynthesis. After a systematic testing of different designs the development of a small stabilising side-plate for the lower screw was developed, and has proven successful in a large number of cases. The thorough scientific platform for this osteosynthesis technique serves also as a proof that osteosynthesis is a valid alternative to arthroplasty in cases where the circulation to the femoral head is not extensively damaged. This means that all undisplaced femoral neck fractures as well as all those femoral neck fractures with only minor displacement are well suitable for osteosynthesis. The importance of surgical skill in general and especially in the treatment of femoral neck fractures is also emphasized. It is important always to keep in mind when performing an osteosynthesis that optimal stability is achieved in the combination of the osteosynthesis material and the bone support available. Examples of optimally performed osteosyntheses are abundant in the present book and serves as good teaching instruction.

The present book on osteosynthesis in femoral neck fractures is very important as it combines the teaching of a successful osteosynthesis method with its scientific basis including consideration of all the biomechanical aspects to support the healing of this challenging fracture. Osteosynthesis for femoral neck fractures is a mini-invasive and less traumatic method imposing little burden to the patients. When the fracture has successfully healed, and when two years have passed after fracture, almost no complications from the hip can be expected whereas after surgery with total or hemi-arthroplasty loosening or cartilage wear will successively increase as the patient grows older.

Lund, January 2007

This thorough and well presented work is highly recommended to all surgeons dealing with hip fractures.

Karl-Göran Thorngren, MD, PhD
Professor, Originator and Head of the
Swedish National Hip Fracture Register

Hans Wingstrand, MD, PhD
Professor

PREFACE TO THE GERMAN EDITION

Femoral neck fractures are lesions most often observed in elderly people. They are of great importance to society and health care providers alike. In spite of a marked improvement of implants, surgical techniques and patient care, these fractures constitute a major burden to our national economies. The incidence of femoral neck fractures is expected to increase worldwide from 1.7 million in 1990 to 6.3 million by 2050. The number of hip fractures in Germany amounts each year to 90.000. Given the ever-increasing age of our population this number is expected to double by 2050.

The improvement over time in the treatment of femoral neck fractures parallels the development of trauma surgery. Consecutive milestones were the treatment by traction, the realization of the importance of early anatomic reduction and above all an effective maintenance of reduction. Contributing to these improvements were design of important fracture implants and development of various types of joint replacement.

In spite of these marked technical progresses the femoral neck fracture remains a problem giving rise to many controversies. The search for solutions extents from epidemiology, osteoporosis research and prevention to the improvement of existing implants and design of new ones. While focusing on solutions one should always keep in mind their impact on the limited resources of our health care systems.

Professor Manninger and his team of hip surgeons merit special praise for their treatment approach to this problematic fracture. Continuous and meticulous clinical and basic research extending over five decades, often performed under difficult political and economic conditions, forms the basis of this book.

The main goal of these research endeavors was not only the search for a stable internal fixation, particularly in older patients having a reduced bone strength, but also to device an operating technique interfering the least possible with blood supply and the patient's general condition. As a prerequisite this team investigated the bony structure of the proximal femur in older subjects, the blood supply to the femoral head, the various fracture patterns as well as biomechanical aspects. Manninger and his team using numerous intraosseous venographies were able to show most elegantly the correlation between disturbed blood drainage from displaced neck fractures and posttraumatic avascular necrosis. They were also able to prove that an early anatomic reduction restores the venous drainage and thus reduces dramatically the risk of avascular necrosis. A meticulous analysis of the postoperative course of several thousand femoral neck fractures allowed to improve steadily the surgical technique and the implants, be it an improved or new design. The results led to the development of a family of implants assuring a stable internal fixation of a wide spectrum of fractures including undisplaced fractures, comminuted breaks and fractures at the trochanteric level.

Thanks to the vision and energy of pioneers such as Prof. Manninger we have nowadays at our disposal a cost efficient joint preserving alternative to arthroplasty. The present monograph reflects the wealth of experience that Manninger during the many years as chief of the National Institute of Traumatology as well as his predecessors in Budapest gained and transmitted to their pupils. Manninger's "Internal Fixation of Femoral Neck Fractures" is a most important work of high scientific value. At a time when the indication for a joint replacement is often established too fast and the technique of internal fixation decreasingly well mastered, trauma surgeons must be thankful to the authors for having written this book.

Hanover, May 2004

Prof. Dr. Harald Tscherne
(former director of the Department of Trauma Surgery,
Hanover Medical School, Hanover, Germany)

FOREWORD TO THE GERMAN EDITION

It is a great pleasure indeed to be able to present to interested readers the German translation appearing two years after the publication of the first Hungarian edition. We would like to profit from this occasion to thank all of our foreign friends and teachers (for listing of their names, see Appendix) who supported and encouraged our research in spite of the "iron curtain". Particular thanks go to Professors Lorenz and Jörg Böhler (Vienna), Hans Willenegger (Basle) and Harald Tscherne (Hanover).

Without this intimate contact between their institutions and the National Institute of Traumatology (Budapest) that stretches over decades, this book would never have been published. The co-operation and execution of common research projects started in 1997 with Department of Trauma Surgery, Hanover Medical School, Hanover, Germany under the guidance of Professor Ulrich Bosch. The mutual co-operation bore many fruits also thanks to the support of the governments of both countries: standardization of techniques and instruments of internal fixation with two cannulated screws, introduction of this method in Germany and joint publications of the results.

Motivated by this success the editors asked Professor Bosch to collaborate in the publication of the German edition. This did not result in a simple translation but in a revision that included an elimination or adaptation of Hungarian aspects not relevant to the German reader. Other parts were added such as the newer developments. Revisions and more quantitative data (statistical analyses with determination of significance) are also found in this edition in which consideration was given to the new German spelling and the proper selection of medical terms. Our thanks go to all those who collaborated in the preparation of the German edition: Dagmar Merkel for the translation and the team of Springer Verlag responsible for this book.

It is with great sorrow that we remember the death of Professor György Kazár who lost his life under tragic circumstances at the age of 85 years. We will also remember the joy of our dear friend and colleague when the Hungarian edition appeared in print; for him it was the high point of his professional achievements.

We sincerely hope that this book will be of value to our German readers. It describes our route searching for the causes of problems associated with joint preserving internal fixation of femoral neck fractures, the source of early and late complications and their solution.

The publication of this edition coincides with the admission on Hungary to the European Union. We believe it is a good omen as it is a perfect example of success of achievements across boundaries. May this work be followed by many other studies to the profit of our (trauma) patients.

Budapest and Hanover, September 2004

Jenő Manninger, Ulrich Bosch
Péter Cserháti, Károly Fekete

FOREWORD TO THE FIRST HUNGARIAN EDITION

With the pooling of our experiences and results in the treatment of femoral neck fractures extending over four decades we intend to contribute to the development of surgery for hip fractures. The evolution of trauma surgery and of medical technology has allowed the elaboration of a treatment concept and methodology based on experimentally proven, clinically verified and finally postoperatively confirmed results. Improvements of implants and in particular the introduction of image intensifiers with ever increasing definition form the basis for the realization of the demanding technique.

The analyses of case histories, of surgical approaches and of the postoperative care of more than eleven thousand patients suffering from femoral neck fractures treated at the National Institute of Traumatology in Budapest over a period of 60 years are the foundation of our work. Of equal importance was our basic research. We took into consideration all questions raised in the literature that were relevant to our clinical practice.

The book consists of eleven chapters:

In the **first three chapters** we summarize the basic aspects of **surgical anatomy, biomechanics,** and **blood supply** of the hip as well as **pathologic aspects** and **diagnosis.**

The fourth chapter is devoted to international and Hungarian advances in the treatment of these fractures, in particular to the technique of internal fixation. The practical experience of the National Institute and its predecessors- is described in detail.

The **three ensuing chapters (5–7)** deal with several special questions concerning fixation of femoral neck fractures – **biomechanical principles, urgency of intervention and reduction.**

In the **eighth chapter** we describe the **implants and instruments for the percutaneous cannulated screw fixation** most frequently used by us. It is followed by the **description of the standard operating technique as well as the means to increase stability of internal fixation.**

In the **ninth chapter** we describe our approach to **undisplaced** (Garden-I and -II) **fractures** and to **atypical neck (juvenile, stress and pathologic) fractures.**

The **postoperative care and treatment of early complications form part of chapter 10.**

In the **eleventh chapter we present the results of the 3–4 year follow-up of patients operated in 1993 and 1994.** This patient collective has been chosen from more than 2500 cannulated screw fixations. The results of our experimental and clinical research as well as the development that is based on our knowledge and experience from this period are analyzed using the **international SAHFE (Standardized Audit of Hip Fracture in Europe) project from the years 1997 and 1998.**

The remote complications and their treatment have also been critically analyzed. Their enumeration would go beyond the scope of this book. They will therefore be treated in a future publication, where we intend to describe our experiences with the diagnosis and treatment of **traumatic and atraumatic avascular necrosis in adults,** a condition steadily gaining **in importance.**

For the spelling of foreign words we accepted the recommendation of the "Hungarian Medical Spelling" (Academy publishers 1992). A great number of patients are presented in each chapter. We always attempted to reproduce radiographs in two planes. To save space we occasionally omitted pictures considered less informative. For the same reason we reproduce lateral radiographs vertically.

Speed (1935) coined the term **"the unsolved fracture"** on account of the frequent remote complications caused by disturbances of blood supply to the head. Even today we cannot pretend that all problems have been solved. We can, however, state that the incidence of avascular necrosis can be lowered if internal fixation is performed as an urgent procedure. In such a case the extent and sequelae of necrosis can be reduced (Manninger et al, 1989;

Manninger et al, 1993). More recent findings indicate that the already established necrosis (collapse and deformity) can be successfully treated in younger individuals with a surgical revascularization (Fekete et al, 1994). The analysis of approximately 3000 intraosseous venographies performed at the time of internal fixation over a period of 25 years has shown that in **80 to 85% of patients the femoral head is vital and can be preserved;** the pathologically increased pressure in the head can be decreased through restoration of the venous drainage – through intraosseous drainage or insertion of drainage devices (Manninger et al, 1979).

The pathogenesis of **atraumatic avascular necrosis** in adults differs from that of traumatic necrosis. The possibilities of treatment and procedures for prevention of more serious complications are, however, identical. Our research team studying hip fractures applied its diagnostic and therapeutic experience gained over 50 years in the care of injured persons also to the care of atraumatic avascular necrosis, a condition increasing since the sixties (Kazár et al, 1960; Manninger et al, 1960; Szabó et al, 1961; Manninger, 1963; Nagy et al, 1975; Fekete et al, 1992; Salacz et al, 1993). Within the framework of these investigations we were the first in Hungary to use pedicled bone transplants (revascularization). We were also the first to employ core decompressions during the early stages of this affection.

In the eleventh chapter we touch briefly problems associated with the **economic impact**. The ever-increasing incidence of hip fractures also constitutes an increasing financial burden to the health care provider and the society. The necessary preoperative preparation of older patients, the prolonged stay on the surgical ward, the following in-patient care on medical or neurologic wards, that becomes necessary on account of inadequate rehabilitation facilities for social reasons, requires a great number of beds and puts high demands on the nursing staff.

During the past decades important steps to reduce costs were initiated foremost in Scandinavia. It was proven that the surgical risk does generally not increase by the use of up-to-date, less invasive techniques performed on an urgent basis. Moreover, the preoperative period was shortened. In addition, the incidence of general complications due to the prolonged confinement to bed is reduced thanks to a **stable fixation that allows an early mobilization**. Consequently, the postoperative hospital stay is reduced.

It became evident that the availability of an **effective homecare program and rehabilitation** further reduces the need for a very expensive hospital stay leading to further savings. In Sweden the costs were approximately halved thanks to up-to-date surgical techniques and homecare (Borgquist et al, 1991; Nilsson, 1991; Thorngren, 1991a; Thorngren, 1991b; Thorngren, 1997). Introduction of these methods would also compensate for the increasing costs due to the larger number of injured persons.

Obviously, we do not believe that our approach constitutes the sole solution. Our goal, however, has been to reach a consensus in Hungary concerning the essential treatment principles. Our standpoint has been reinforced by analysis of considerable patient collective as well as the continuous experimental and clinical research extended over many decades.

We have to get ready for a continuous **considerable increase in number of hip fractures**. In writing this book we felt it important to take this fact into consideration. It is our duty **to heal older patients with the least possible pain and complications while restoring their activities**. A fast return to a pain-free ambulation and independent living is of foremost importance to patients and relatives. From the standpoint of injured persons and the entire society considerations for optimal treatment is not trivial (Thorngren, 1991a).

Without the full support of members of the National Institute of Traumatology (Budapest) our book would not have been possible. For this we owe them our gratitude and would like to profit here to thank colleagues, doctors, assistants and nurses who work often at night under difficult circumstances.

Our thanks are directed to all those in our institute, in Hungary and in foreign countries who participated in our mutual endeavor and supported our research during the last 50 years. The long list of our colleagues and friends is found in the Appendix (only in the Hungarian edition).

We also would like to thank the members of the publishing house “Medicina” for the meticulous care

they took of our book: Professor Tamás Salacz and Professor Zoltán Záborszky for their input as lectors, Mrs Ottó Koltai, Mrs Béla Sárközi and Mr Miklós Manninger for the production of the photographs, Mr András Tekus for the digital picture material, the secretaries Mrs Mirtill Kis, Mrs Marianna Pál Farkas and Mrs Ibolya Gál Szilágyi for typing!

Thanks to our families, our spouses and children for their patience and helpfulness that allowed us in addition to our clinical obligations to spend a greater part of our free time with the preparation of this book!

May this book be of help to many colleagues. We also hope that we can advance together the unsettled treatment of this injury.

Budapest, February 2001

Jenő Manninger, Péter Cserháti,
Károly Fekete, György Kazár †

Chapter 1

PROXIMAL FEMUR FRACTURES. DEFINITION, EPIDEMIOLOGY, ANATOMY, BIOMECHANICS

1.1 Introduction

Nowadays, the most important socioeconomic problem is osteoporosis; its incidence increases steadily. The expression and the most severe complication of its senile form is the **proximal femur fracture** that contributes considerably to the **mortality** in **old people** due to preexisting diseases and to the complications resulting from confinement to bed.

During the second half of the 20th century the average age of the population increased markedly while the **incidence of hip fractures** grew many times, particularly in industrialized countries. Although the age-specific incidence varies from country to country, a continued increase worldwide is expected during the first half of the 21st century. In Scandinavian countries **every third or fourth hospital bed was occupied by these patients** in the eighties; moreover, **these patients spend yearly more days in hospital than cancer patients** (Thorngren, 1991a). In spite of the fact that medicine and society spend ever increasing energy on prophylaxis and efficient therapy of osteoporosis, successes have been mainly limited to postmenopausal bone loss (Hofeldt, 1987; Nilsson, 1991; Poór, 1992). Consequently, we must expect in the future a rise in femoral neck fractures, necessitating a continuous development of therapeutic and surgical methods and rehabilitation.

In the meantime, the **treatment costs have also risen.** These expenses have reached in Sweden levels reaching those for persons suffering from **diabetes and hypertension** (Borgquist et al, 1991; Thorngren, 1991b). In 1992 the care of a quarter million proximal femur fractures amounted in USA to **8.7 billion dollars;** the expenses multiplied in instances of complications (Kyle et al, 1994). **Diagnosis and surgery** further increased the expenses caused by introduction of newer techniques (MRI, CT, DSA, image intensification) and a multitude of newer implants and instruments for internal fixation and joint replacement. Should the old patient be unable to return to his previous home, an **expensive in-house rehabilitation** is unavoidable (Holmberg and Thorngren, 1988).

To alleviate this situation a proper treatment, avoidance of complications, lowering of the mortality rate, a speedy, effective and a socioeconomic restoration of quality of life become a priority for our society.

Two types of proximal femoral fractures must be distinguished: **femoral neck fractures and trochanteric fractures,** although in principal they give rise to the same problems. The latter are characterized by a more severe course, a greater blood loss, a higher death rate and usually more general complications. The break itself does not cause problems; it even heals under conservative management (Lawton et al, 1981; Jakobssen and Stenstrom, 1984; Elmerson et al, 1986; Hedlund et al, 1987; Koval et al, 1996; Wirsing et al, 1996).

For displaced **femoral neck fractures,** on the other hand, a **healing** can only be expected when the stability can be **restored successfully during surgery.** This does not present a problem in younger patient with a good bone stock; internal fixation is recognized worldwide as the treatment of choice in persons less than 60 years of age. As a stable fixation in older patients with **porotic bones always present problems,** a joint replacement is often the treatment of choice.

Well-known orthopedic surgeons and traumatologists have recognized already decades ago: the optimal place for a viable femoral head is its replacement on the femoral neck (Dickson, 1953; Nicoll, 1963; Sarmiento, 1973). For this reason, research focused in many countries on the improvement of stability of internal fixation – in Hungary for economic reasons. The main question was: **is it possible to obtain a stable fixation even in the presence of a porotic bone?** Since comprehensive insurance coverage had been available in the past decades (reimbursement for prostheses and adequate rehabilitation) in the majority of industrialized countries, no impetus for serious research in respect to a biologic approach existed. Recently this situation has changed as health care providers make efforts to contain costs.

The attainment of a stable internal fixation of a porotic bone with the least possible interference with blood flow and without putting too great a strain on the patient was the goal of our research endeavors, as presented in this book. We analyzed **the bone structure of the elderly and the vascularization, the fracture types and the biomechanics.** This led to the development of a **set of implants** allowing an adequate, stable internal fixation of fractures that range from undisplaced to severely comminuted and displaced fractures to trochanteric fractures.

Up to the eighties our results were analyzed and published mostly using our own criteria. In 1990 we followed the call in the Acta Orthopedica Scandinavica for a **Multicenter Hip Fracture Study** (Editorial, Acta Orthop Scand, 1988; Thorngren et al, 1990; Thorngren, 1993; Kitamura et al, 1998; Tolo et al, 1999; Cserháti et al, 2002a; Partanen et al, 2002). On the international level this study represents an equivalent to the Swedish "Rikshöft" project that led to excellent results over many decades. In 1990, we treated 754 patients with recent hip fractures. Standard questionnaires containing details as to the initial care, the follow-up results after four months, one and five years, were analyzed with the help of a computer. We published the results in several scientific journals (Cserháti et al, 1992; Laczkó et al, 1992; Laczkó et al, 1993; Cserháti et al, 1997; Kazár et al, 1997; Cserháti et al, 2002a). In 1994, two members of our research team received a stipend to analyze our data at the Swedish institute responsible for the development of the study (University of Lund, Orthopedic Hospital). This excellent cooperation led to an invitation from Prof. Thorngren to join the SAHFE (Standardized Audit of Hip Fracture in Europe) sponsored by the European Union. We were one of the eight founding members and the only member from the former East block countries (Thorngren, 1998; Parker et al, 1998c; Cserháti et al, 2002b). The participants of this cooperation, at present including 16 countries, list in a standardized fashion their patients with hip fractures including their treatment. It is hoped that this wealth of material will allow to formulate the principles of optimal surgery and rehabilitation of femoral neck and trochanteric fractures currently still controversial (Cserháti et al, 2002b).

The parameters of our patients who were treated with the cannulated screw since 1990 were prospectively documented using an adaptation of the multicenter study. In 1992, we presented our first results in Freiburg-Germany. In Hungary during a symposium at the University of Debrecen (1995) we reported together with several Hungarian departments our results and analyzed them. Since 1998 our surgical technique has also been introduced in other countries particularly at the **Trauma Department of the Hannover Medical School, Germany** (Fekete et al, 2000b; Fekete et al, 2000c; Bosch et al, 2001; Sträuli et al, 2001; Bosch et al, 2002; Szita et al, 2002).

Therefore we are confident that a comparison of our results with those of other authors will become possible. This will then be our contribution to the establishment of proper principles, indications and treatment of femoral neck fractures (Kazár et al, 1993b; Fekete et al, 1997b; Fekete et al, 2002; Szita et al, 2002).

1.2 Definition and frequency of hip fractures

1.2.1 Definition and basic concepts

In the Anglo-American literature and in the colloquial language the fractures of the proximal femur are known as "hip fractures" on account of their frequency and their medical and socioeconomic impact. This term is imprecise and has therefore not been accepted in other languages. In the pertinent literature one finds terms such as proximal femur fractures, fractures of the upper third of the femur and femoral fractures close to the hip.

Two major groups of hip fractures have been recognized in the pertinent literature and in trauma surgery. We distinguish between **intracapsular (medial neck-)** and **extracapsular (lateral neck-also known as basal, as well as trochanteric and subtrochanteric) fractures** (Figs. 1 and 2).

An increasing number of researchers insist that in respect to mean age, degree of osteoporosis and

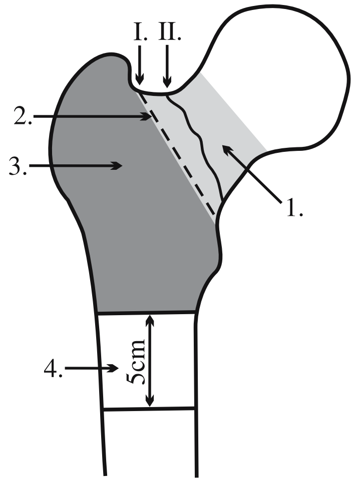


Fig. 1. Recommendations of classification of hip fractures according to Parker and Pryor (1993).
I. Limit between neck and trochanter region. II. Most frequent localization of recess of joint capsule. Medial neck fracture (1.). Extracapsular fractures (2., 3. and 4.). Lateral and base of neck fracture (2.). Per- and intertrochanteric fracture (3.). Subtrochanteric fracture (4.)

general condition a distinction must be made between the two fracture types in respect to the patient collective (Lawton et al, 1981; Hedlund et al, 1987; Karagas et al, 1996; Mautalen et al, 1996; Fox et al, 1999; Michaelsson et al, 1999; Huang et al, 2000). Moreover, the principle differences in the causes of the disease and the treatment (surgical techniques) justify a distinction between both groups as also accepted by the International Classification of Diseases (ICD).

Moreover, an essential difference lies in the fact that the **blood loss of the intracapsular fractures is minimal,** that the fracture line in general lies inside the joint capsule, that the injured person tolerates the fracture better, that the patient can be operated immediately and that the incidence of early mortality is lower (Jakobssen and Stenstrom, 1984; Koval et al, 1996). On the other hand, **the blood loss of extracapsular fracture,** particularly for comminuted fractures, can be considerable given the great surface of exposed cancellous bone and the concomitant injury to surrounding blood vessels. These facts must be considered during treatment; they may play a role in the increased incidence of mortality.

Further on, another definite difference is found in the fact that the **blood supply to the femoral neck is at greater risk in intracapsular fractures** (Manninger, 1963). The retinacular arteries and veins supplying the femoral head may tear or become incarcerated between the fragments. If these vessels are severely injured or if the decompression is not done in a timely fashion due to a delayed reduction, a partial or complete necrosis of the **femoral head** may result. The consequence is a nonunion or after consolidation **a progressive deformity and later a collapse of the head** resulting in a severe osteoarthritis.

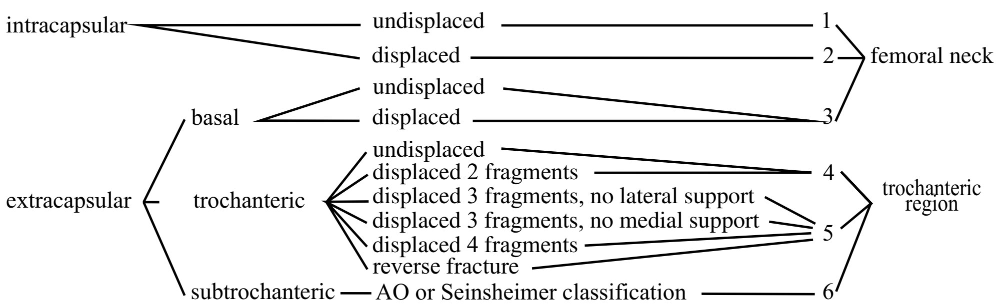


Fig. 2. Detailed classification of hip fractures (Parker and Pryor, 1993).
The Multicenter Hip Fracture Study and the SAHFE project also use this terminology as well as the six code numbers

The displacement of the fracture and the intraarticular hematoma cause a compression of the thin-walled veins. Blood drainage can also be impaired or interrupted by the fracture itself. Therefore, an **impaired drainage must be foremost expected** as well as venous congestion in the femoral head and a consecutive increase in **intraosseous pressure.** This results in the death of osteocytes (Woodhouse, 1964; Arnoldi and Linderholm, 1969; Arnoldi et al, 1970; Arnoldi and Linderholm, 1972; Arnoldi and Linderholm, 1977). The **intraosseous drainage** and the blood supply can be improved by an early intervention/reduction that will also restore the retinacular venous circulation.

Should the patient survive **an extracapsular fracture,** a consolidation can be expected in the majority of cases. **Late circulatory damages are an exception.** Obviously this influences the analysis of outcome. For fresh medial neck fractures an **emergency intervention is the procedure of choice,** hopefully restoring the vascularization of the head. For extracapsular fractures an **early intervention** after compensation of the blood loss is advisable as a blood loss in older patients constitutes a threatening situation.

1.2.2 Frequency of fractures – international and Hungarian data

The hip fracture is an injury characteristic for older patients with osteoporosis. Its incidence depends on the age distribution of the population. The correlation is exponential as we could already show 40 years ago when we analyzed the age and sex distribution of 1000 patients with femoral neck fractures (Manninger et al, 1960). This trend was also confirmed by our later studies (Kazár et al, 1997) (Fig. 3).

The epidemiology of this injury occupies an ever-increasing place in the international literature. According to Scandinavian and American publications the incidence in industrialized countries has doubled between 1960 and 1985 (Nilsson and Obrant, 1978; Zetterberg and Anderson, 1979; Schröder et al, 1988; Jarnlo et al, 1989; Lütje et al, 1993). The explanation for this trend can be partially explained by the absolute increase in number of older patients. An increased incidence within the same age group has also been found, most probably due to changed life style with decreased physical activities.

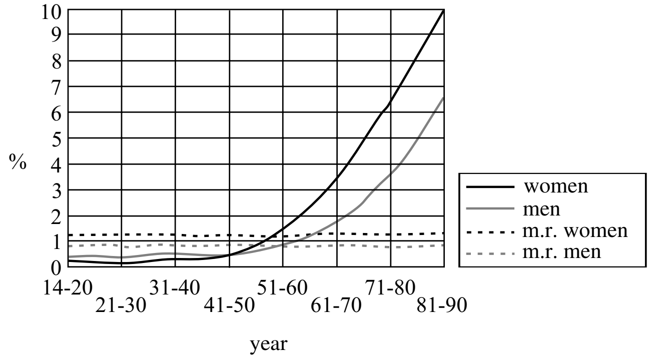


Fig. 3. Age- and sex specific frequency of femoral neck fractures in Hungarian population.
The distribution of frequency of 1000 patients according to age shows an exponential curve for both sexes. Around the 50th resp. 60th year of life it exceeds the level of mean risk (m.r.) (Manninger et al, 1960)

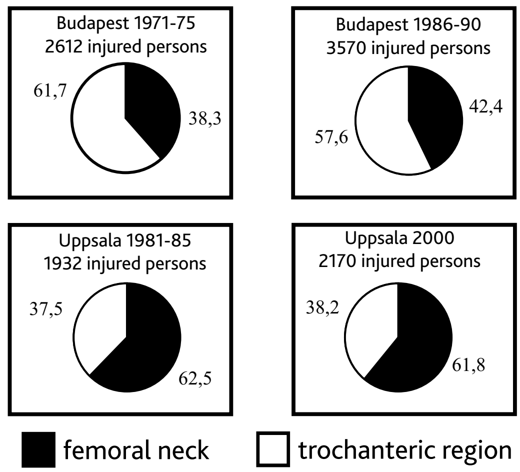


Fig. 4. Distribution of frequency of femoral neck and trochanteric fractures.
The difference in respect to both fracture types is evident as well as the increase in number of patients at the National Institute of Traumatology (Budapest) in two 5-year periods and in Uppsala (Sweden) according to the expectation for the year 2000

In Hungary the yearly incidence of hip fractures is 1:500 persons; in 1998 18435 fractures were registered (Huszár et al, 2000). This incidence is rather high in light of the fact that the mean age of both sexes lies below the European average. The average age of Hungarian patients with hip fractures amounted to 78 years. Only 4–6% of patients with femoral neck fractures were younger than 50 years (Zetterberg et al, 1982; Manninger et al, 1984; Fekete et al, 2000a). In children and adolescents these fractures are even rarer; their complications constitute, however, a considerable long-term problem (Zolczer et al, 1972).

International studies have shown an ethnic difference in the incidence of hip fractures (Solomon, 1968; Levine et al, 1970; Makin, 1987; Karlsson et al, 1993). The reason for a lower incidence in Japan in general and in USA and South Africa among the colored population can be sought in the greater physical activity of these groups. This view is confirmed by a Scandinavian study that showed a lower incidence in the rural than in city dwellers (Finsen and Benum, 1987; Mannius et al, 1987; Sernbo et al, 1988; Larsson et al, 1989).

A geographic difference is also seen in the distribution of intra- and extracapsular fractures. In Northern Europe neck fractures are three times more frequent than trochanteric breaks. In USA and Western Europe the ratio is 1:1, whereas in Southern Europe and in Hungary trochanteric fractures are more frequent amounting to 3:5 (Alffram, 1964; Melton et al, 1982; Lüthje, 1985; Rasmussen, 1990; Dretakis et al, 1992; Lee et al, 1993; Rowe et al, 1993; Kaastad et al, 1994; Hinton et al, 1995). More recent reports indicate that in Scandinavia the incidence of trochanteric fractures is increasing (Sernbo et al, 1997a; Rogmark et al, 1999) (Fig. 4).

1.2.3 Frequency of femoral neck fractures at the National Institute of Traumatology (Budapest) between 1940 and 2002

Since its foundation our Institute is foremost involved in the treatment of people from the capital. As the number of weekly admissions, the size of the area served and the number of beds have changed several times (the number of beds between 150 and 363), reliable epidemiologic conclusions of the yearly admissions cannot be drawn. **Over a period of 60 years a marked increase in the number of femoral neck fractures** has been registered (Fig. 5).

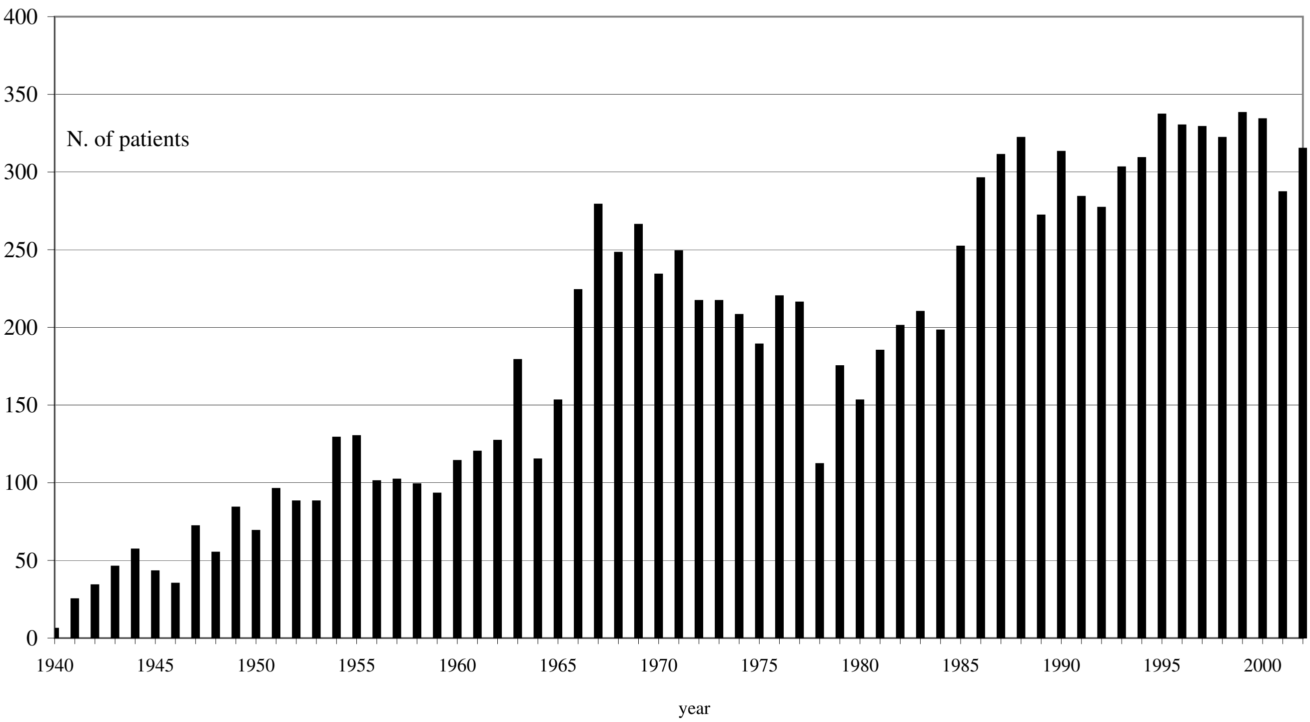


Fig. 5. Yearly distribution of frequency of 11792 neck fractures treated at the National Institute of Traumatology (Budapest) respectively its precursors between June 1st 1940 and December 31st 2002

During the first half of the forties mostly work-related accidents were treated at the General Compensation Board Hospital. After WW II our activities expanded to the treatment of accidents and the number of beds increased to 200. Accordingly, the number of treated hip fractures increased. In 1957, the trauma department of the hospital in the Péterfy Sándor Street was opened, a fact that explains the temporary decrease in the number of injured patients. Thereafter the number of hip fractures increased again from year to year. At the end of the sixties it reached the present level. At the beginning of the seventies several new trauma departments were opened in Budapest (in the Csepel-, St. Johns-, Árpád- and Uzsoki-Hospitals). After a short lasting decline the number of our patients stabilized between 200 and 250. In 1978, the number decreased considerably but temporarily due to the forced relocation of our institute. But already at the beginning of the eighties we could treat in our 200 beds in the Baross Street building an average of 200 neck fractures. After return to our 363 bed institute we treat **more than 300 femoral neck fractures** yearly. The modification of our admission system introduced in Budapest in 1992 did not alter this number.

1.3 Topographic and surgical anatomy

(Pernkopf, 1989; Hulth, 1956; Lanz and Wachsmuth, 1972; Szentágothai and Réthelyi, 1985; Vajda, 1989) The entire femoral head as well as a good part of the neck lie inside the joint capsule that has a fold at the lateral part of the neck (capsula reflecta). At this site the neck is covered by a relatively thin synovium. Its posterocaudal and cranial parts, containing irrigating vessels, is thicker. The posterocaudal part is known as retinaculum Weitbrechti (Hulth, 1956). The synovium that is cranially tightly and caudally loosely attached to the neck has no cambium layer; for this reason **no periosteal callus will develop** here after a fracture. Such a formation will only occur in the extraarticular caudal part after a vertical (Pauwels-III) fracture (Fig. 6).

The vessels that supply the head and part of the neck enter the retinaculum from distal. At the anterior aspect of the neck, in the region between intertrochanteric line and capsular fold run the **lateral circumflex femoral artery and vein.** At the posterior aspect medial to the intertrochanteric crest the most important vessels are found: the **medial femoral circumflex artery and vein.** Under normal circumstances the **artery and vein in the round ligament** play a minimal role, however, following a hip fracture their importance can increase (Figs. 7 and 8).

The femoral head resembles a sphere under normal circumstances. Two thirds of its surface is covered by hyaline cartilage (Menschih, 1987). Its diameter is 41 to 53 mm, average 48 mm. In its medial, slightly anteriorly positioned portion one finds the **fovea capitis** that is free of cartilage, the point of

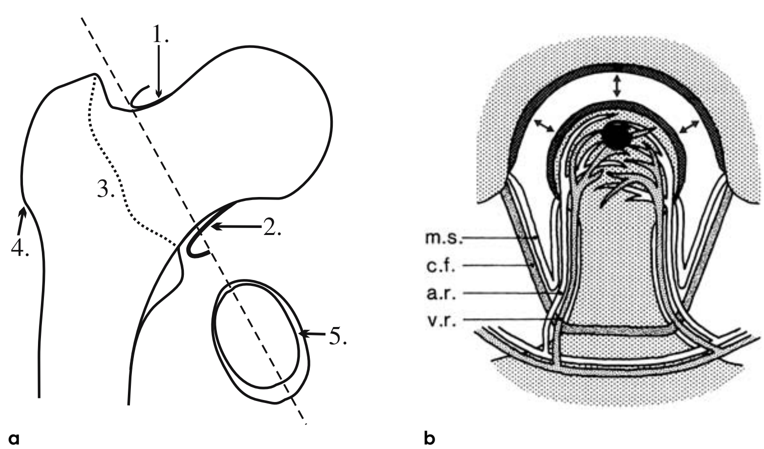


Fig. 6. Proximal end of the femur.
a. Frontal and sagittal cuts. The retinaculum inserts cranially as a thin adherent structure (1.). Posterocaudally the retinaculum is thicker and inserts loosely and more extensively on the neck (2.). The intertrochanteric crest forms posteriorly the limit of the base of the neck (3.). The gluteal tuberosity also known as trochanter tertius (Vajda, 1989) (4.) serves during nailing as a reference point for the introduction of the guide wire. The sagittal transverse section of the neck is oval in the middle and lateral thirds. The posterior and caudal cortex is thicker (5.).
b. Schematic representation of the topography of the retinacular vessels, the synovium and the joint capsule (according to Arnoldi, 1994).
m.s. = synovium, c.f. = fibrous capsule,
a.r. = retinacular artery, v.r. = retinacular vein

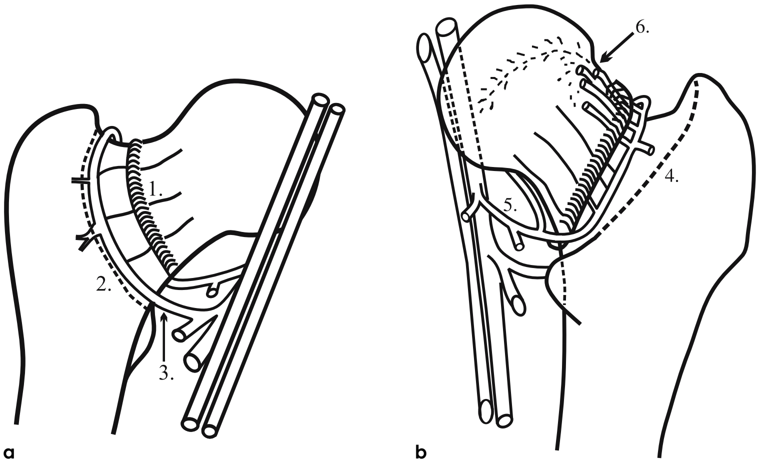


Fig. 7. Topography of joint capsule fold and blood supply.
Schematic view from **a.** = anterior and **b.** = posterior.
The interrupted line (1.) represents the most frequent localization of origin and fold of the capsule. The anteriorly entering small vessels are the branches of the lateral femoral circumflex artery (3.) running along the intertrochanteric line (2.). The posterior network originates from the medial femoral circumflex artery (5.) running medial to the intertrochanteric crest (4.). An important point is the cranially situated Claffey's point (6.) where the most important arteries enter the femoral head

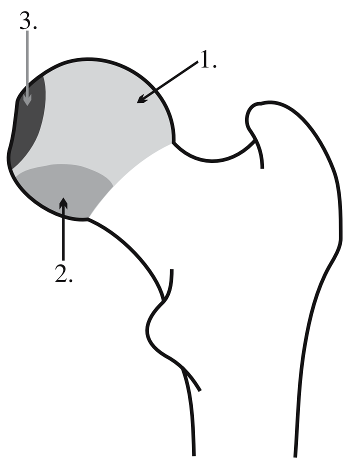


Fig. 8. Area supplied by the three principle arteries under physiologic conditions (schematic) (Parker and Pryor, 1993).
The lateral epiphyseal system (1.) is the most important one, it originates from the posterocranial retinacular arteries. Of lesser importance is the caudal metaphyseal network originating from the posterocaudal arteries (2.) and the arterial branches from the round ligament of the femoral head (3.)

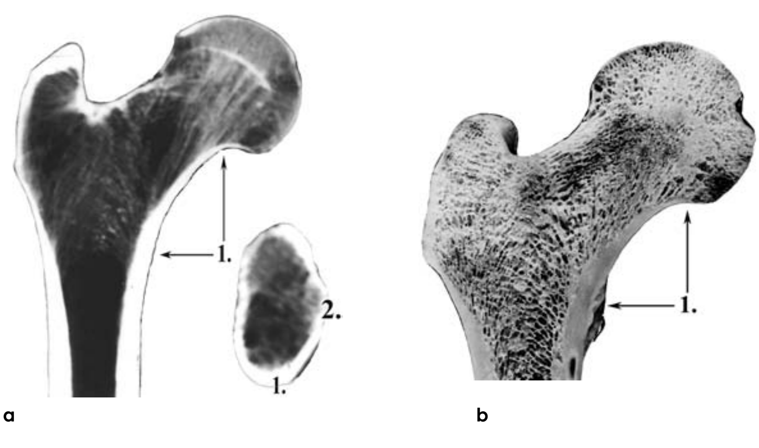


Fig. 9. Proximal end of femur
a. Frontal and sagittal CT cut;
b. Frontal cut of a cadaver specimen.
Both images taken in the frontal plane show the extent and thickness of Adam's arch (1.) and its connection with the compression trabeculae. The sagittal CT cut allows very well recognizing the thickening of Adam's arch (1.) and of the posterior cortex (2.)

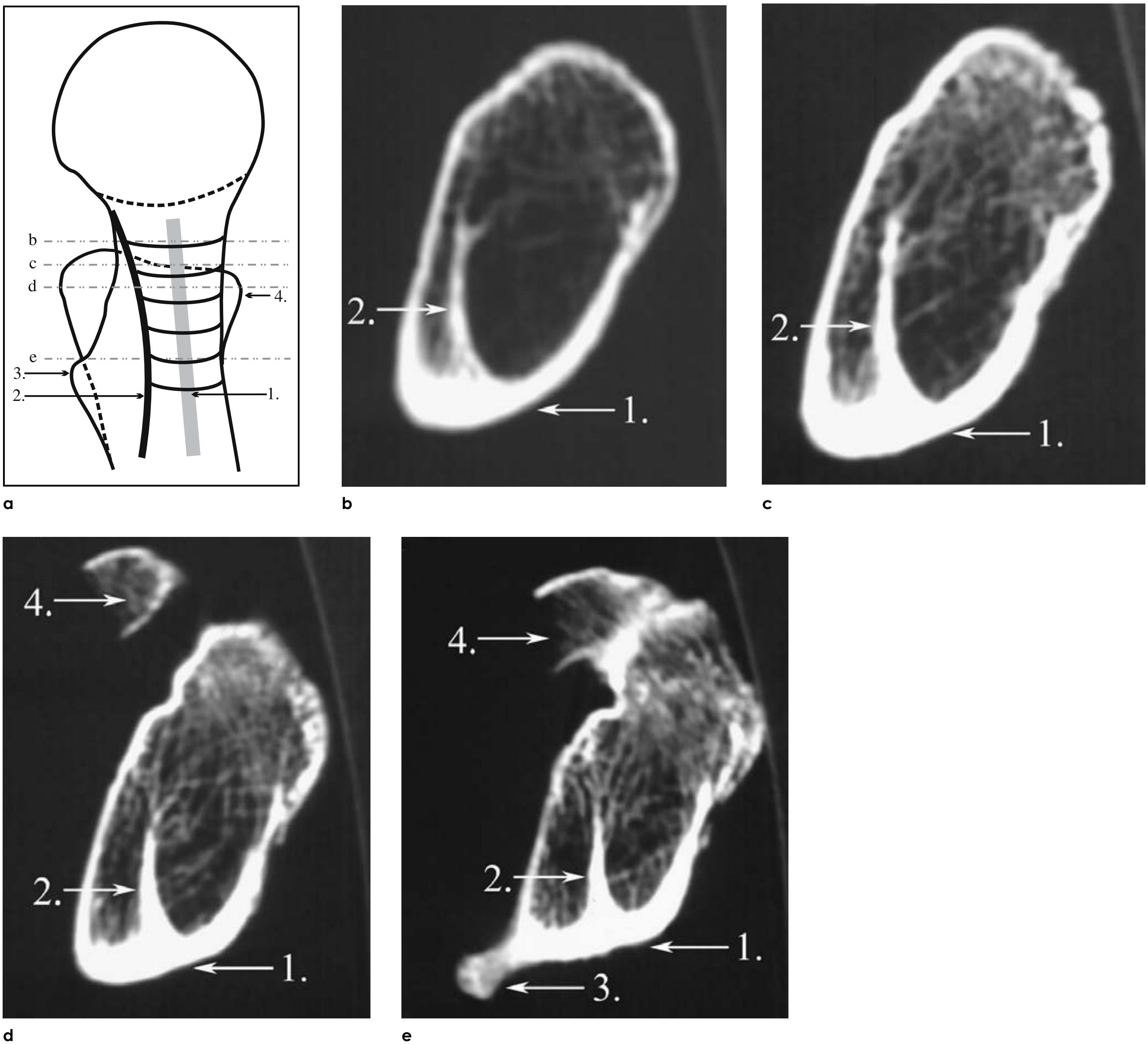


Fig. 10. Calcar femorale. a. Schema of a typical lateral radiograph of the neck; **b–e.** Sagittal CT serial cuts of the proximal femur specimen. The level of the CT cuts in (**a**) are marked with b. c. d. e. lines. Adam's arch (1.) and calcar femorale (2.) form a gutter in the direction of the head. The lesser trochanter (3.) lies posteriorly and the greater trochanter (4.) projects itself on this schema behind the femoral neck

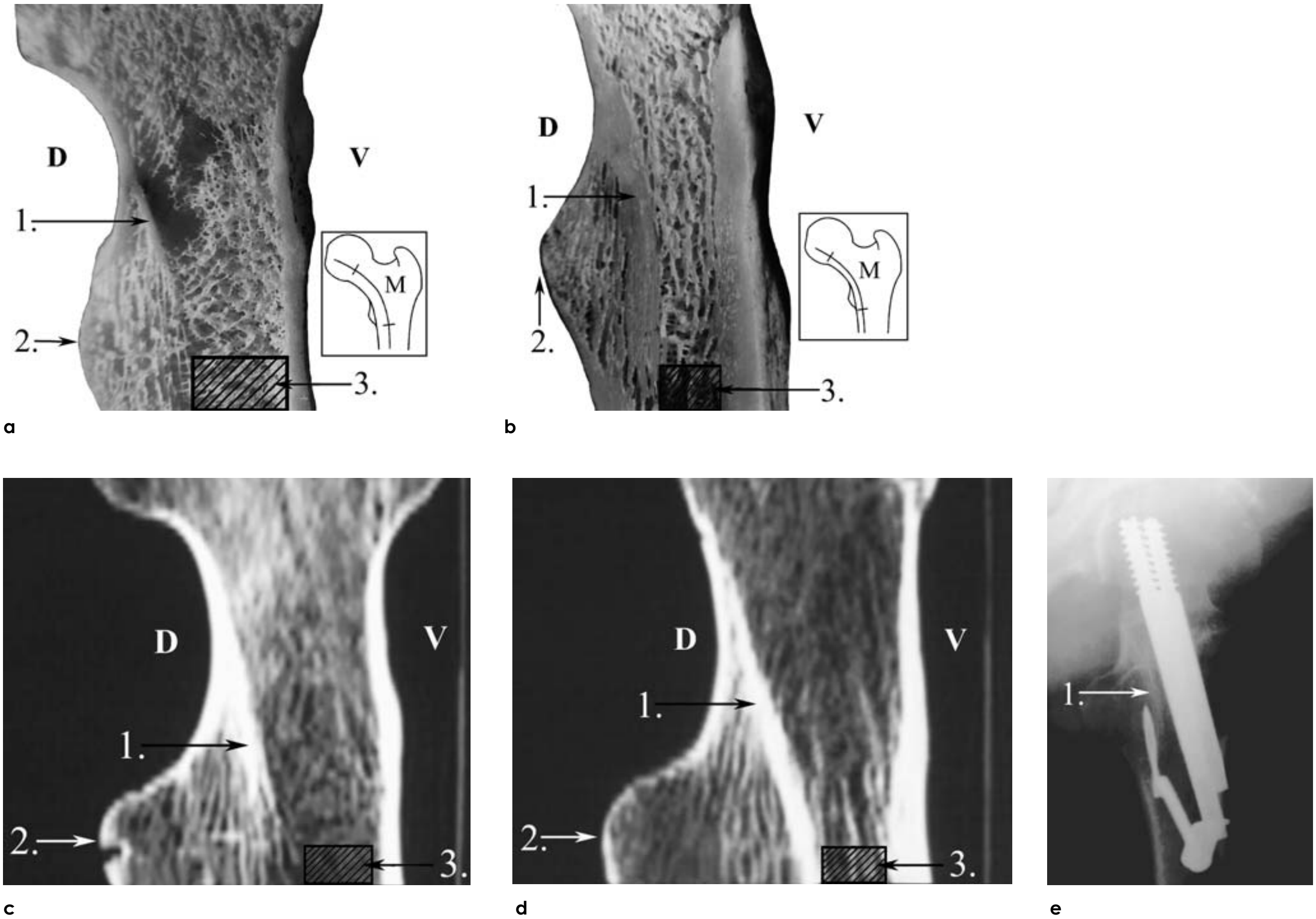


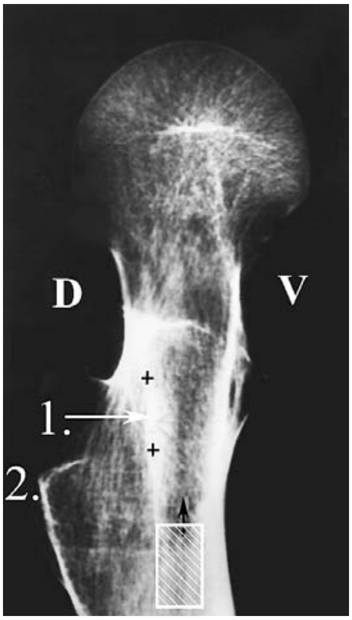
Fig. 11. Localization and course of the calcar femorale. Cadaver specimen.
a. Almost in mid-femoral neck; **b.** Close to Adam's arch, curved cut. **c, d.** Corresponding to CT cuts.
The schemata show the plane of cutting (M). The photographs were taken from caudal. Posterior side (D), anterior side (V). The calcar femorale (1.) runs intraosseously from the middle of the femoral neck to the lesser trochanter (2.) and ends in the posteromedial cortex of the cranial neck where it unites with Adam's arch. (Not visible here). (**a, c**). Close to the Adam's arch (**b, d**) the calcar femorale is thicker. The hatched area (3.) shows the ideal slightly anteriorly situated position of the caudal screw between calcar femorale and anterior neck cortex. At this site one obtains a better support than in the middle where drilling damages the calcar femorale. **e.** The importance of the calcar is well seen on the postoperative lateral radiograph. During faulty aiming the spiral drill bit can break in the hard calcar

insertion of the **capital femoral ligament** that originates in the acetabular fossa.

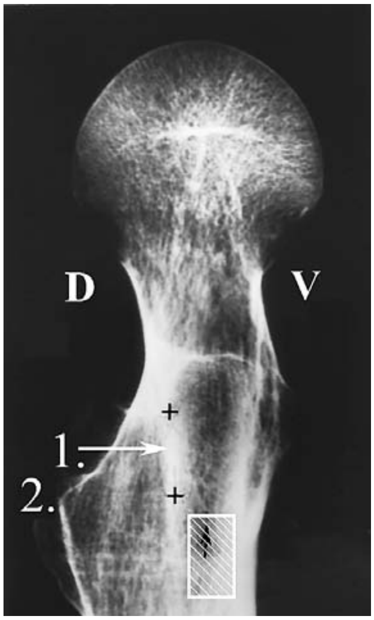
The very strong medial cortex of the femoral diaphysis continues on the medial side of the neck as **Adam's arch.** From the lesser trochanter to the head the calcar gets thinner and ends in a system of compression trabeculae (Fig. 9).

The cross section of the neck is mostly not circular but more oval caudally, as also seen in CT serial sections (see Fig. 10b–e). Most of the fractures pass through the oval zone; its vertical diameter (32 to 39 mm) is almost one cm longer than the sagittal (25 to 31 mm).

A thick bone plate, known as the **calcar femorale,** extends from the caudal half of the neck to the head. The calcar femorale together with Adams'arch forms a **U-shaped gutter** on the postero-medial side of the neck. The calcar femorale is a continuation of the posterior cortex of the femoral diaphysis. Appositional growth of the lesser trochanter during



a



b

Fig. 12. Fine-grained typical lateral radiograph of a cadaver femoral neck specimen.
a. Specimen slightly externally rotated;
b. Specimen slightly internally rotated.
Posterior aspect (D), anterior aspect (V). The course of the calcar femorale (1.) in relation to the lesser trochanter (2.) is well demonstrated. The hatched rectangle projects itself over the correct position for the caudal screw

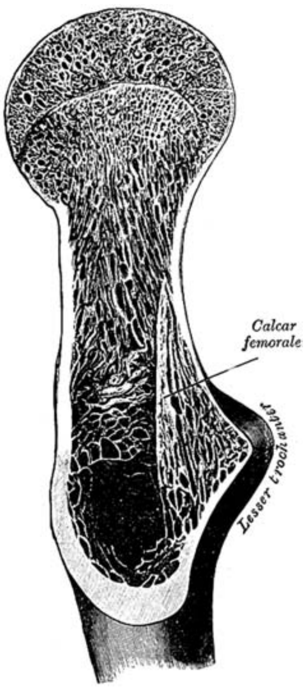


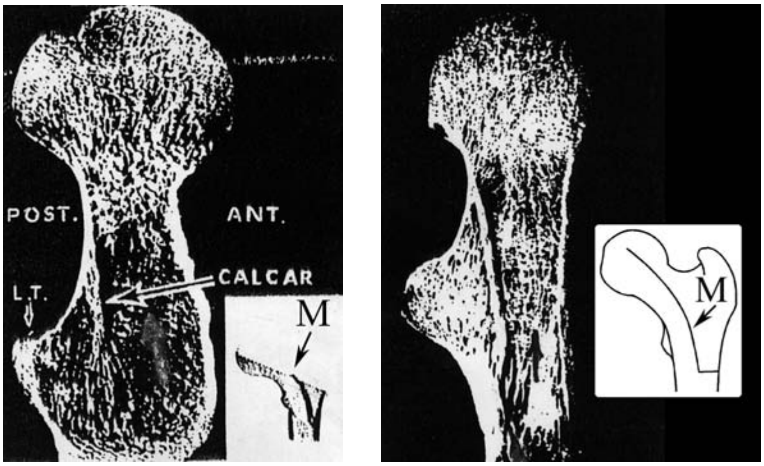
Fig. 13. Speed (1942) demonstrated on this drawing of the curved cut the position of the calcar femorale

ontogenesis leads to its migration to the center of the neck (Harty, 1957) (Figs. 10–12).

In many publications, particularly in the Anglo-American literature, no distinction is made between calcar femorale and Adam's arch; both are termed calcar. In the German literature the term "Schenkelsporn" (calcar spur) denotes that in poorly impacted fractures the calcar remains attached to the neck fragment and is lodged in the femoral head. Already 40 to 50 years ago, many well-known authors discussed the importance of the calcar femorale (Speed, 1942; Harty, 1957; Harty, 1965; Harty, 1966) (Figs. 13 and 14).

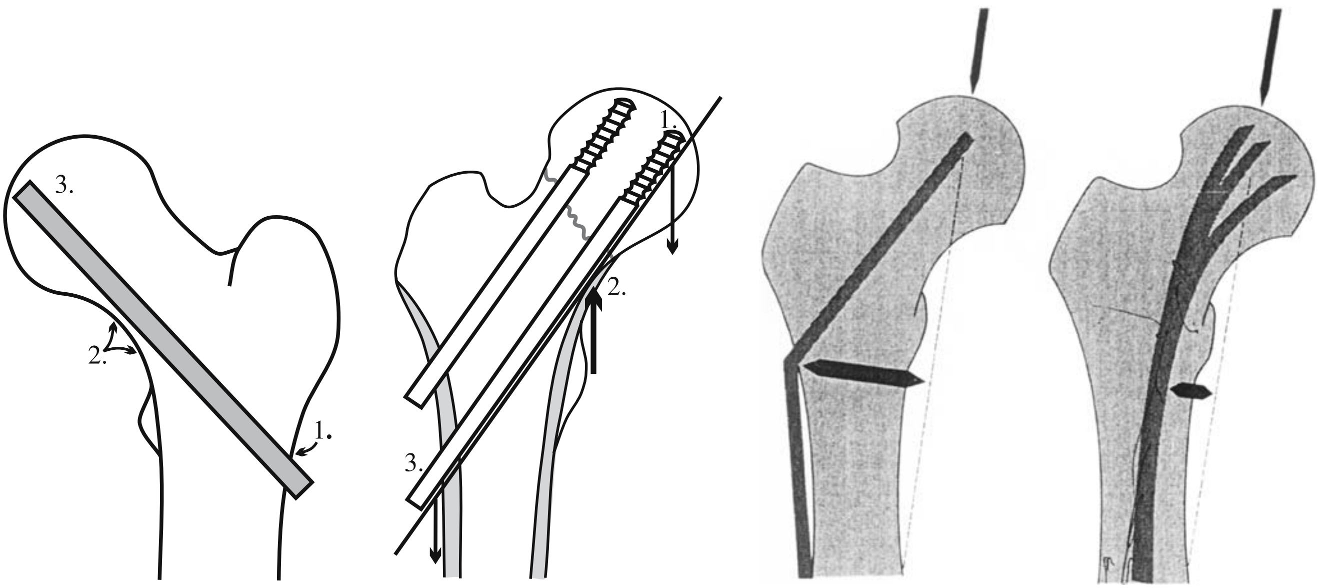
The bundles of cancellous bone (Adam's arch and calcar femorale) starting in the diaphysis eventually unite in the femoral head in a gutter-like structure and reinforce similar to a gothic arch **the medial and posterior wall of the neck.** This gutter plays an important role in the stability of internal fixation. These trabeculae support the implant that rests similar to a lever with two arms on this support (Fig. 15).

Adam's arch forms together with the caudal contour of pubic branch a vault, known as **Shenton's line,** which is only interrupted during extreme external rotation. Any interruption of this line is indicative of a neck fracture. In instances of doubtful



a b

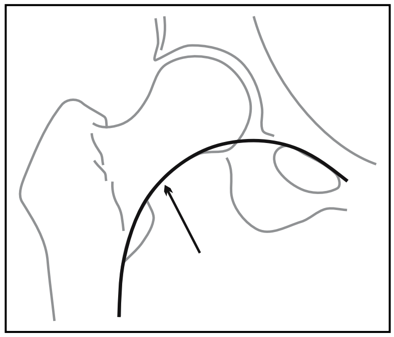
Fig. 14. Calcar femorale as seen on the original figures by Harty (1957).
a. Original drawing of the cutting plane (M);
b. Personal schema of the same plane



a b c

Fig. 15. The principle of the three-point buttressing.
a. The original figure of Harty (1966): "Points of firm bony contact recommended for adequate pin fixation of subcapital fracture of the femur". **b.** Own schema. The statically most important areas for internal fixation are the subchondral zone of the femoral head (1.), the gutter between Adam's arch and calcar femorale (2.) and the lateral cortex (3.). The sequence of numbers between both pictures has been reversed as today we proceed from cranial to caudal in the pertinent literature. **c.** The importance of medialization according to Ender (1975). The importance of medialization of the pivot during elastic nailing was stressed by Ender. Shortening of the lever arm decreases the load on the lateral cortex even in instances where the cannulated screw rests on Adam's arch

a



b

Fig. 16. The Shenton-Ménard line.
a. As seen on a typical radiograph; **b.** Schema

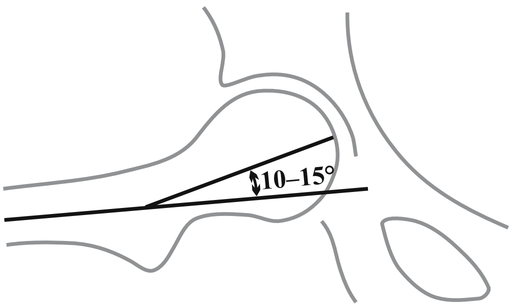


Fig. 17. Anteversion of the femoral neck as seen on lateral radiographs (Le Damany, 1903).
The longitudinal axes between femoral head/neck and femoral shaft form normally an angle between 10 and 15°

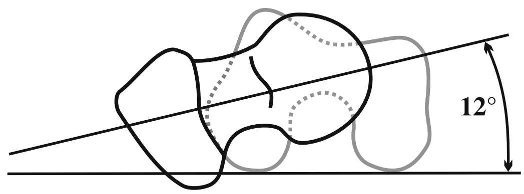
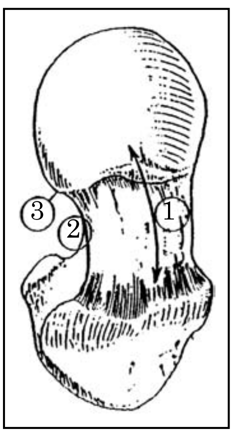
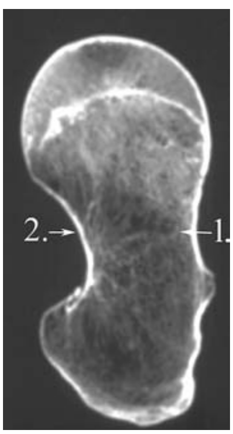


Fig. 18. Anteversion of the femoral neck in relation to the axis of the femoral condyles (Lanz and Wachsmuth, 1972).
Top view of the femur: both epiphyses are projected on each other. The axis of the femoral neck and the posterior plane of the condyles form an angle of 12°

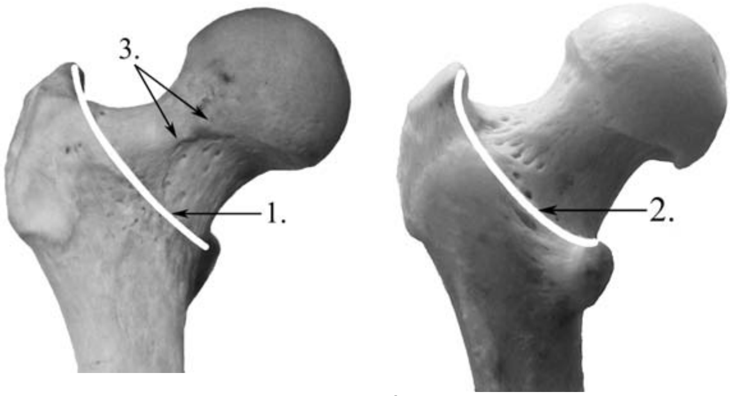


a



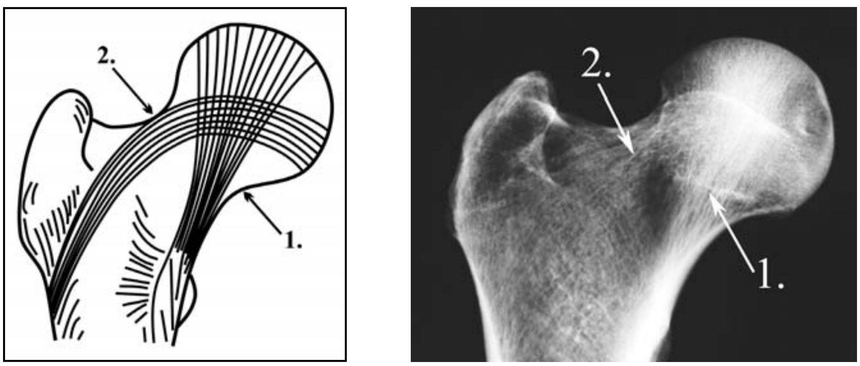
b

Fig. 19. Contours of the femoral neck.
a. Schema of a typical lateral radiograph (Pannike, 1969); **b.** CT cut of a cadaver specimen.
The anterior contour (1.) is convex, the posterior (2.) is concave.
The posterior border (3) of the femoral head exceeds the posterocaudal part of the neck



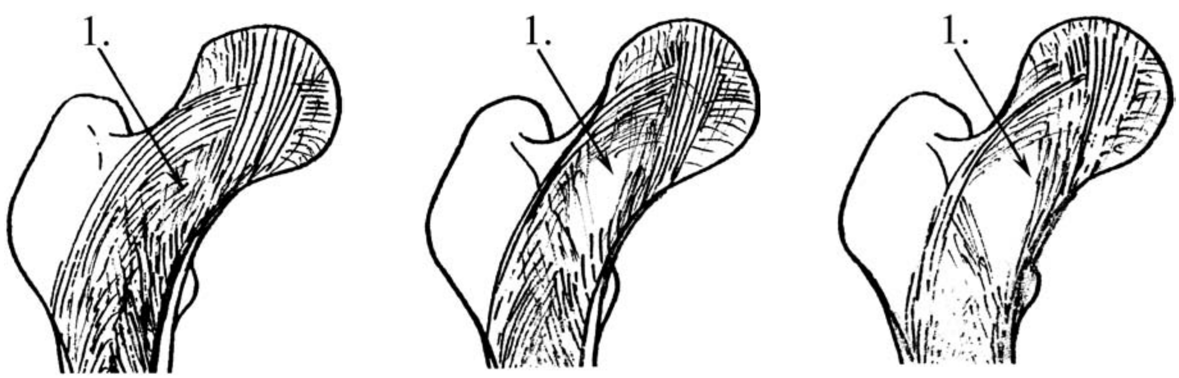
a b

Fig. 20. Cadaver specimen of the proximal femur.
a. Anterior view; **b.** Posterior view.
The white lines mark the intertrochanteric line (1.) and the intertrochanteric crest (2.). The anterior view allows identification of the anterocranial reinforcement (3.) situated under the iliofemoral ligament



a b

Fig. 21. Proximal end of femur.
a. Schema; **b.** Fine grain a.-p. radiograph of a cadaver specimen.
Adam's arch continuing into the compression trabeculae, the tension trabeculae are well visible



a b c

Fig. 22. Proximal femur. Schema.
Correlation between extent of Ward's triangle (1.) and age (Manninger and Fekete 1982). **a.** In younger person; **b.** In 60- to 70-year-old patient; **c.** In 90-year-old patient

diagnosis or after internal fixation a little kink in this line indicates the site of fracture or displacement (Fig. 16).

The longitudinal axis of the neck is angulated anteriorly by 10–15° in relation to the longitudinal axis of the shaft (anteversion) (Fig. 17).

The anteversion develops during growth through a mechanism of rotation. The proximal end of the femur rotates anteriorly by 10–15° in relation to the transverse axis of the femoral condyles. It would therefore be preferable to talk about an antetorsion. However, the majority of orthopedic textbooks use the term anteversion in accordance with the clinical usage (Fig. 18).

The anterior contour of the neck is slightly convex and the posterior concave. The posterior border of the head projects over the neck. The latter is therefore slightly rotated backwards like an arch (Fig. 19).

Anteriorly, the **intertrochanteric line** and posteriorly, the much stronger **intertrochanteric crest connect** the greater and lesser trochanter. Both lie approximately at the base of the neck. The intertrochanteric line runs slightly more cranial from the cranial border of the lesser trochanter to the apex of the greater trochanter. The intertrochanteric crest lies slightly more caudal, running from the middle of the lesser trochanter to the apex of the greater trochanter. The knowledge of position and projection of the lesser trochanter is important as it indicates on the a.-p. film the rotational position of the proximal femur. In the presence of external rotation it appears much bigger whereas in internal rotation of 15–20° only its apex can be seen. At the anterior surface of the neck under the iliofemoral ligament an **anterocranial reinforcement** (crest, eminence) is well visible (Fig. 20).

The **gluteal tuberosity** (trochanter tertius, tuberculum innominatum) lies lateral to the greater trochanter (see Fig. 6). From the standpoint of traumatologists the term innominatum = without name is unjust. It regularly serves as a point of orientation during the formerly done open reduction (double nailing according to Smith-Petersen). The entry point of the guide wire should be two-finger breadth distal to this tuberosity. It is also the site of origin of the vastus lateralis, a muscle we incise and partially detach during the retromuscular approach. It constitutes the third point of support when we are forced to proceed with an open internal fixation.

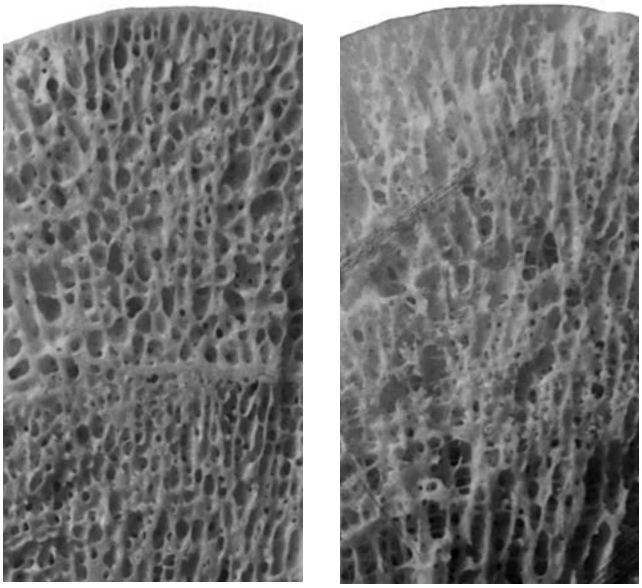
The proximal end of the femur contains cancellous bone. The most important trabeculae, the **compression trabeculae,** run from Adam's arch to the weight bearing surface of the head whereas the **tension trabeculae** form a vault at the cranial part of the neck (Fig. 21).

If the cranial screw during fixation with cannulated screws is placed posteriorly, it avoids the middle bundle of the compression trabeculae under the most important weight bearing surface of the head (and thus does not weaken it). On the lateral film the screw tip can be seen posterior to these trabeculae. In elderly patients (over 80 years of age) the more anteriorly placed screw does not damage this important zone (see Fig. 136b). Sparing the compression trabeculae during surgery is not only important from the point of view of stability but also for the avoidance of circulatory disturbances.


a


b

Fig. 23. Proximal femur. Cadaver specimen.
a. 70-year-old man: the cancellous bone of the femoral head is still dense, Adam's arch thick, but the cancellous bone of the neck is porotic;
b. 91-year-old woman: cancellous bone of the head is preserved but porotic; great parts of the neck (Ward's triangle) and the trochanteric area are already hollow, the lateral cortex and Adam's arch are smaller



a b

Fig. 24. Four times magnification of areas marked in Fig. 23.
a. 70-year-old man; **b.** 91-year-old woman.
Decrease in size and number of trabeculae with age without forming cavities. The bone at the bone/cartilage junction remains compact during lifetime

Necrosis occurs most often in the middle of the weight bearing zone where these trabeculae are found.

With advancing age **Ward's triangle** between the two bundles of trabeculae in the middle of the femoral neck becomes visible. Also accompanied by increasing osteoporosis the number of trabeculae decreases and finally they disappear being replaced by fat. It follows that the cranial implant is not supported inside the neck (Figs. 22 and 23).

To the contrary, in the head no cavities form similar to Ward's triangle. Even in older persons the subchondral bone mass at the weight bearing surface remains dense (Fig. 24).

Therefore we always can count on a good purchase of screws in the head. Depending on the degree of osteoporosis the stability can be increased by choosing screws of a larger diameter or by the addition of screws. On the other hand, one should always obtain a good subchondral fixation (Rehnberg and Olerud, 1989; Olerud and Rehnberg, 1993). Already 18 years ago we recommended in the fifth volume of the Hungarian specialty journal that during nailing the implants should be advanced up to 3–4 mm of the head contour. This led to a good purchase. When reaching this position during hammering a greater resistance can be felt and a higher sound is heard. One hears a so-called falsetto (Manninger and Fekete, 1982).

1.4 Correlation between osteoporosis, age and sex for hip fractures

Osteoporosis becomes an ever-increasing health problem world wide. It leads in older persons, starting in women already with the menopause, to an increased incidence of fractures. We are dealing with metabolic changes that involve all elements of bone tissue. Primarily we are facing a decrease of cancellous bone affecting its microarchitecture. Bone cannot resist even minor forces, to a point where fractures can occur spontaneously.

Two main kinds must be distinguished: the **primary** and the **secondary** (accompanying other diseases) **osteoporosis.** The primary kind predominates in hip fractures of elderly patients. It can be subdivided into two types: type I is the postmenopausal osteoporosis and type II the senile osteoporosis (Riggs and Melton, 1992; Demster and Lindsay, 1993). Different **risk factors** play an eminent role in the development of osteoporosis. They may aggravate an existing osteoporosis or they themselves may induce bone loss as in alcoholics, after a prolonged immobilization in a cast or in a fixateur externe (Lindsay, 1993; Szücs, 1995).

The clinical symptoms of osteoporosis are few. The diagnosis rests on **radiologic and laboratory examinations. Standard radiographs** are not suitable for an early diagnosis since they are unable to document a bone loss of 30 to 50% (Singh et al, 1970). A more conclusive indicator is the **radiomorphometric index,** a mathematical determination of the cortical and total bone thickness. Currently the index is determined either at the **metacarpal, femur or vertebral body.**

A modern method to diagnose the decrease in mineral content is the **Bone Densitometry.** Three different methods are known, the **photon or radioabsorptiometry,** the **quantitative Computer Tomography (CT)** and **ultrasound** (Mazess et al, 1988; Lindsay, 1993; Szücs, 1995). The latter two examinations have not found acceptance in Hungary due to their elevated costs and in instances of CT due to its relatively high exposure to radiation.

The principle of photon or radioabsorptiometry rests on the absorption of the Röntgen or isotope rays by bone and that in turn depends on its mineral content. These methods eliminate any interference by soft tissue. For mass screening and diagnosis of osteoporosis using mostly the distal radius the single **Photon or X-ray Absorptiometry (SXA)** has gained acceptance. The absorption by clinically more important and deeper lying bones such as femoral neck or vertebral body in respect to osteoporosis and its complications is better measured with the **Dual Energy Photon or Dual-Energy X-Ray Absorptiometry (DEPA, DEXA).** It establishes the mineral content of bone at the bony surfaces in direction of the beam expressed in g/cm^2 and is known as **Bone Mineral Density (BMD).** The value thus calculated in grams is the **Bone Mineral Clump (BMC)** (Riggs and Melton, 1988; Mazess et al, 1988; Szücs, 1995). As the values are age and sex specific they must be compared with average values of a population having the same age and sex. Any deviation from the normal value is known as the Standard Deviation (SD). The highest mineral content is recorded during the 30th year of life and is termed peak bone mass.

The osteodensitometric report contains a **Z-** and a **T-Score.** The Z-score represents the deviation of patient's bone mineral content from the average value of a group of persons of same age and sex, expressed as SD. The T-score, a more reliable indicator of fracture risk, shows the deviation from normal values of a young population (peak bone mass), also in SD. Accepting the recommendation of WHO the normal values for the Z-score are in the range +2 to –1 SD and for the T-score +1.5 to –1 SD. If the Z-score values deviate from the average values of the age and sex matched group by –1 to –2 and if the T-score values by –1.5 to –2.5, we are speaking of a **decreased mineral content.** If the values are greater than –2 resp. –2.5 we are dealing with a **manifest calcipenic osteopathy.** In clinical practice the term **severe osteopenia** is used. It denotes a condition where a manifest calcipenic osteopathy is accompanied by a typical osteoporotic fracture.

Biochemical tests can supplement the densitometric examination (osteocalcine in the serum, bone specific serum alkaline phosphatase, urinary hydroxyproline, urinary calcium/creatinine quotient). These laboratory tests play an important role in the differential diagnosis of various calcipenic osteopathias (Lakatos 1994).

The two types of primary osteoporosis, the **postmenopausal** and the **senile osteoporosis,** are characterized by different fracture patterns (Härmä et al, 1985; Meine, 1991; Poór, 1992; Szyszkowitz and Seggl, 1995). **Distal forearm and vertebral body fractures** are typical of the former type whereas **hip fractures** after insignificant trauma are characteristic of the latter type. Hip fractures merit special attention on account of complications secondary to confinement to bed (pneumonia, thromboembolism, decubitus, urinary sepsis) and in respect to the incidence of mortality that is still elevated nowadays. It is for this reason that trauma surgeons as well as researchers study epidemiologic aspects (Märtensson, 1963; Alffram, 1964; Solomon, 1968; Levine et al, 1970; Zetterberg and Andersson, 1979; Jensen, 1980; Lewinnek et al, 1980; Melton et al, 1982; Wallace, 1983; Falch et al, 1985; Lüthje, 1985; Jacobsen et al, 1990; Rasmussen, 1990; Rockwood and Horne, 1990; Lüthje, 1991; Martin et al, 1991; Dretakis et al, 1992; Hinton and Smith, 1993; Rowe et al, 1993; Kaastad et al, 1994; Sernbo et al, 1997a).

It remains to be clarified which factors play a role in the increasing incidence of osteoporosis. Without question, the **incidence of hip fractures increases exponentially with advancing age.** Ethnic, geographic and climatic factors are also involved. In addition, it is believed that the increase is also due to the decrease in activities and to the more comfortable life style of the population in the industrialized countries. More recent studies (Lips and Cooper, 1989; Rogmark et al, 1999) are unable to document for how long the increase of hip fractures will continue. This tendency depends primarily on two factors: the different proportion of age distribution and the success of osteoporosis prevention and treatment. Some data showing an increasing incidence of osteoporosis in the group of population of the same age (due to a more comfortable life?), parallel with an increased incidence of trochanteric fractures among the injured persons (advanced

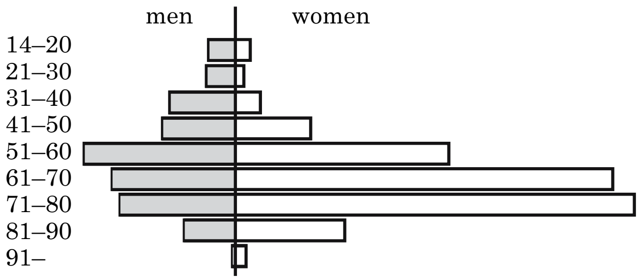


Fig. 25. Distribution of femoral neck fractures by age and sex in the former Trauma Hospital of Budapest (the later National Institute of Traumatology, Budapest) between 1940 and 1955 (1057 patients).
Most of the women belonged to the 71- to 80-year-age group and most men to the 51- to 60-year-age group (Manninger et al, 1960)

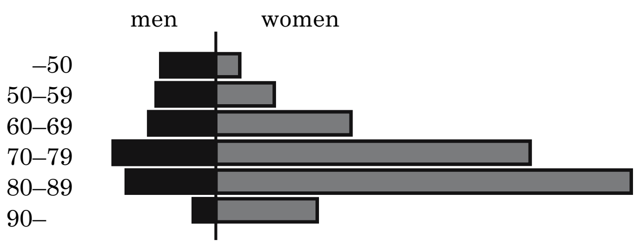


Fig. 26. Distribution of femoral neck fractures by age and sex at the National Institute of Traumatology, Budapest in 1990 (312 patients).
Most of the women belonged to the 80- to 89-age group and the men to the 70- to 79-age group (Laczkó et al, 1992)

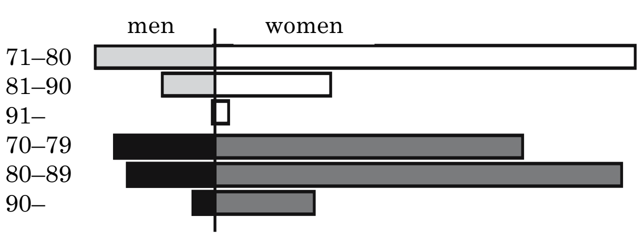


Fig. 27. Distribution of femoral neck fractures in patients over 70 years of age from figures 25 and 26.
This shift by one decade becomes even more evident

osteoporosis?) seem to point to a continued increase of hip fractures (Rogmark et al, 1999).

The hip fracture is a characteristic injury of women. The relation of women to men is 3–4:1. This can be explained in part by the fact that the number of elderly women is greater than that of elderly men. It has also been shown that the exponential increase of fractures in women starts approximately ten years earlier. Newer studies show, however, that the age specific incidence of fractures in men approaches that of women (Szepesi et al, 1991).

Our own investigations led to the same result. In our institute between 1940 and 1955 women aged between 71 and 80 years of age with femoral neck fractures represented the biggest group. The peak value in men was found at the age between 51 and 60 years. Forty years later, these values were seen in women one decade older and in men two decades older (Figs. 25–27).

Despite the fact that the average patients' age of the two main types of fractures, intracapsular neck fractures and trochanteric fractures, failed to show a marked deviation, many authors are of the opinion that the trochanteric fractures are due to a more severe osteoporosis. They interpreted this fact that in spite of a similar injury mechanism (fall) in the majority of cases two different fracture types resulted (Lawton et al, 1981; Elmerson et al, 1986; Ferris et al, 1987; Wirsing et al, 1996).

Currently two worldwide research projects are under way with the goal to prevent postmenopausal and senile osteoporoses. The efficiency of adequate hormonal therapy is evident in postmenopausal osteoporosis. The place of prevention in the senile group and thus the avoidance of hip fractures is still object of the study. An active physical and mental life style of elderly people slows the development of osteoporosis. It also slows down the mental and physical regressive changes (better reflexes) and thus plays an important role in the decreased frequency of fractures (Jarnlo and Thorngren, 1993).

In summary, we can state that epidemiologic and demographic studies have shown that an effective prophylaxis of senile osteoporosis has yet to be found. Consequently, we cannot expect a **marked decrease of hip fractures** during the next decades.

1.5 Selected biomechanical characteristics of the proximal femur

Already in the 19th century the construct of proximal femur has been compared to that of a lamppost or a crane as an example of functional adaptation (Müller, 1957).

The forces acting on the femoral head during normal gait are a multiple of the body weight. The abductor muscles of the weight bearing leg must counterbalance the body weight. The vector of the body weight goes through the center of gravity. The femoral head constitutes the center of a two-arm lever system, whereby one arm is the lever arm of the body weight and the other arm of muscle force of the abductors. The ratio of the two arms is 3:1. The resultant compressive force acting on the femoral head amounts to 4, in other words the pressure on the femoral head is four times greater than the body weight (Fig. 28).

The pressure increases during running and jumping. The design of the trabecular system of tension and compression trabeculae has developed in response to this strong demand.

The increased load on the femoral head during gait is exerted not only in the frontal plane. During flexion and extension of the hip as well during ab- and adduction the load bearing surface changes in relation to the anteversion of the femoral neck by 10 to 15°. According to Garden (1961a) the trabeculae can be compared to a system of uniform, elastic rods that rotate in the femoral neck. The projection of two independent trabecular systems into one plane is deceptive as it ignores the third dimension (Fig. 29).

Due to the functional adaptation the strength of bone is not identical at all points. It changes also with increasing age. **In children and puberty the entire head and neck is compact. The cancellous bone and the trabecular system develop only at the end of puberty.** With advancing age the spaces between the main trabeculae at the trochanter and in the neck increase to a point of forming a cavity (Ward's triangle). Contrary to this, the dense medial part of the neck **(Adam's arch)** as well the **calcar femorale** that form together the gutter are preserved to a major part. Also the **subchondral bone** maintains its compactness. **The lateral cortex is not as strong** and becomes even weaker cranially at the upper limit of the tension trabeculae. For this reason an implant positioned cranially and in varus position is unstable.

The optimal entry point for a nail or screw lies at the level of the lesser trochanter. Considering the weak lateral cortex a reinforcement is necessary, particularly in elderly patients. During the days of the Smith-Petersen nailing the lateral cortex often splintered while preparing the entry bed with chisels. As a result the nails backed out. To prevent such a backing-out, we designed a buttressing plate and later a screw connecting plate and nail (Fig. 30).

Already while introducing cannulated screws we attempted a similar additional stabilization. Until development of an adequate technique we performed the internal fixation with only two screws in the majority of patients. During the analysis of the first 100 patients we noticed in many patients a complaint of pain over the trochanteric area persisting for months. We attributed this to a cortical thickening around the caudal screw end **(biologic plate).** These experiences forced us to develop a small tension plate for anchorage of the caudal

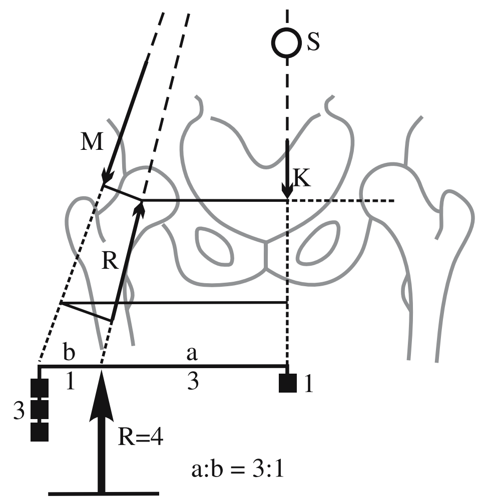
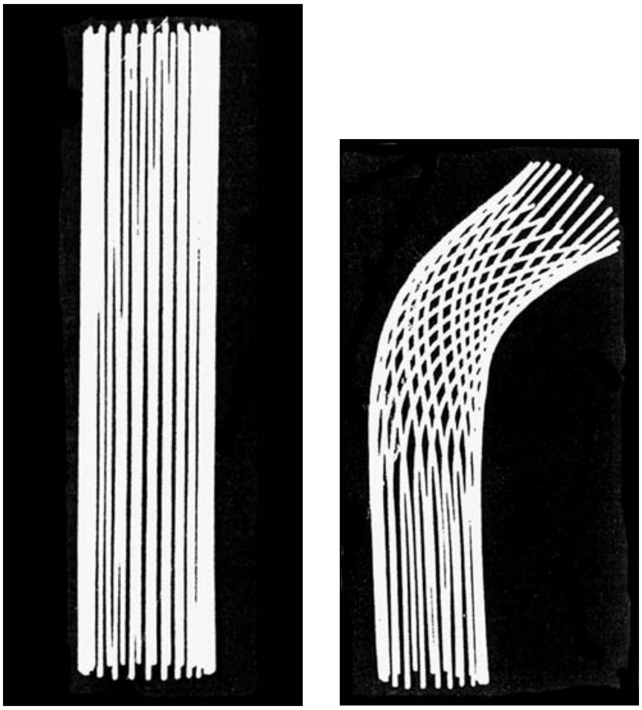
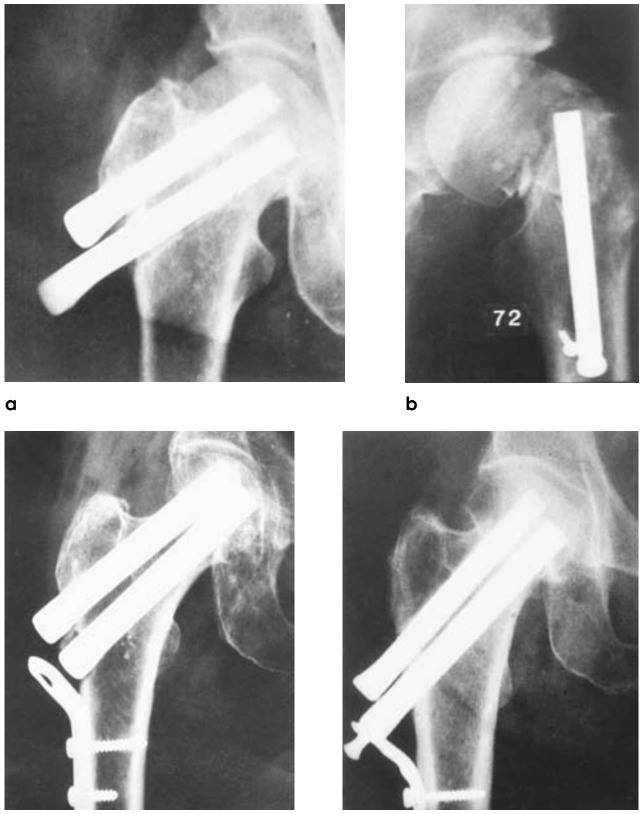


Fig. 28. Under normal anatomic conditions the correlation between body weight (load arm) and muscle power (force arm) is 3:1 during one-legged stance.
M = muscle power of abductors; K = body weight minus weight of weight bearing leg; R = resultant of forces (muscle power and body weight) acting on the femoral head; S = center of gravity (Pauwels, 1936)



a b

Fig. 29. Radiograph of a cylinder composed of parallel wires.
a. A projection of the straight wires on top of each other seems to look like a cortex; **b.** After torsion and bending of the wires a pattern appears that resembles a trabecular system (Garden, 1961a)



a b c d

Fig. 30. Concept of a distant buttressing of nailing.
a. Without anchorage and buttressing the Smith-Petersen nails backs out, the fracture tilts in varus; **b.** Buttressing with one screw proved insufficient, the nail backed out beside the screw; **c.** The buttressing plate prevented in general the backing-out of the nail but did not prevent a tilting of the head in varus; **d.** For this reason, a screw was designed to connect plate and nail (Manninger et al, 1961b; Manninger and Fekete, 1982)

screw, particularly in displaced fractures and old patients. It also prevented rotation up to a certain point. This additional plate acts as third **buttressing point** in neck fractures.

The caudal screw combined with the tension plate represents a two-arm lever at the intact Adams's arch and decreases the forces exerted on the femoral neck thanks to a longer lever arm. At the same time, it eliminates shear and tilting moments exerted on the fracture (see Figs. 15b and 241a).

We like to mention biomechanical peculiarities, their knowledge is necessary not only for performing an adequate internal fixation but also for a proper planning of osteotomies (for avascular necrosis or dysplasia) or insertion of endoprostheses.

The shape of the half-sphere of the bony acetabulum is completed by a cartilaginous rim that increases the stability. The range of motion of ball and socket joint is theoretically possible in all planes. It is, however, limited by the shape of the acetabulum and the femoral head and also by ligaments and other periarticular structures (Szentágothai and Réthelyi, 1985).

The articular cartilage is supported by cancellous bone. Both guarantee the necessary elasticity. The horseshoe- or half moon-shaped acetabular cartilage **(facies lunata) can** distend under loading, thus completing the congruency with the head. In other words, the joint can adapt to increased loading (Fig. 31).

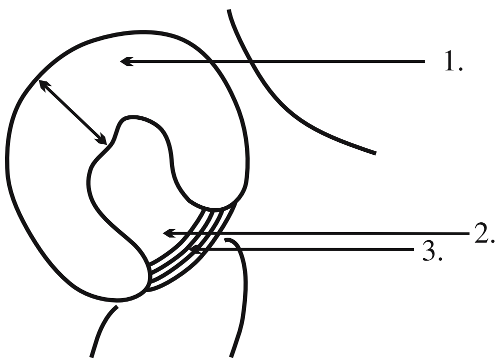


Fig. 31. Schema of the acetabulum.
The transverse ligament (3.) spans the horseshoe or half moon shaped, cartilaginous socket (facies lunata) (1.). Both encircle the acetabular notch (2.) (Müller, 1957)

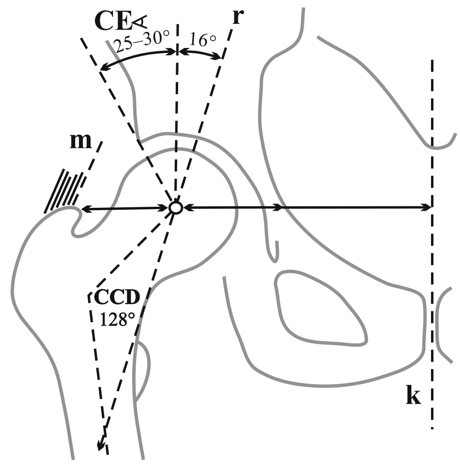


Fig. 32. Caput-Collum-Diaphysis (CCD-) angle under normal anatomic conditions.
CE = Wiberg's angle determining the coverage of the femoral head (measure for dysplasia). m = direction of pull of abductor muscles. k = midline of body weight. r = direction of resultant (Müller, 1957)

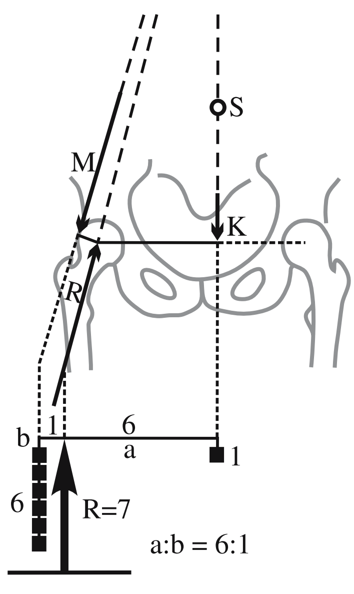


Fig. 33. In the presence of coxa valga the correlation between load arm and power arm is 6:1 during one-legged stance.
The muscle arm is shorter and requires a compensation of muscle power leading to an increased loading of the femoral head (For explanation of symbols see Fig. 28) (Pauwels, 1936)

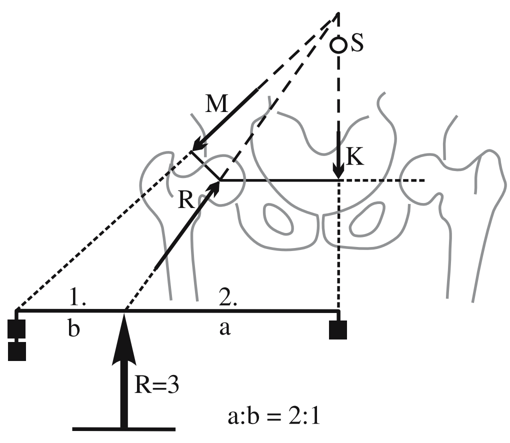


Fig. 34. In the presence of coxa vara the correlation between load arm and power arm is 2:1 during one-legged stance.
The muscle arm becomes longer, the necessary muscle force smaller and the loading of the femoral head less. (For explanation of symbols see Fig. 28) (Pauwels, 1936)

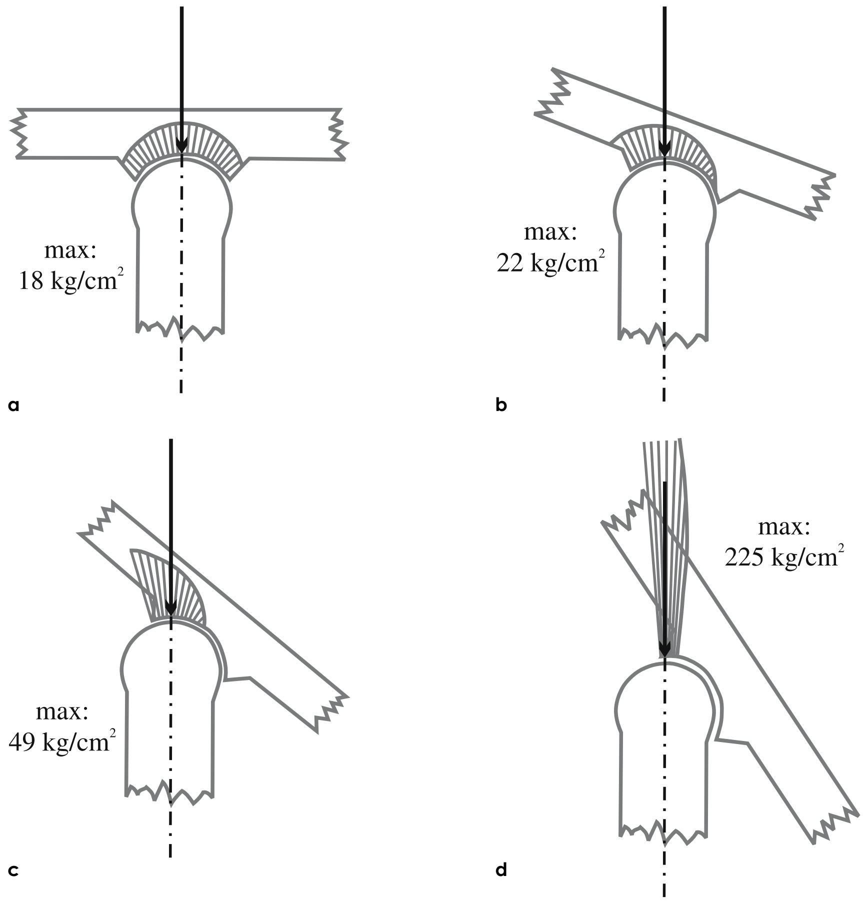


Fig. 35. Dependency between the degree of pressure forces on the head and the size of the contact area.
a. If the pressure acts on the center of the head, its distribution is even; **b–d.** The more the pressure moves toward the edge, the more the surface of pressure decreases and the unit of area of pressure increases (Pauwels, 1936)

The compressive forces act perpendicular to the surfaces of the healthy femoral head. Bending and shear moments act on the femoral neck (Pauwels, 1935). The size of these forces depends primarily on the neck-diaphyseal angle and thus on the length of the lever arm of the body weight and that of the muscle force of the abductors. The normal **caput-collum-diaphysis (CCD) angle varies between 128 and 135°** (Fig. 32) (Müller, 1957).

If the CCD angle is greater **(coxa valga),** the muscle pull increases due to shortening of the muscle arm and due to simultaneous decrease of the weight bearing surface. Consequently, the compressive forces acting on the head increase, in other words, the compressive forces per unit area of surface increase (Figs. 33, 35 and 36a).

If the CCD angle is smaller **(coxa vara)** the muscle arm becomes longer (the distance between tip of the trochanter and midline of the body increases) and the muscle pull and thus the compressive forces acting on the head decrease. At the same time the compressive forces per unit area of surface decrease (Figs. 34 and 36c).

The best joint among all joints of the human lower limb to perform a surgical intervention – namely **a varus osteotomy** – is most probably the hip, as **a marked reduction of the compressive forces** is obtained through a change in the lever arms. By performing a varus osteotomy one can prevent a collapse of the femoral head in instances of partial necrosis. More recently, it has become possible to restore the weight bearing surface of the

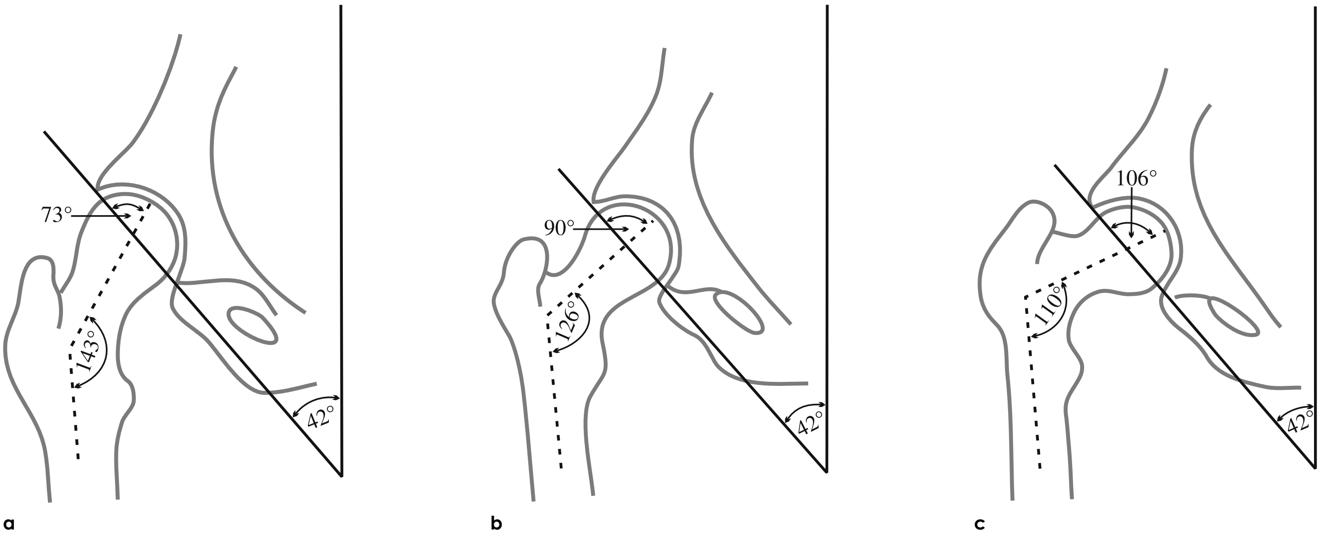


Fig. 36. Dependency of pressure area size to the CCD angle.
The pressure area measured under normal conditions (**b**), decreases in coxa valga (**a**), but increase in coxa vara (**c**). The plane of the acetabular opening has been assumed to be constant (42°) (Lanz, 1949)

head by a combination of an osteotomy with a vascular-pedicled bone graft (Fekete et al, 1994; Hankiss et al, 1997). Through rotation the already collapsed weight bearing surface can be relieved from being loaded. At the same time the weight bearing surface can be lifted and supported with a well vascularized transplant or morcellized cancellous bone. Through decrease of compressive forces the progression of osteoarthritis can be slowed down or arrested. This exemplifies the importance of biomechanical knowledge when planning a surgical intervention.

During gait the movement of the hip joint is not uniaxial. A slight internal and external rotation occurs during each step. If an incongruence of the ball-and socket joint is present, damage to cartilage and bone will ensue. A painful chronic synovitis will begin followed by osteoarthritis and later by extensive degenerative arthritis.

The iliofemoral ligament (Bertini or Bigelow) merits special attention. It is a strong ligament that runs in front of the hip joint from the anterocranial acetabulum to the base of the neck. It plays an important role during walking and more so during standing. Through its strong passive stabilization in slight hyperextension of the hip it decreases or replaces the muscle activity while standing. Paraplegic patients are able to stand and to walk thanks to this passive stabilizer.

1.6 The blood supply to the proximal femur

1.6.1 Anatomy of the arterial supply

For hundred years the idea prevailed that fractures of the femoral neck and their complications were foremost due to already inadequate vascularization of femoral head and neck that worsened with age (Cordasco, 1938). Nowadays, we are of the opinion that the **vulnerability of the supplying vessels is the deciding factor;** it is due to the intraarticular position of the 7 cm long portion of head and neck. During childhood this vulnerability is already present and is increased by the absence of anastomoses and the fact that vessels do not cross the growth plate (Trueta, 1957).

The most important vessel supplying the head is the **medial femoral circumflex artery** that is a branch of the deep femoral artery or, less frequently, the common femoral artery (Fig. 37, see also Fig. 7).

The extraarticular network of vessels plays an important role thanks to its richness of anastomoses. This network includes the **lateral femoral**

circumflex artery, superior and inferior gluteal arteries and also the **obturator artery** via the **Weathersby anastomosis** (see Fig. 41b) (Weathersby, 1959). Thanks to the anastomoses a blockage of the main artery has no catastrophic consequences in respect to femoral head necrosis. On the other hand, the rich extracapsular network of vessels confirms the clinical experience that per- inter- and subtrochanteric fractures are usually accompanied by considerable local blood loss.

The blood supply of the femoral head has been summarized by **Trueta and Harrison** (1953), **Sevitt and Thompson** (1965) and **Judet** and collaborators (1981) after decades of research (Fig. 38).

The **lateral epiphyseal vessels** (branches of the medial femoral circumflex artery and vein), that normally play an important part in the vascularization of the head, are particularly prone to injury (Fig. 39, see also Fig. 8).

The cranial retinaculum is attached tightly to bone and ruptures therefore easily torn during fracture, particularly in the presence of displacement. If the fracture is impacted, the vessels can become incarcerated (see Fig. 49). It can happen that the fracture line reaches the cranial part of the femoral neck at a point where the vessels already lie inside the bone (medial to Claffey's point). This leads to a rupture of the vessels (Claffey, 1960). It has been assumed that this fact plays an important role in the etiology of head necrosis. However, clinical results failed to confirm this assumption.

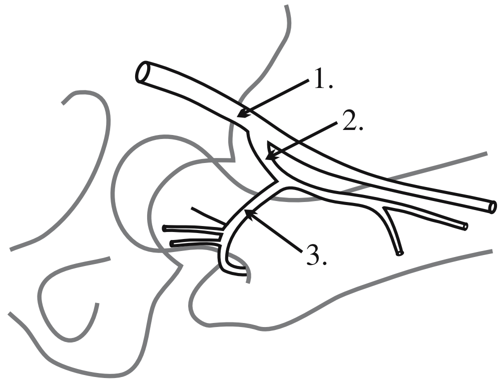


Fig. 37. Course of the principle arteries in relation to the proximal femur (as seen from the medial aspect of the left lower limb drawn after an angiography with the hip in slight external rotation).
Common femoral artery (1.), deep femoral artery (2.), medial femoral circumflex artery (3.)

The incidence of necrosis in Pauwels-III fractures, that start subcapital, is not much different from that in Pauwels-II fractures. Some authors even attribute the more favorable results to Pauwels-III fractures (Banks, 1962; Böhler, 1996). These authors explain this observation by the fact that the caudal fracture line does not disrupt the

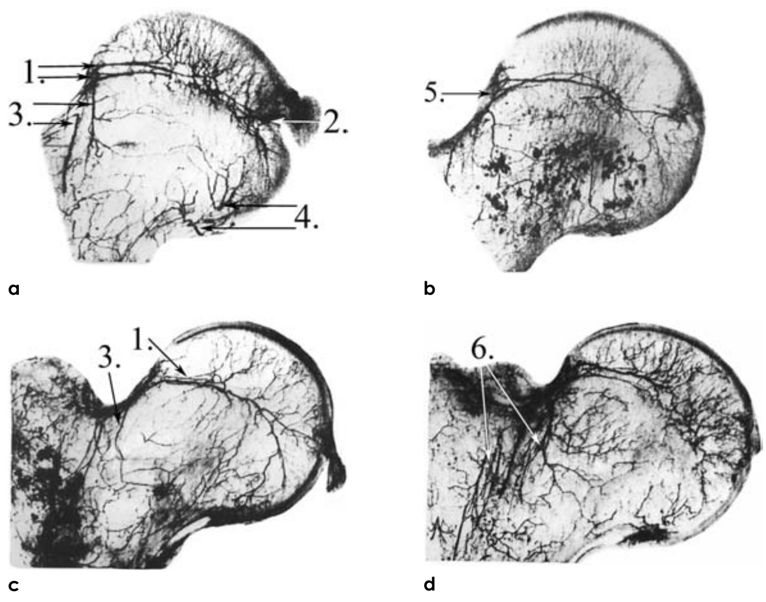
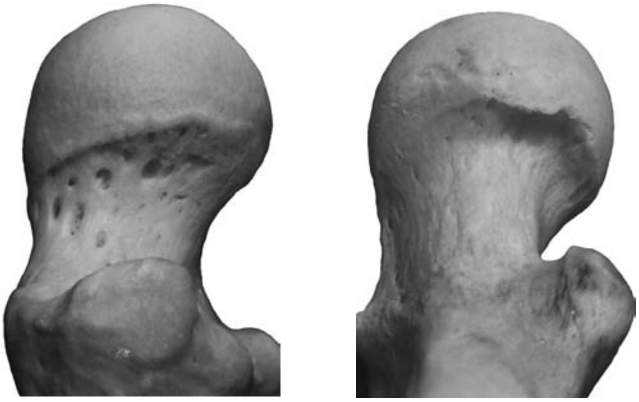


Fig. 38. Arterial supply to the femoral head.
a, b. Horizontal cut through a femoral head specimen of a 70-year-old man using Trueta and Harrison's technique (1953). One can recognize: lateral epiphyseal arteries (1.), medial epiphyseal artery (2.), superior metaphyseal arteries (3.), inferior metaphyseal arteries (4.) and Claffey's point (5).
c, d. Horizontal cut through a femoral head specimen using Sevitt and Thompson's technique (1966). The cut (d) shows very well the variation first described by Judet et al (1981) whereby the superior metaphyseal arteries separate from the lateral epiphyseal arteries (6.) only at Claffey's point. In such an instance a neck fracture can affect the supplying branch and also damage the blood supply to the neck (risk of necrosis)
(Manninger et al, 1979)



a b

Fig. 39. Importance of the lateral epiphyseal arteries.
In this specimen of a 40-year-old man the distribution of the supplying vessels is well demonstrated: **a.** At the cranial aspect multiple opening for vessel entrance averaging four to eight in number can be seen at the cartilage/bone junction; **b.** On the caudal aspect only a few small vessel entries are seen at the border of the head

loose network of vessels **(inferior metaphyseal arteries).** Consequently the major part of the head receives adequate blood supply through anastomoses (see Figs. 6 and 8).

In adults the **intraosseous metaphyseal vessels** supply also the femoral head. They originate mostly from the **inferior metaphyseal arteries** (and to a smaller part from **superior metaphyseal arteries)** situated in the caudal retinaculum. The importance of the intraosseous blood supply increases particularly during the revascularization after injury.

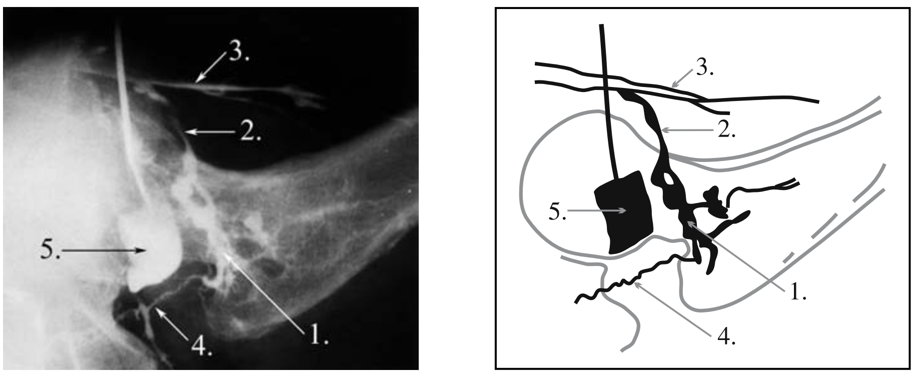
Vessels in the femoral head ligament supply normally the femoral head to different degrees. Their contribution is rather small. Their importance may play a **considerable compensatory role** in vascular disturbances after injury (Hulth, 1956; Manninger, 1963; Sevitt, 1964; Forgon and Miltényi, 1970; Manninger et al, 1979).

1.6.2 Anatomy of the venous network

(Pernkopf, 1989; Hulth, 1956; Manninger et al, 1979)

The venous blood drains from the double **circumflex femoral vein** system via the **deep femoral vein** into the **common femoral vein** and from the medial epiphyseal vessels via the **obturator vein** into **the** internal iliac vein. **The posterior** inferior and superior gluteal veins **play also an important role; they likewise drain into the internal iliac vein** (Figs. 40–43).

Hulth found that the venous network (with paired veins) runs closely to the arteries at the



a b

Fig. 40. Intraoperative intraosseous venography.
a. Lateral radiograph; **b.** Schema as seen from the medial side of the left lower limb drawn after an intraosseous venography with the hip in slight external rotation.
Recognizable are: medial femoral circumflex vein (1.), deep femoral vein (2.), common femoral vein (3.), the latter is paler due to the thinning. The double gluteal vein (4) is seen posteriorly. On the a.-p. film this vein is usually obscured by the cranial part of the head.
On the point of the needle entry the contrast material leached into the capsule (5.)

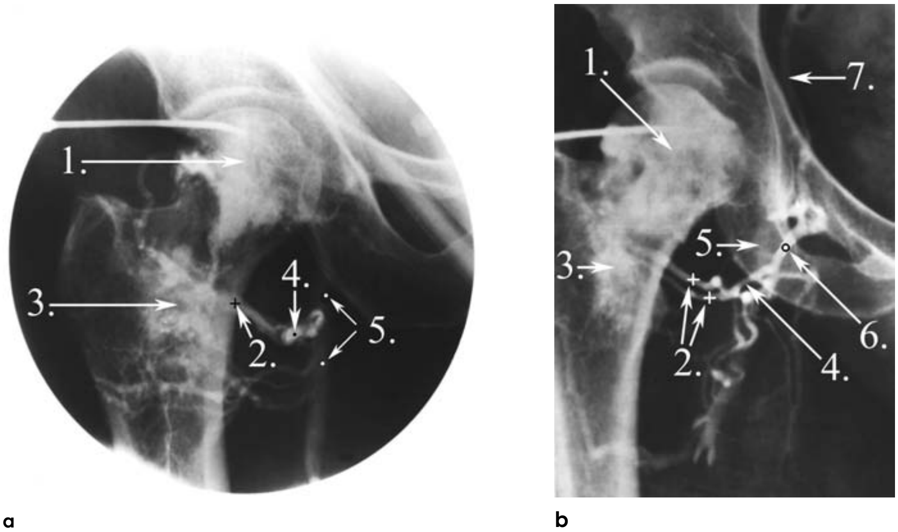


Fig. 41. Intraoperative intraosseous venography.
In both cases femoral heads are well filled but congested (1.). The double medial circumflex vein (2.) and the intraosseous drainage into the metaphysis (3.) are better seen in picture **b.** The deep femoral vein (4.) and the common femoral vein (5.) are better seen in picture **a.**, whereas the Weathersby anastomosis (6.) and the obturator vein (7.) are better recognized in picture **b.** The good filling is a positive sign

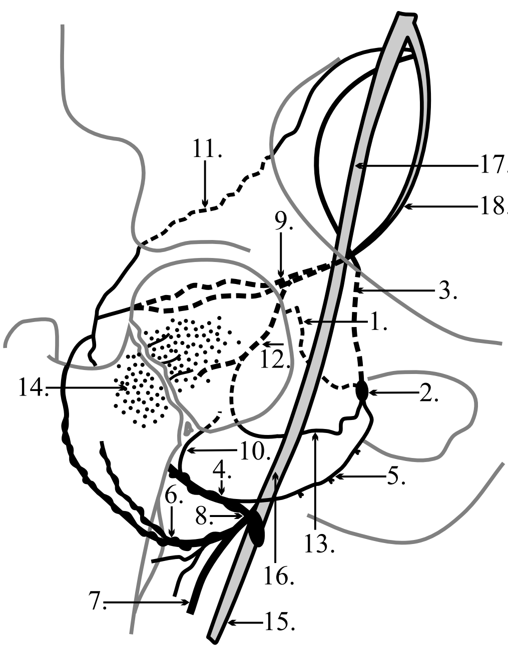
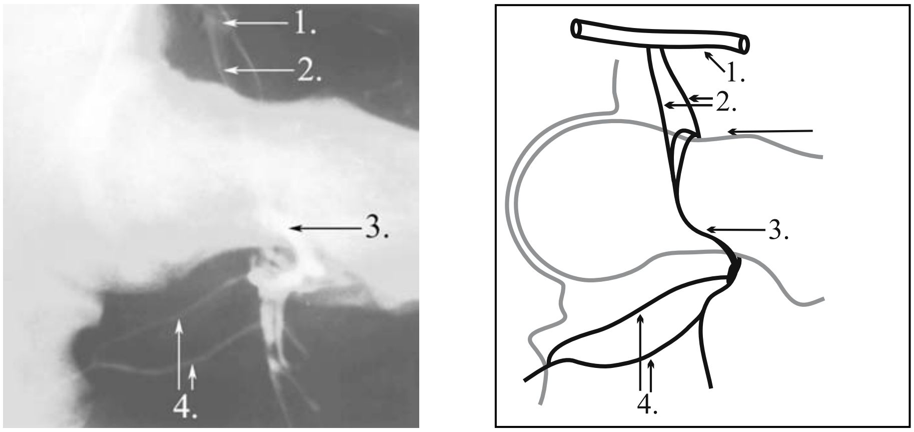
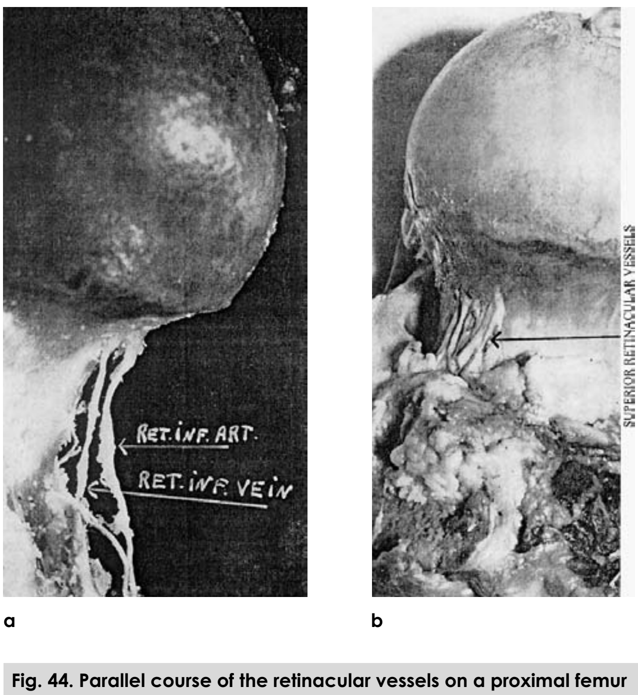


Fig. 42. Most frequent appearance of the entire venous network of the proximal femur. Schema. Result of many positive intraosseous venographies (Manninger, 1979).
The medial femoral vein (vena capitis femoris) (1.) flows into the obturator vein (3.) at a site (2.) where it meets the Wheathersby anastomosis (5.) originating from the medial femoral circumflex vein (4.). The lateral femoral circumflex vein (6.) empties in general into the deep femoral vein (7.). At this site one or several venous valves are found (8.). The superior gluteal vein (9.) is often doubled and communicates cranially via an anastomosis with vessels of the proximal femoral region. Caudally the inferior metaphyseal veins (10.) drain the venous blood from the head and neck into the medial femoral circumflex vein. The superior gluteal vein (11.) and the inferior gluteal vein (12.) run in a posterior direction whereby the inferior gluteal vein also flows into the obturator vein (13.). Often the intraosseous drainage (14.) is well visible with a flow of the contrast material through the fracture site into the trochanter. The principle collector vessel is the superficial femoral vein (15.). It empties into the common femoral vein (16.). The flow continues into the external iliac vein (17.) as well as into the internal iliac vein (18.)



a b

Fig. 43. The venous drainage in relation to the proximal femur.
a. As seen on lateral radiographs of the intraosseous venography; **b.** Schema (slightly external rotation of the left lower limb as seen from the medial side).
Common femoral vein (1.); deep femoral vein (2.); medial femoral circumflex vein (3.); pair of superior gluteal veins (4.)



a b

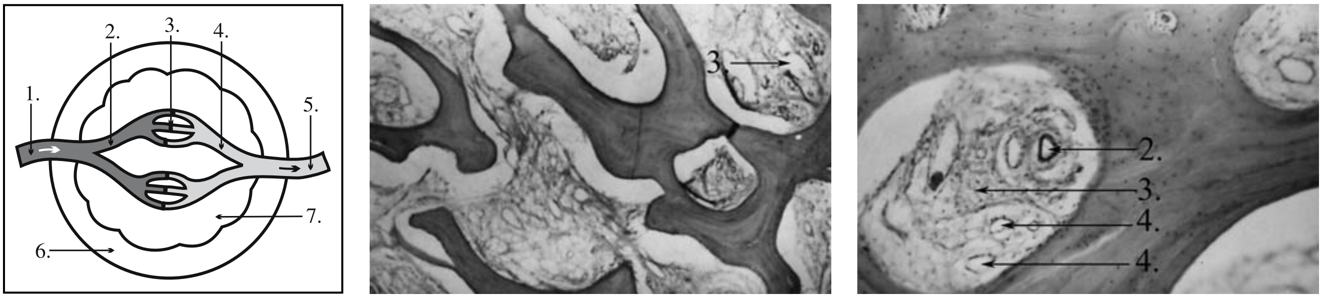
Fig. 44. Parallel course of the retinacular vessels on a proximal femur specimen. Original photograph by Hulth (1956)
a. Artery and vein of the caudal retinaculum side by side;
b. Vessels of the cranial retinaculum side by side

femoral neck. Therefore, indirect information about arteries can be gained, when we follow the veins (intraosseous venography) (Fig. 44) (Hulth, 1956). If the intraosseous venography shows intact veins, one can assume that the arteries are not damaged.

1.6.3 The capillary circulation

As in other organs arteries branch into arterioles that continue as capillaries; the latter consist of arterial and venous portions. Special to the intraosseous circulation is the fact that cancellous bone has a honeycomb structure with rigid walls preventing dilation of draining vessels. The walls of the cancellous bone are lined with osteoblasts, the spaces are filled with red marrow in children and with yellow marrow in adults. On the other hand, similar to liver and spleen **sinusoids,** vessel enlargements without adventitia are found here that are responsible for the nutrition of bone tissue (Fig. 45).

The significance of **intraosseous drainage,** interrupted by the fracture, has been highlighted in the last years (Kazár et al, 1992; Kazár and Manninger, 1993). The development of avascular necrosis often depends on the **increased pressure** in the femoral head. Its etiology includes: (1) compression of sinusoids due to an altered fat metabolism



a b c

Fig. 45. Capillary network in the proximal femur.
a. Schematic representation of sinusoids according to Solomon (1990). Structure of a sinusoid: artery (1.), arteriole (2.), network of capillaries without adventitia (3.), venule (4.), vein (5.), bone (6.), marrow (7.); **b, c.** Sinusoids in the cancellous bone of the head. Histologic sections with different magnifications.
Sinusoids are found between the trabeculae. Greater magnification (**c**) allows to recognize better sinusoids, five thin-walled venules and a small arteriole in an intertrabecular space. At the wall of this space osteoblasts can be seen as small dots; osteocytes are seen in the bone (Láng and Nagy, 1951).
In the presence of a fracture, a congestion develops in the inelastic sinusoids; it leads to an increase in pressure similar to a compartment syndrome

(alcohol consumption, Gaucher's disease, steroid medication), (2) **venous congestion due to post-capillary blockage and increased pressure secondary to displaced neck fractures with damage to the intraosseous circulation in the femoral metaphysis** (Arnoldi and Linderholm, 1969; Arnoldi et al, 1970; Arnoldi and Linderholm, 1972). The **immediate reduction and internal fixation** is not only important for the restoration of circulation but also for the prevention of **closure of fractured cancellous bone surfaces.** On the condition of early and good reduction and adaptation of fragments **the congested blood can drain through the fracture gap.** As in adults the circulation of epiphysis and metaphysis is not anymore separated by the physis, a drainage of the femoral head through the metaphysis is possible (see Figs. 55 and 56).

Chapter 2

PATHOLOGY OF FEMORAL NECK FRACTURES

2.1 General pathology

The anatomic peculiarities of the proximal femur, the intra-as well as the extraarticular location of the femoral head, the vulnerability of the vessels, the anteversion of the neck and the senile regressive changes explain the characteristic **pathology of fractures: localization, direction, type, displacement, circulatory disturbances** and the threatening problems of local complications. Although not belonging directly to the pathology of the fracture, the **general condition of the patient** influences considerably the chances of healing (Ceder et al, 1979; Molnár et al, 1979; Sartonetti et al, 1995). Concomitant diseases and changes that increase in severity and frequency with age are of **decisive importance** when deciding on the type of surgery and rehabilitation.

In the pertinent literature a distinction is made between **medial subcapital, mid cervical and basal fractures.** These terms, however, are often not used accurately; this explains the difficulties while attempting to identify the fracture type. In general, the fracture line lies between cranial and middle third of the neck (Klenerman and Marcuson, 1970; Parker and Pryor, 1993); it may extent in a caudal direction secondary to comminution. A displacement of the fracture line cranially up the neck/head junction due to resorption and wear is mostly seen in remote fractures. In younger patients, on the other hand, lateral fractures are prevalent.

In our opinion also expressed by several other authors the **type of fracture** (smooth, jagged, simple, comminuted) has a great influence on the stability of fixation; this must be taken into consideration when choosing the kind of internal fixation (Scheck, 1959; Fekete et al, 1989b; Parker and Pryor, 1993) (Fig. 46).

During the fifties and sixties guide wires could only be introduced under intraoperative radiographic control. Since there was no overlapping with the implant present, the fracture gap could be well identified in the majority of cases as a jagged fracture surface. A cortical fragment broken out either caudally or posteriorly, even multiple displaced fragments, can be detected. Avulsed fragments in the entire fracture gap can be seen either anteriorly or cranially (Scheck, 1959; Kazár, 1963; Fekete et al, 1989b). We classify these fractures as fractures with zones of comminution. Their closed reduction is fraught with problems. In postmortem specimens it was even impossible to fit the fragments together under direct vision. The defect caused by loss of small fragments of the comminuted neck during preparation is well seen in these cadaver specimens (Figs. 47 and 48).

Fractures in the elderly lead to a bone defect secondary to a fragmentation of the posterocaudal cortex and a compression of the thinned trabeculae. The cortical defect cannot be bridged by callus formation as the neck is not covered by a periosteum (Pauwels, 1935; Pugh, 1955). Usually the result is a consolidation through an **impaction of the fragments amounting to** 3–8 mm, sometimes to 10–15 mm or even 20 mm (Pugh, 1955; Manninger et al, 1961a). This fact plays an important role when deciding on the kind of internal fixation.

It should be emphasized again that the **cause of complications does not lie** in the fact of a preexisting inadequate or absent blood supply to the femoral head in the elderly (Cordasco, 1938). Also dogmatic statements in the past that the fate of the neck fracture is decided at the time of injury given the primary disturbance of blood supply, cannot be accepted nowadays (Shin and Wang, 1991). The displacement of fragments can worsen due necessary care during a delay of surgery or the non-compliance of the elderly patient. The fracture becomes unstable as the jagged surfaces of the fragments wear down during movements of the lower limb. This leads to variable degrees of transient or permanent damage of the vessels supplying the head (Forgon, 1970) (Fig. 49).

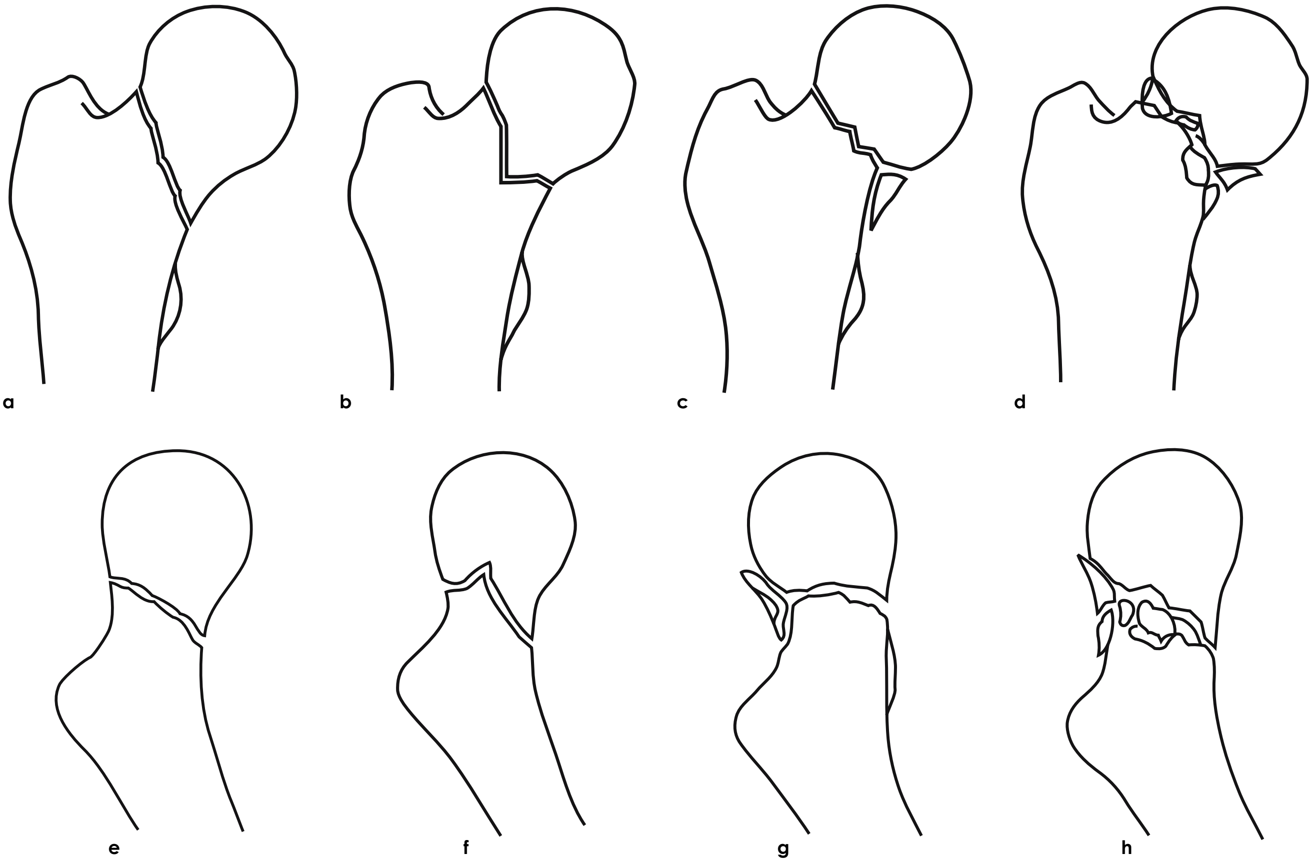


Fig. 46. Main types of fracture lines at femoral neck. Schematic representation of a.-p. and lateral films (Fekete et al, 1989b).
a, e. Smooth fracture surfaces; **b, f.** Jagged fracture surfaces (rare); **c, g.** In the majority of cases at least one fragment is avulsed, usually cranial and posterior; **d, h.** Frequently multifragmentary and comminuted fractures are present

Practical experience supports the importance of **an immediate reduction and internal fixation.** In addition, experimental and clinical data point to two other advantages of an immediate, adequate reduction (inside six hours): **prevention of progression of vascular disturbances and timely liberation of incarcerated blood vessels.** Through adaptation of the fracture surfaces the retinacular and metaphyseal drainage can be restored or improved. The decompression of the venous congestion leads also to **a decrease of the intraosseous pressure restoring the blood supply to the femoral head in the majority of cases.** This allows lowering the number and the severity of late complications (Forgon, 1970; Hertz and Poigenfürst, 1982; Pelzl, 1982; Swiontkowski et al, 1984; Barabás and Manninger, 1989; Manninger, 1989; Manninger et al, 1989; Renz et al, 1991; Manninger et al, 1993; Bonnaire et al, 1995).

The occurrence of **mechanical complications** such as loss of reduction and screw avulsion depends foremost on the **severity of osteoporosis.** In the presence of trabecular atrophy a stabilization of the fracture with classical methods – a sole implant – cannot be obtained (Forgon, 1967). In the elderly patient the avascular necrosis presents an as serious problem as the loss of reduction and pseudarthrosis. The necessary stability can only be obtained with an internal fixation that respects the anatomic and pathologic conditions and the three point buttressing (Brittain, 1942; Garden, 1961b; Harty, 1965; Parker and Pryor, 1993).

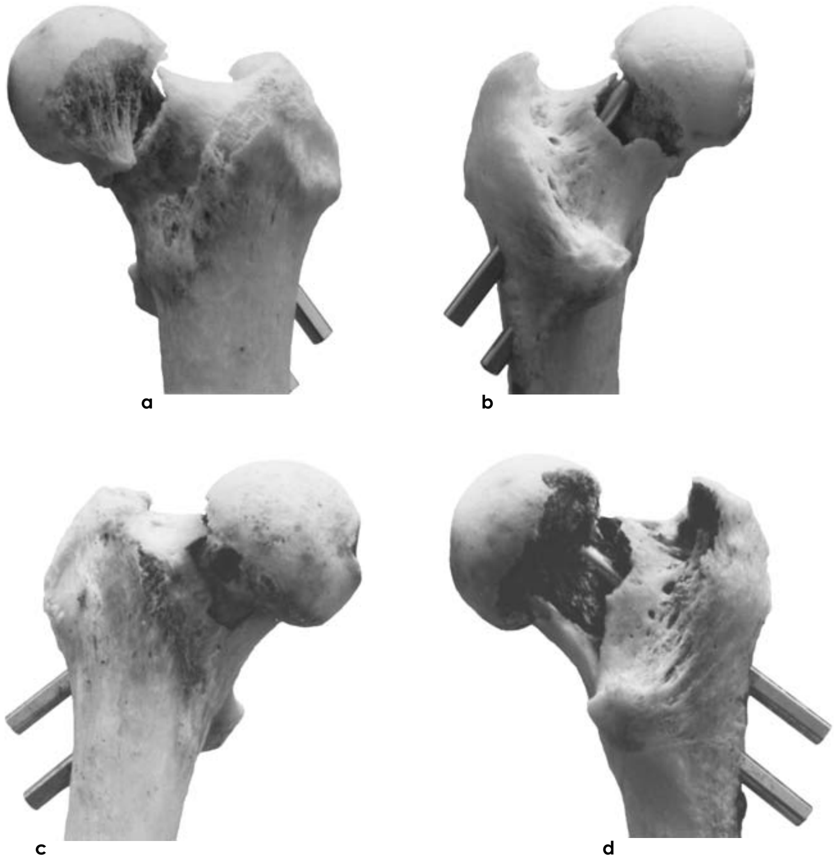


Fig. 47. Comminuted neck fracture. Specimens of two deceased patients originally treated by screw fixation (the avulsed fragments are missing). **a.** A fracture of the left neck with small anterior bony defect (incorrect reduction); **b.** Posteriorly big fragments are avulsed. There is barely a bony contact area; **c.** Fracture of the right femoral neck with big fragments avulsed from the anterior cortex; **d.** The entire neck half is missing posteriorly. Close reduction of these fractures is usually impossible. They should not be internally fixed after unsatisfactory reduction; a reduction after opening of the joint is preferable. If this does not lead to a satisfactory position (good adaptation of the fracture surfaces), an arthroplasty is indicated

Adult bones are very strong; they break only after major impact. In elderly persons the bone of the proximal femur is weaker due to atrophy and decrease of trabeculae, even in the absence of pathologic processes with the result that bone breaks easily after a simple fall. These fractures should not be considered pathologic **(typical fracture).**

The femoral neck fracture happening without a fall is seen by many authors as a special type and called a **spontaneous fracture** (Jefferey, 1962; Freeman et al, 1974; Sloan and Holloway, 1981; Parker and Tremlow, 1997). The history reveals in the majority of these patients that an unaccustomed loading and protracted hip pain preceded the fracture; therefore they must be considered as **stress fractures** (Ernest, 1964; Erne and Burckhardt, 1980; Kaltsas, 1981; Ochy and Vogt, 1985). **Fractures caused by a pathologic process** – cyst, osteomalacia, Heine-Medin disease (poliomyelitis), benign or malignant tumors, systemic diseases – that weaken the bone and occur after a minor trauma, cannot be called spontaneous fractures.

In the past decades two local factors, **the angle of inclination of the fracture** (Pauwels, 1935) and the **degree of displacement** (Garden, 1961b) have received such an attention that we have to consider them separately. In the section of this chapter

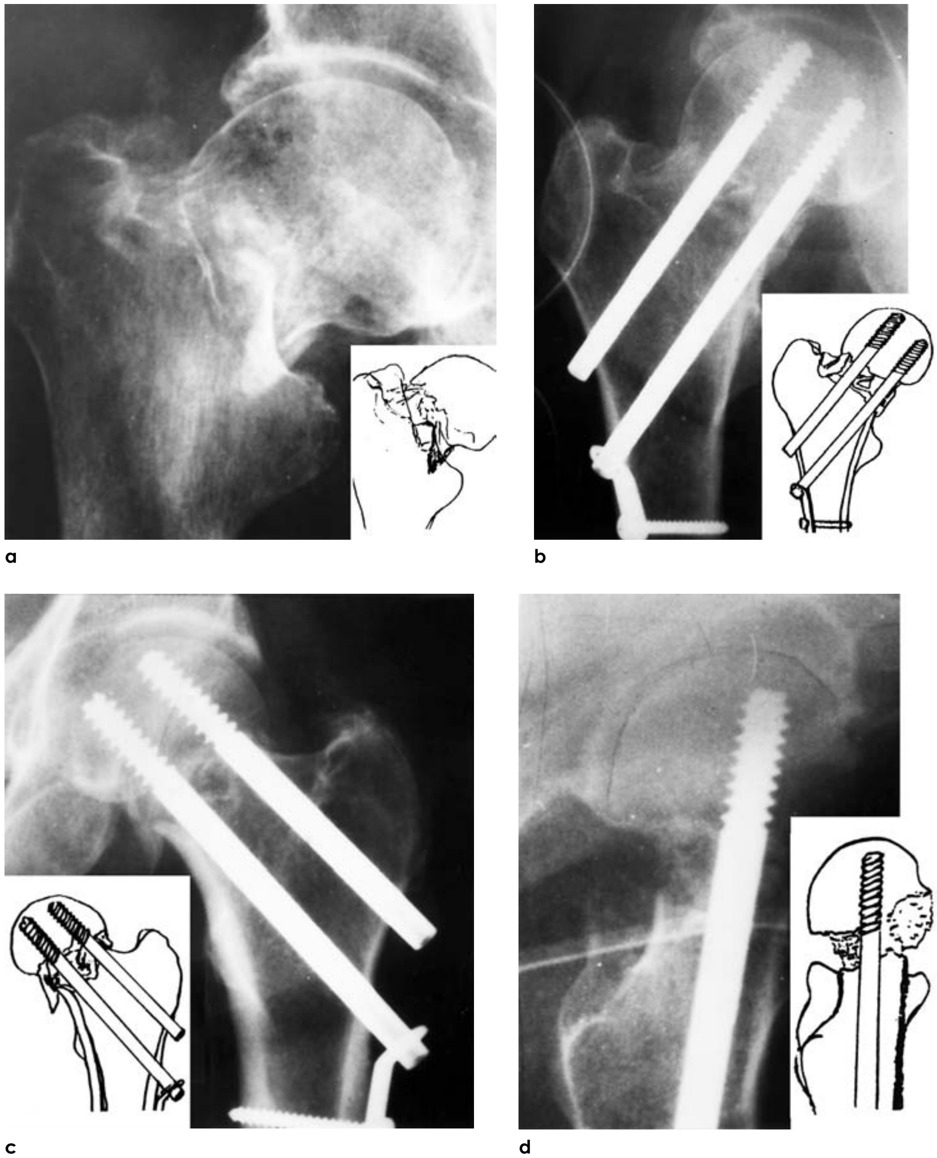
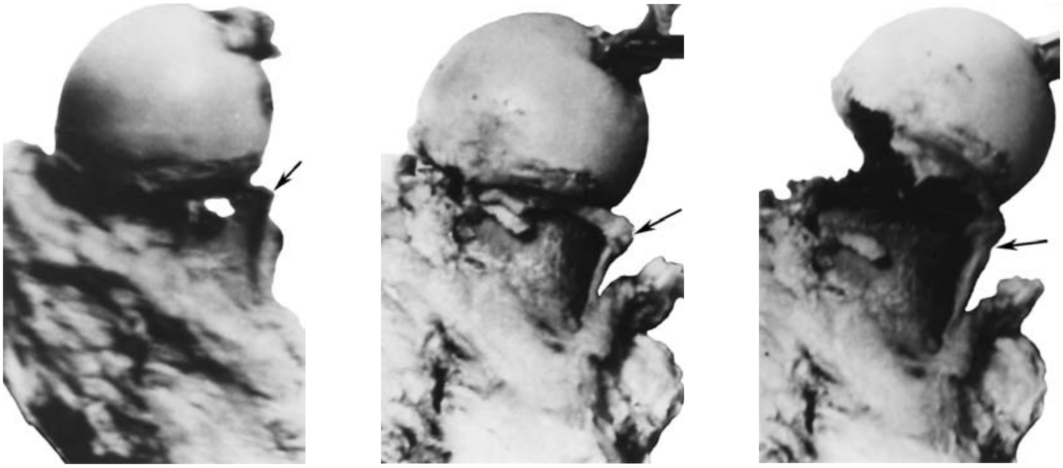


Fig. 48. Multifragmentary and comminuted fractures of the neck.
a, b. A.-p. radiograph and schematic representation of a neck fracture with multiple fragments (**a**) before, and (**b**) after internal fixation;
c, d. Postoperative a.-p. (**c**) and lateral (**d**) radiographs and schematic representation of a comminuted fracture

we describe the presently accepted **classifications of neck fractures** and in this context we elaborate also in details special pathologic aspects of the **undisplaced as well as neck fractures impacted in valgus.**

When treating neck fractures, the role of **concomitant and regressive changes** and their increasing incidence with age should not be neglected; according to the pertinent literature these changes are found in the majority of injured persons (Molnár et al, 1979; Sartonetti et al, 1995). They result in death **within six months to one year** in a considerable percentage of patients either directly or due to complications (Laczkó et al, 1993). This should be kept in mind when deciding on the method of treatment.



a b c

Fig. 49. Representation of kinking of the caudal retinaculum in cadaver specimens (Manninger, 1963).
a. If the neck fracture is maintained in valgus, the still intact caudal retinaculum is put under tension and rides on the neck stump;
b. If head and neck are aligned properly (reduced), a loosening of the retinaculum can be observed; **c.** While lifting the head (original displaced fracture position) the big defect and the tensioned anterior border of the retinaculum are well seen. (The arrows point to the retinaculum)

2.2 Stress- and spontaneous fractures of the femoral neck

The femoral neck fracture usually occurs after an adequate trauma, unexpectedly and suddenly like any other fracture. Some patients, however, report at admission and before the diagnosis is established that they had felt hip pain and loss of function (limping, weakness) during the preceding weeks or months; radiographs do not show a recent fracture but already signs of ongoing repair.

This injury is termed a **stress fracture (fatigue fracture)** in the pertinent literature. The mechanism is explained by the fact that cortex and trabeculae of a healthy bone do not break at the same time **but in succession** after an unaccustomed repetitive overloading in the absence of previous training. The end stage is a complete fracture eventually with displacement (more severe symptoms).

Stress fractures of the neck were first described by Asal (1936). During the subsequent years they were only sporadically described (Branch, 1944; Bingham, 1945). Three decades later Ernest (1964) observed fatigue fractures in 13 young recruits. Some became permanently invalid. Jörg Böhler (1968) observed during a visit to army hospitals in the United States during the sixties quite a number of unfit youngsters with fatigue neck fractures. They were never involved in sports, were driven everywhere by car and were admitted to hospital after unaccustomed marches.

Since that time numerous publications listing several patients have appeared (Erne and Burckhardt, 1980; Kaltsas, 1981; Menoman et al, 1981; Ochy and Vogt, 1985). This type of injury is seen typically in young recruits who are not accustomed to the demands of long marches with heavy packsacks. Similar observations were made in athletes and marathon runners (Kerr and Johnson, 1995). Fatigue fractures have also been described after total knee replacement caused by altered biomechanics and increased activities.

Devas (1965) distinguishes between different types of fractures that initially can be separated only with great difficulty: the transverse and the compression type.

The more frequent **transverse fractures,** later called **distraction fractures,** open up cranially **when not treated and subsequently displace** (Figs. 50 and 51b).

The **compression fractures** usually run medially, at Adam's arch, close to the lesser trochanter.

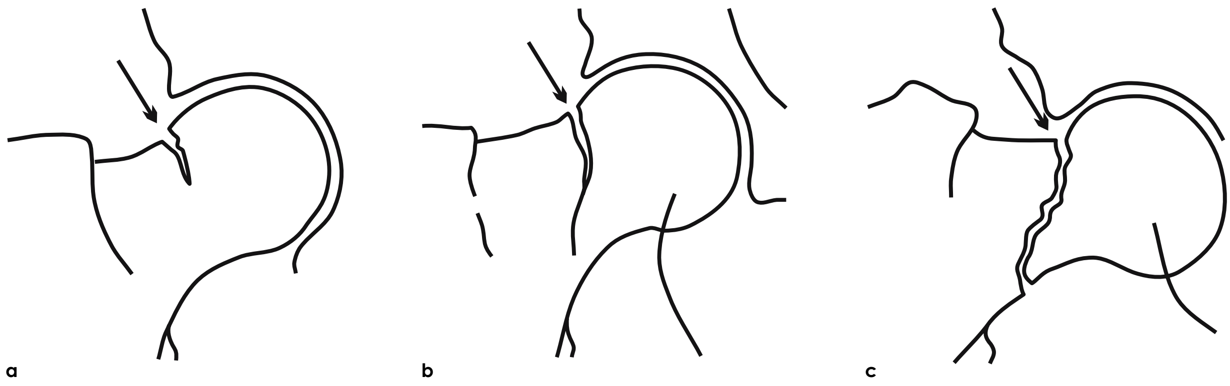


Fig. 50. The three phases of the transverse fatigue fractures of the femoral neck (Schema based on radiographs).
a. Gapping of the cranial cortex; **b.** Incomplete fracture; **c.** Complete fracture

Typical for these fractures is the simultaneous occurrence of progression and healing. Radiographs demonstrate that next to the fracture line an intraosseous callus soon appears, initially seen as a small band of ill defined density with the fracture line in its center. The head tilts slightly in varus. The result of both processes is a spontaneous healing or a healing occurring under conservative treatment. Should the pain increase, immobilization is indicated (Erne and Burckhardt, 1980; Kaltsas, 1981; Menoman et al, 1981; Tountas and Waddell, 1986) (Fig. 51a).

Fatigue fractures can exhibit the following clinical features:

(1) Normal radiographic appearance of hip in both planes, positive bone scan;
(2) Crack of one cortex. Medial: compression fracture. Lateral: distraction fracture (usually with separation);
(3) Intraarticular fracture without displacement;
(4) Displaced fracture.

(The third and fourth features are usually only seen in distraction fractures.)

In elderly persons it may happen that hip pain without history of injury appears weeks and months before a diagnosis of fracture is made (Jefferey, 1962; Freeman et al, 1974; Sloan and Holloway, 1981; Parker and Tremlow, 1997). In these instances a complete fracture appears gradually due to bone atrophy **without a fall during normal activities (walking).** Some authors also call this fracture a fatigue fracture but other authors include them in the group of **spontaneous fractures,** as porotic bone cannot be considered to be healthy (Jeffery, 1962; Parker and Pryor, 1993; Bucinto et al, 1997; Parker and Tremlow, 1997) We believe, however, that this explanation is wrong as in this case a great number of hip fractures would belong to the **pathologic fractures.** Contrary to the well known Latin expression "senectus ipse morbus" we are of the opinion that the **age** and the senile osteoporosis associated with it, cannot be **regarded as a pathologic process.** Some authors speak of a spontaneous fracture when – according to the patient's statement – the fall is **not the cause but the consequence** of the fracture (due to the advanced osteoporosis) (Sloan and Holloway, 1981). The reported incidence is around 5% (Parker and Pryor, 1993). Such a mechanism is difficult to ascertain in clinical practice.

The symptoms can precede the radiologic appearance by weeks and months. Uncharacteristic hip or groin pain increased by activity is reported. The interference with the range of motion is minimal and hip movements are painful at the end position only. These features distinguish them from synovitis. In the patient's history we often find a preceding strenuous activity (hard garden work) being mentioned. If we fail to consider early on the possibility of a fatigue fracture, it is possible that the patient will **fall because of the increasing pain.**

Fig. 51. Stress fractures of the femoral neck. a. Compression fracture; **b.** Transverse (distraction) fracture

A displaced fracture is then seen. If the radiographs are normal, tomography should be done. If it fails to confirm the diagnosis and the symptoms persist, a bone scan is recommended as it can confirm a fatigue fracture with a 90% accuracy.

Senile stress fractures occur twice as often in women than in men. In one third of these patients with hip fracture a compression fracture of a vertebral body is already present. In many patients a varus position of the femoral head and neck is also seen.

Summary: We call a break a **stress fracture** when it has occurred after a strenuous activity but without a well-defined trauma. We term a break **pathologic fracture** when it occurs secondary to a local or systemic disease but without a well-defined trauma.

We avoid the term **spontaneous fracture in our practice.** On one hand, many fractures happen without a fall but are caused by stress or pathologic changes. Consequently they do not belong to this group. On the other hand, for many injuries called spontaneous without good reason a preceding slight injury or overloading can be usually documented, both sufficient in older persons with osteoporosis to cause a fracture. Therefore, this break can be included in the group of ordinary or fatigue fractures. If, however, the degree of osteoporosis is severe (greater than that for the patient's age), we must speak of a pathologic fracture and examine and treat the patient accordingly.

The major problem of stress fractures lies in the **difficult diagnosis often made too late.** More than one publication reports that in **30–40% of analyzed patients the diagnosis had not been made during the first visit.** Weeks, sometimes months later, a displaced fracture is diagnosed which under optimal circumstances is minimally displaced and already in the process of remodeling (Menoman et al, 1981; Ochy and Vogt, 1985). Minimal displacement is rather typical for elderly patients and remodeling for younger individuals.

2.3 The pathologic neck fracture

A fracture of a diseased or damaged bone, usually after trivial trauma, is rare at the femoral neck.

The causes for pathologic fractures usually are:

(a) **Cysts** (juvenile unicameral retention cysts or solitary cysts in adults) (Ehlers and Grimschl, 1960; Cotta and Roche, 1984; Berentey, 1989);

(b) **Osteomalacia** such as rickets in adults and osteomalacia (metabolic or nutritional), today very rare (Cotta and Roche, 1984);

(c) **Osteopetrosis** (Albers-Schönberg- disease, usually in children (Hasenhuttl, 1962; Cotta and Roche, 1984; Greene and Torre, 1985);

(d) **Osteosclerosis,** usually in adults (Hinkel and Beiler, 1955);

(e) **State after poliomyelitis,** usually after many years (Cotta and Roche, 1984);
(f) **Paget disease** (Tachdjian et al, 1959; Ehlers and Grimschl, 1960);
(g) **Osteogenesis imperfecta** (Ehlers and Grimschl, 1960);
(h) **Prolonged steroid therapy** as for rheumatoid arthritis (Ehlers and Grimschl, 1960);
(i) **Osteoid-osteoma** (Tachdjian et al, 1959; Ehlers and Grimschl, 1960);
(j) **Tumors. A primary** tumor is rare (Ehlers and Grimschl, 1960; Cotta and Roche, 1984). During 50 years we did not find a single one. **Metastases** are more frequent (Tachdjian et al, 1959; Ehlers and Grimschl, 1960; Poigenfürst et al, 1968; Cotta and Roche, 1984; Berentey, 1989; Mutschler et al, 1989; Friedl, 1995). Metastases of breast, bronchi, prostate, thyroid cancer as well as of hypernephroma into long bones, mostly the femur, are prevalent.

2.4 Circulatory disturbances

The blood supply to the femoral head is usually disturbed in the presence of intraarticular fractures. In extraarticular fractures the extensive network of anastomoses is able to compensate even for the injury of major vessels.

The most frequent and most severe injury of intraarticular fractures occurs through rupture, incarceration or kinking of vessels affecting usually the cranial retinaculum. The vessels of the femoral head ligament remain always intact and those of the thicker loose caudal retinaculum often intact. The latter vessels are important during reduction (Fig. 52, see also Fig. 49).

A tear is irreversible. If, however, the continuity of the vessels remains intact, the circulatory disturbance caused by torsion, kinking or bruising secondary to displacement is reversible during the early phase (Fig. 53).

Woodhouse (1964) observed in animal experiments that a disturbed perfusion becomes irreversible **six hours** after interruption of the femoral head supply (occlusion of all irrigating vessels) since after this time **cells of the bone tissue start to die.** If this limit has been transgressed, any restoration of blood supply is in vain. One has always to anticipate a necrosis (Rösing and James, 1969; Forgon, 1970). In the clinical situation, a total ischemia never happens as part of supplying vessels; foremost those of femoral head ligament remain intact in spite of a marked displacement. For this reason a consolidation of a several days-old fracture is possible without late complications (see Figs. 158 and 160).

Necroses of limited extension can heal. More extensive vascular damages will result in a **collapse of the femoral head** or in a **necrosis accompanied by pseudarthrosis** of the neck.

In the view of some authors a **compression of the retinacular vessels** is foremost responsible for the development of necrosis. They believe that this compression is due to an increased intraarticular pressure caused by **an intraarticular hematoma.** They claim that the decreased neck/head circulation as seen during scintigraphy confirms their opinion (Strömqvist et al, 1985; Wingstrand et al, 1986; Schwarz and Leixnering, 1989). **The intraarticular pressure** does not reach **average arterial pressure** even in the presence of a tension hematoma. Therefore, the pressure can at the best decrease the blood supply (Drake and Meyers, 1984; Maruenda et al, 1994). **The walls of the veins** are thinner and the venous pressure is lower. **The intraarticular hematoma** rather decreases or interrupts the **venous drainage** from the femoral head.

Numerous authors investigated the changes of **intracapsular pressure** in the presence of an intact capsule in **various positions of the limb** – and this independent of the amount of intraarticular fluid collection (Soto-Hall et al, 1964; Ewerwahn and Suren, 1970; Vegter, 1987; Strömqvist et al, 1988; Bonnaire et al, 1998). The highest pressure is seen during internal rotation and extension; the values are lower during flexion and slight external rotation. Should an operation been delayed due to the general condition of the patient, this fact must be taken into consideration during the necessary treatment in traction. To ensure a slight flexion, the leg should be positioned on a Braun splint and not on a pillow. Internal rotation should not exceed the neutral position. The reduction must be done under radiographic control!

The role played by the hemarthrosis is questionable considering that particularly in the presence of

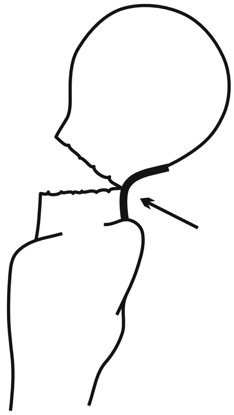
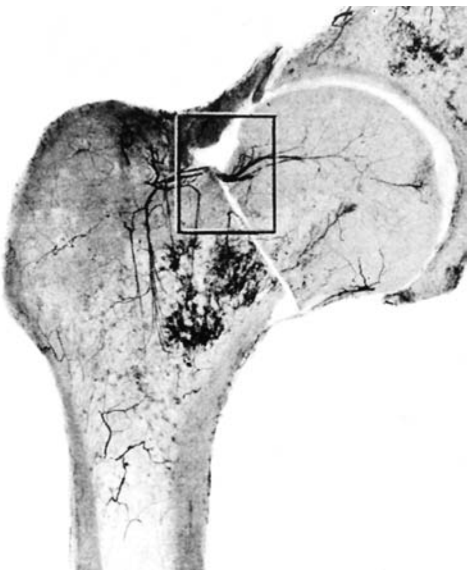


Fig. 52. The thicker, posterocaudal retinaculum as drawn by Parker and Pryor (1993). In the presence of an intact retinaculum it acts during reduction like a hinge (ligamentotaxis)



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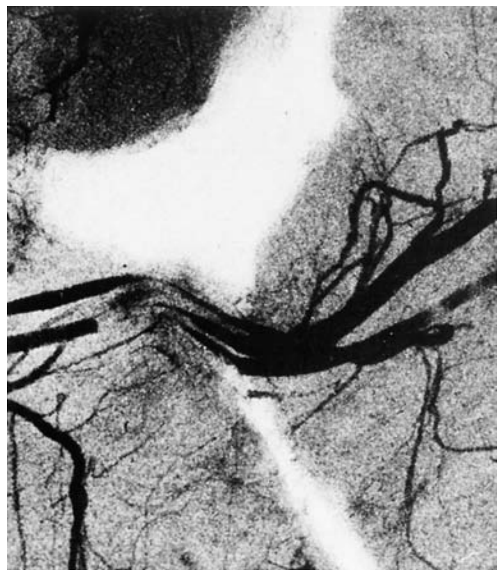


b

Fig. 53. Barium angiogram of a cadaver specimen (Forgon, 1970)
a. Overview; **b.** Four times magnification: kinking of the vessels in the fracture gap, the blood flow disturbances are still reversible when an immediate reduction is performed

marked displacement of the fracture the capsule ruptures and that therefore the intracapsular pressure cannot increase. On the other hand, the incidence of late avascular necrosis is the highest in this group according to pertinent publications and our own results (Nagy et al, 1975; Manninger et al, 1979; Drake and Meyers, 1984) (Fig. 54).

The damage to the blood supply has also an intraosseous component (Arnoldi and Linderholm, 1969; Arnoldi et al, 1970; Arnoldi and Linderholm, 1972; Arnoldi and Linderholm, 1977; Kazár and Manninger, 1993). At the level of the fracture the **capillary network between the trabeculae** ruptures and thus **impedes drainage** from the head. The consequence is an increase in the intraosseous pressure leading to an appearance similar to a microscopic compartment syndrome (Fig. 55).

The importance of this mechanism is highlighted by the fact that even in **aseptic, non-traumatic head necroses** of various causes an increase in pressure is observed (Hungerford and Lennox, 1985; Solomon, 1990; Arnoldi, 1994; Ficat, 1997).

a b c

Fig. 54. Intraoperative intraosseous venography after reduction of a severely displaced femoral neck fracture.
In all three examples the contrast material can be well seen in the periarticular tissues. It is evident that after tear of the capsule the intraarticular hematoma can escape, therefore, an intraarticular increase in pressure is unlikely

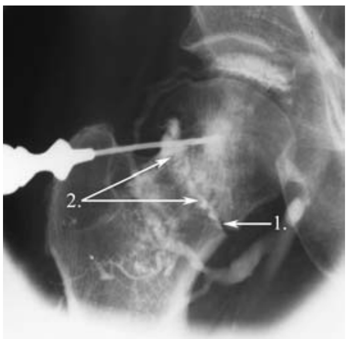


Fig. 55. Intraoperative intraosseous venography in an instance of overdistraction of a neck fracture.
The slight overdistraction remaining after reduction creates medially a diastasis interrupting the flow (1). In the cranial two thirds of the fracture a normal flow is seen (2)

The possible correlation between intracapsular and intraosseous increase in pressure has been the object of many experimental and intraoperative studies using intraosseous pressure measurements such as Laser-Doppler-Flowmetry (LDF), investigations of metabolism, Tc 99 bone scan or oxygen consumption measurements (Soto-Hall et al, 1964; Arnoldi and Linderholm, 1969; Everwahn and Suren, 1970; Drake and Meyers, 1984; Vegter, 1987; Schwarz and Leixering, 1989; Maruenda et al, 1997; Bonnaire et al, 1998).

In summarizing we believe that the cause of femoral head necrosis is usually due to a disturbance of the venous drainage.

The arterial supply is only decreased in the presence of major displacements. This vascular disturbance is not due to hemarthrosis causing increased pressure, but due to a tear of the vessels. In the majority of patients no hemarthrosis can form since the capsule has ruptured. On the other hand the thin walled retinacular veins are not only more prone to injury but also exposed to **compressive forces inside the intact capsule** caused by intraarticular bleeding.

In undisplaced fractures the capsule remains intact allowing an increase in pressure due to the hemarthrosis. One would expect a higher incidence of necrosis if this mechanism were operative; this, however, is not reflected by the clinical experience. **The damage or interruption of the intraosseous drainage (drainage through the fracture site)** leads to a great extent to a decrease of venous drainage.

The **result** of both facts, the damage to the retinacular and intraosseous venous drainage, **is a blood congestion, an increase in intraosseous pressure in the femoral head** (Fig. 56).

If the congestion secondary to the increased intraosseous pressure and the interruption of drainage are the main causes of vascular disturbances, as documented by the studies of **Arnoldi** and col-

a

b

Fig. 56. Intraoperative intraosseous venography done 10 minutes after reduction of a displaced neck fracture.
Even in the presence of a good drainage through the femoral circumflex vein (1) or through the metaphyseal (2) drainage, a marked congestion of the contrast medium (3) in the head is seen

laborators (1970 and 1972) and our own intraosseous venographies (Kazár and Manninger, 1993), then a decrease in pressure and an improvement of drainage as achieved by immediate surgery is of eminent importance.

2.5 The intraosseous femoral head drainage

Already in the sixties we could observe during serial intraosseous venographies of fresh neck fractures that the contrast agent did not pass through the veins running parallel to the arteries but passed first through the fracture gap, then through the distal fragment and through the veins in the trochanter area into the draining veins (Manninger et al, 1979). **Hulth** (1956) judged this result as a false positive. During the follow-up of our patients with neck fractures we found out that the incidence of late necrosis in these false positive patients was not more elevated than in those patients where the drainage of the contrast agent occurred through the femoral head veins (true positive result) (Manninger et al, 1979).

Theses observations concur with the publications by **Arnoldi** made in the seventies. He established that the femoral head's vitality is not compromised by the interruption of blood supply following a fracture but by the **interruption of the venous drainage.** This therefore plays an important role in the development of femoral head necrosis (Arnoldi and Linderholm, 1969; Arnoldi et al, 1970; Arnoldi and Linderholm, 1972; Arnoldi and Linderholm, 1977).

Later publications by **Hungerford and Lennox** (1985) and **Ficat and Arlet** (1997) proved that an essential factor in the occurrence of non-traumatic avascular necrosis is the **intraosseous increase in pressure** due to interference with the venous drainage.

According to measurements done by **Strömqvist** the intraarticular pressure in neck fractures without displacement or impacted in valgus increases significantly. He attributed an important role in the development of head necrosis to the increased pressure (Wingstrand et al, 1986; Strömqvist et al, 1988). Comparing his data with our intraosseous venographies we came to the conclusion that **the intraosseous drainage** – the drainage through the fracture gap – is practically normal, particularly **in undisplaced fractures or fractures impacted in valgus.** This can be explained by the good contact between the fragments (Manninger et al, 1979). From the well known, statistically supported data that the incidence of femoral head necrosis in Garden-I and -II fractures amounts maximally to a third of the incidence seen in displaced fractures we concluded that **not the increase in articular pressure but the interrupted or inadequate venous** drainage and therefore the resulting increase in intraosseous pressure in the head **is the determining factor** of this complication. For this reason the result in respect to avascular necrosis can be improved by **an early femoral head drainage.**

We have observed a considerable drainage of contrast material **along the nails** exiting laterally from the bone in the course of intraoperatively performed intraosseous venographies after Smith-Petersen double nailing. For this reason we designed a new implant, the cannulated neck screw, facilitating improved drainage. The screw has four transverse holes at the tip of the threads that are connected to the bore of the screw (cannulated screw). This system permits the congested blood or serum to escape laterally to the soft tissues where it can be aspirated by a suction system. Later on, we made further improvements to the drainage system by adding notches over the entire length of the screw shaft (Fig. 57).

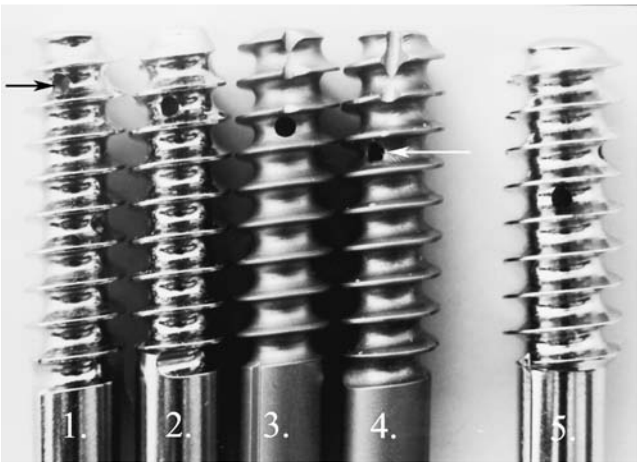


Fig. 57. Close-up of screws with 8 or 9.5 mm threads. The screws 1 to 4 are turned by 90° to demonstrate the four drainage holes. Screws 1 and 3 show in addition longitudinal grooves in the screw shaft. The threads of the fifth screw have a diameter of 9.5 mm. Screws 1, 2 and 5 are made of stainless steel and 3 and 4 of titanium

Fig. 58. Set-up for selective measurement of the drainage fluid via the cannulated screw (postoperative a.-p. radiograph).

Suction drains (12 to 14 CH) were screwed into the cannulated screw at the end of surgery. This allowed to measure the amount of drained blood and to compare it with the aspirated blood from the wound. In ten patients we increased the vacuum to 100 mm Hg to prevent early blockage. We observed that daily amount of serum was 190 ml during the first two to three days. It is interesting to point out that normally the blood aspirated from the wound amounts only to 30 ml (Hungerford and Lennox, 1985; Ficat and Arlet, 1997) (Fig. 58).

Záborszky and collaborators (1997) placed cannulated titanium screws in the core decompression channels in patients with avascular necrosis. They attached drains to the screw ends and could thus obtain a good, prolonged decompression of the femoral head.

2.6 Types of femoral neck fractures

Our intention is to clarify terms often contradictorily used in the pertinent literature and in the daily practice by describing various fractures with the help of radiographs. The border between **medial** (intracapsular) and **lateral** (extracapsular) types is formed by the fold of the joint capsule (see Figs. 1 and 7).

Many authors use **"subcapital"** as a synonym for intracapsular fractures (Garden, 1964; Strange, 1969; Garden, 1971; Barnes et al, 1976; Schwarz, 1982; Cobb and Gibson, 1986; Ferris et al, 1987; Bucinto et al, 1997). The subcapital fracture can only be classified as a subtype as **no stump of the neck remains attached to the broken head.** This subtype is mainly seen in remote fractures when the patient attempted to walk after the injury and the fragment ends have been worn off. Its significance lies foremost in the **difficulty of fixation;** a screw with a short thread must be used (Fig. 59).

a

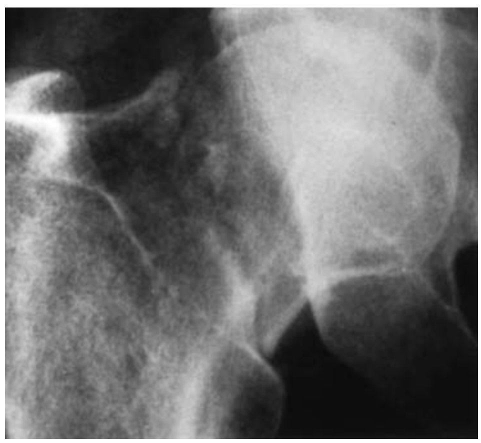
b

Fig. 59. Subcapital neck fracture (rarely seen as fresh fracture).
82-year-old woman with Parkinson's disease. A neck stump is neither seen on the first a.-p. film (**a**) nor on the lateral view (**b**). In spite of the fact that the radiographs show a remote fracture, the relatives reported that the patient was still walking 24 hours before admission

A similar controversy concerns the medial break termed **transcervical** (Gosset, 1950; Abrami and Stevens, 1964; Brown and Abrami, 1964; Cabanac et al, 1964; Catto, 1965a) (Fig. 60a). Admittedly, the majority of femoral neck fractures occur between cranial third of the neck and fold of the joint capsule. The course of the fracture can considerably vary on account of fracture plane and number of fragments. A fracture with a vertical angle of inclination (Pauwels-III) terminates in generally caudally and extraarticular (Fig. 60b). This is important since the caudal retinaculum is intact and advantageous for the restitution of femoral head circulation. On the other hand, stabilization is more difficult. Absence of Adam's arch (second buttressing point) must be compensated by an angle-stable implant (see Fig. 192).

The fracture between the fold of the joint capsule and the base of the neck is known as **lateral** neck fracture. Here the **neck stump** remains in continuity with the distal fragment. From the standpoint of circulation the fracture belongs to the extracapsular fractures. Given the considerable anatomic variations, damage to the supplying vessels may occur and thus a head necrosis develops. The differentiation of borderline cases may repre-

a



b

Fig. 60. Transcervical neck fracture.
a. Most frequent type of a displaced fracture (Pauwels-II); **b.** Vertical angle of inclination (Pauwels-III)

sent difficulties, particularly, when the quality of radiographs is poor. Given their rare occurrence their clinical significance is low; they occur mostly in adolescents (Fig. 61).

The basal neck fracture is distinguished by the fact that the **stump of the neck does not form part anymore** of the distal fragment (the trochanters remain intact) (Fig. 62).

No distinction between lateral and basal fracture is often made in the pertinent literature. These fractures are erroneously called “laterobasal” or “basocervical”.

Atypical forms are known to occur; they do not fit into this classification. **Fractures with spiked surfaces** are difficult to reduce but are more stable than common fractures thanks to the interdigitation of the spikes (Fig. 63a). **Comminuted fractures** (Fig. 63b) and fractures that show in the lateral projection **big anterior or posterior beaks** (Fig. 63c, d) also present problems on account of difficulties in reduction and maintenance of reduction. In isolated instances a bigger stump of the neck remains in continuity with the head fragment, the fracture line runs almost **horizontal** (reverse Pauwels-III?) (Fig. 63e). Medial neck fractures that start very proximal and end in the trochanteric region **(cervicotrochanteric type)** are rare (Fig. 63f). The risk of circulatory disturbances is similar to that of medial fractures.

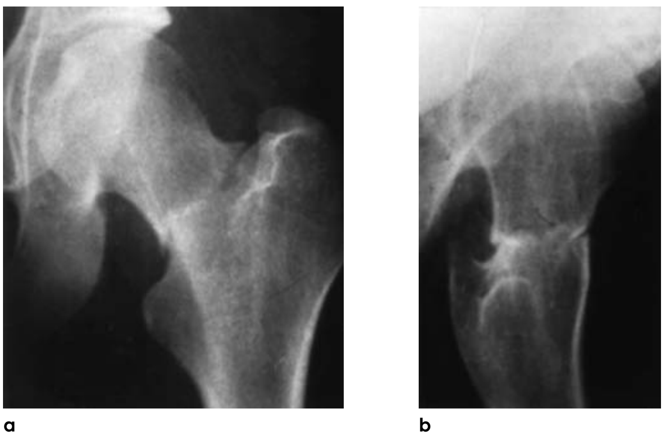


Fig. 61. Lateral neck fracture in an adolescent.
a. A.-p.; **b.** Lateral view. As can be seen in both views the stump of the neck remains in continuity with the distal fragment

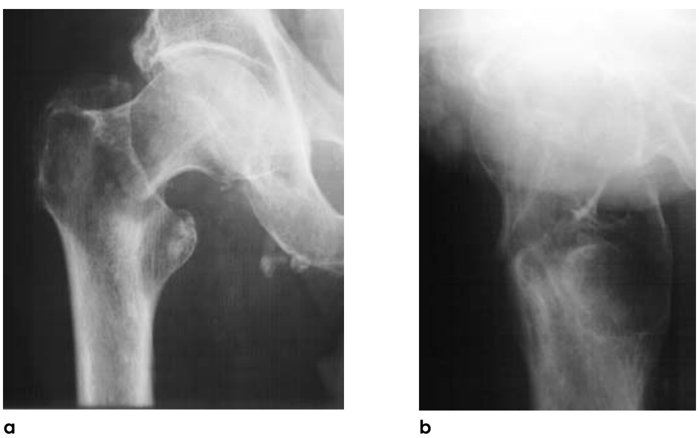


Fig. 62. Basal neck fracture.
a. A.-p.; **b.** Lateral radiograph

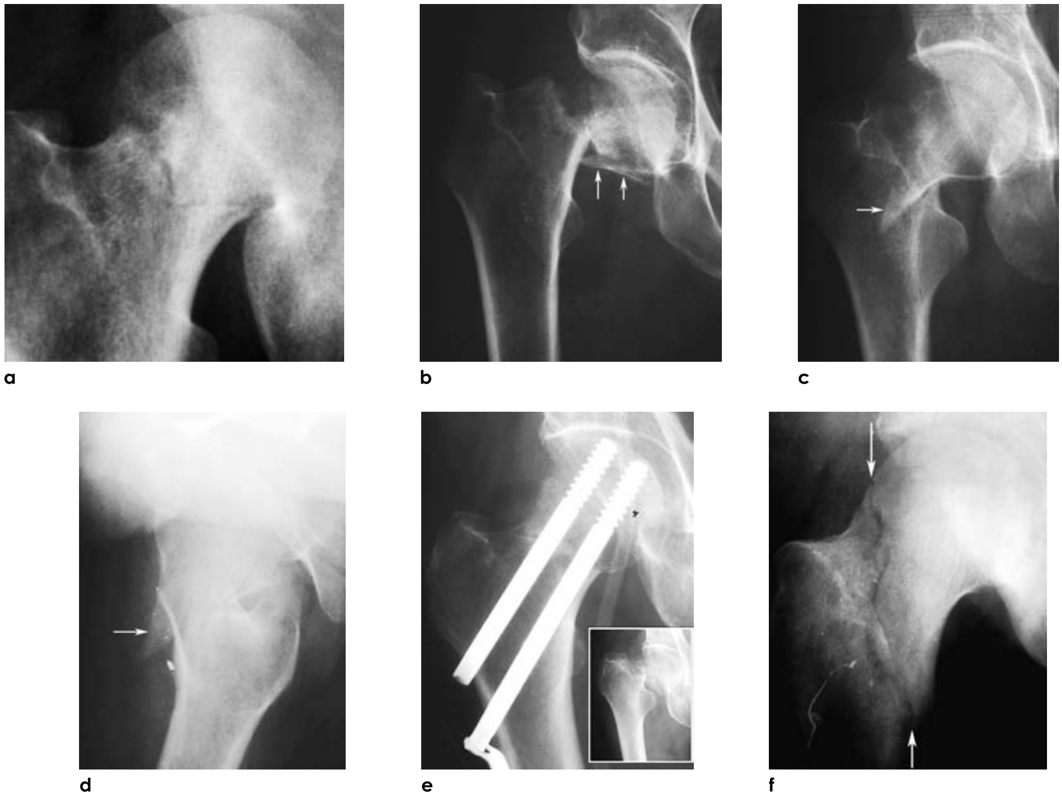


Fig. 63. Atypical neck fractures.
a. Fracture with a spiked surface; **b.** Avulsion of a major fragment from Adam's arch and the caudal third of the femoral head; **c.** Already on the a.-p. film one can see the beak of the cranial fragment; **d.** This fragment is better seen on the lateral film; **e.** Transverse neck fracture; **f.** Cervicotrochanteric fracture (Kazár, 1963)

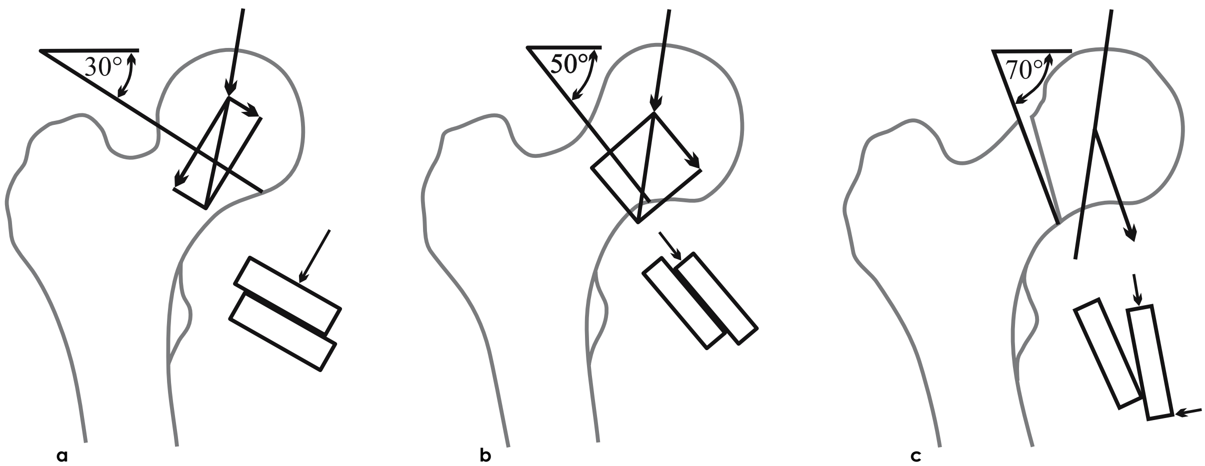


Fig. 64. The importance of the angle of inclination of a fracture as seen in the classic drawings of Pauwels (1935).
The inclination of the fracture is measured by an angle between the plane of the fracture line and the horizontal plane of the pelvis. It is divided into three groups: type I: up to 30° (**a**), type II: between 30 and 50° (**b**), type III: > 50°; (**c**). In type I the fracture line is nearly perpendicular to the resulting compressive forces. In type II shear stresses act at the fracture surfaces. In type III shear and tilting forces are operative

2.7 Grouping of fractures: Pauwels-, Garden- and AO-classification

In 1935, at the beginning of surgical treatment of femoral neck fractures, Pauwels who also was an architect, drew the attention of surgeons to the importance of the biomechanical aspects of fractures for clinicians. His analysis of mechanical factors and his classification of fractures had a lasting impact (Fig. 64).

For a long time this classification formed the basis for surgical indications in various countries, particularly in German-speaking areas. **Today** it has lost **almost completely** its **importance** (Kazár et al, 1960; Dynan and Parker, 1998). On the one hand, it became evident that **fracture surfaces are not smooth,** they are almost always **jagged and fragmented** modifying considerably the interaction between the fragments. On the other hand, the stability of internal fixation has been considerably improved over the years. Therefore, it is nowadays considered obsolete to base the choice of a **surgical**

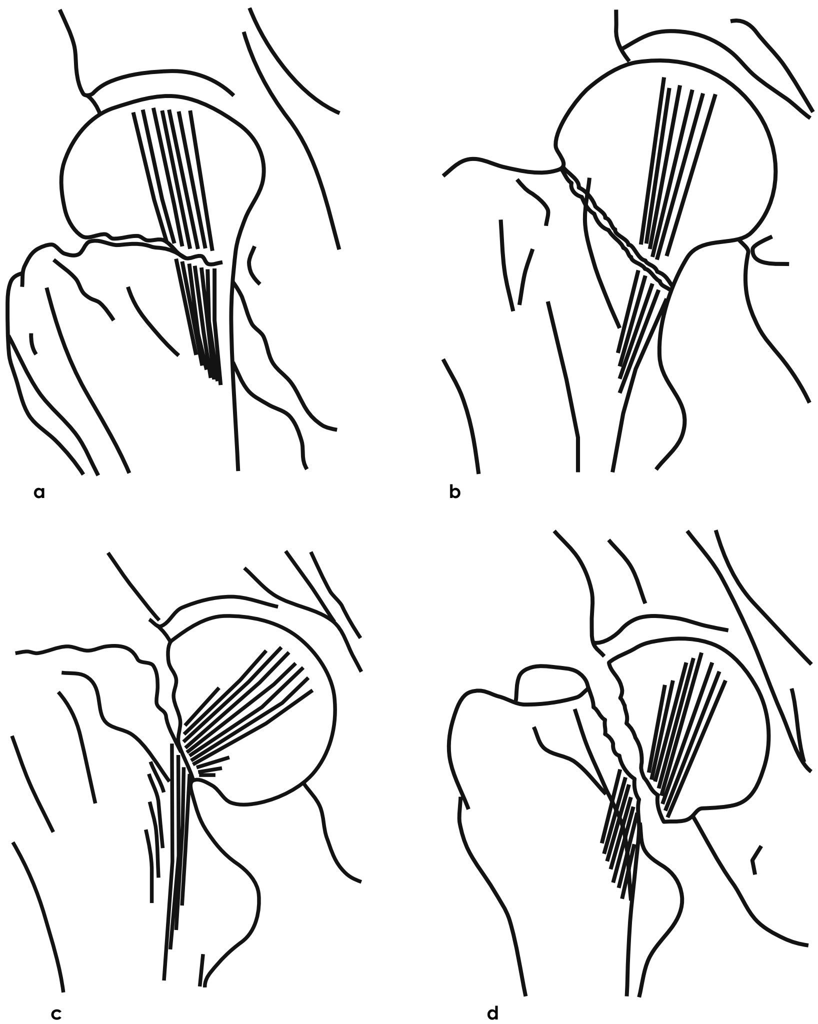


Fig. 65. Classification of femoral neck fractures after Garden.
a. Garden-I, valgus position, incomplete fracture; **b.** Garden-II fracture without displacement; **c.** Garden-III tilted in varus, the main compression trabeculae are broken but the fracture surfaces are partly in contact; **d.** In the Garden-IV the compression trabeculae of the femoral head remain parallel to those of the neck but are shifted. The fracture surfaces are not in contact anymore (Manninger and Fekete, 1982)

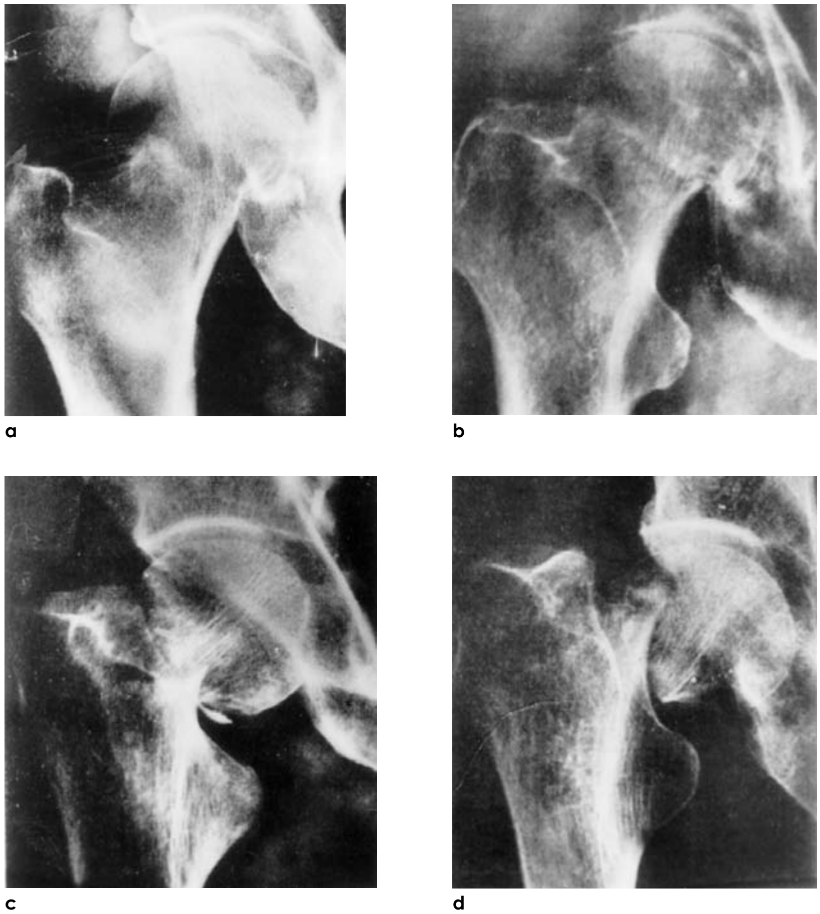


Fig. 66. Original radiographs of the four types of Garden classification (1961b). **a.** Garden-I; **b.** Garden-II; **c**. Garden-III; **d.** Garden-IV

method on the angle of inclination, i.e., for a Pauwels-II fracture an internal fixation and for a Pauwels-III fracture an arthroplasty. It is an error to make a decision based on radiographs taken with the limb in external rotation. The distal fragment on these films usually shows a vertical angle, a fact that does not correspond to reality (Gosset, 1950; Hulth, 1961).

The Pauwels angle is today of importance in two situations:

(1) Some authors recommend a valgus osteotomy according to Pauwels for vertical pseudarthrosis of the neck; in changing the shear moments into compressive forces a consolidation can be achieved (Marti et al, 1989; Anglen, 1997). We do not perform this operation anymore because the incidence of pseudarthrosis has been considerably lowered thanks to modern, dynamic implants and the introduction of angle-stable plates increasing the stability and thus eliminating the considerable surgical trauma of an osteotomy. In addition, as described in section 1.5 a valgisation of the hip is always accompanied by an increased stress on the femoral head, a fact, that influences unfavorably the blood supply.

(2) **The medially running Pauwels-III fracture** is problematic on the account that the entire Adam's arch remains either attached to the proximal fragment or is avulsed. In these instances, the **second buttressing point is lost** and the two-armed lever action of the implant is transformed in a single lever arm because of its insufficient but-

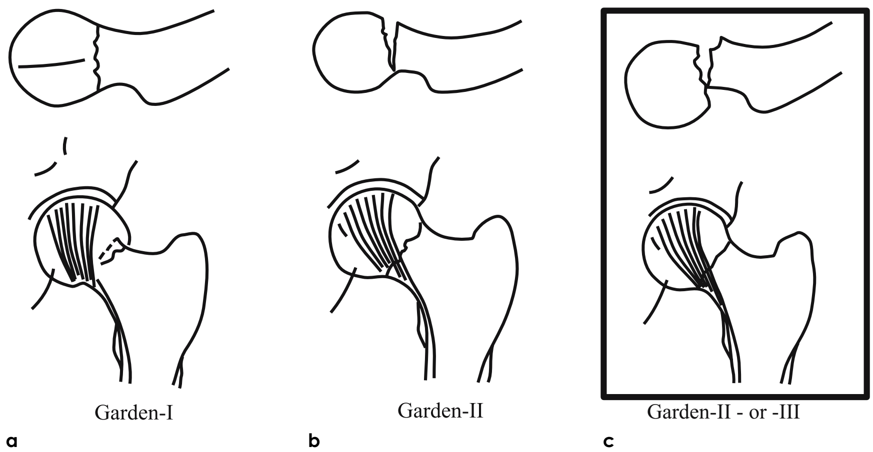


Fig. 67. The importance of lateral radiographs when using the Garden classification, schematic representation (Manninger et al, 1992). Based on a.-p. films all three fractures (**a, b, c**) belong to the group of undisplaced fractures. However, lateral films taken in example **c** show such a degree of antecurvature and lateral translation that the fracture must be considered to be displaced (Garden-III?)

tressing (see Fig. 211c–g). In this instance a more stable fixation must be chosen to maintain the neck/shaft angle to prevent a loss of reduction resulting in a varus deformity with a posterior displacement. The use of a caudal cannulated screw with longer threads (34 or 44 mm) is advisable as it has a better purchase in the long head fragment.

Garden (1961b and 1964) based his classification on the displacement of fractures as seen on the a.-p. film. He distinguishes **between fractures in valgus (Garden-I), without displacement (Garden-II), with slight displacement in varus** (the fracture surfaces are partly in contact) **(Garden-III) and with complete displacement (Garden-IV)** (Fig. 65 and 66).

Garden assumed that type-I fractures (valgus type) are not complete. This happens, however, very rarely as in fatigue fractures. Many authors use the term **undisplaced fractures** for Garden-I and -II fractures. This terminology is also used by the Multicenter Hip Fracture Study and by the SAHFE project (Editorial, Acta Orthop. Scand., 1988; Thorngren et al, 1990; Thorngren, 1998). The justification for combining **Garden-I and -II fractures** is said to be their **identically favorable prognosis in respect to stability and development of a late avascular necrosis.** Similarly, the term **displaced fractures** is used for Garden-III and -IV fractures, in spite of the fact, that some authors separate strictly both groups and recommend for type-III fractures an internal fixation and for type IV an arthroplasty (Hulth, 1961; Galla and Lobenhoffer, 2004). Publications in the pertinent literature fail to show a **significant difference in the incidence of necrosis.** This depends also on the fact that the **degree of displacement as seen on the original radiographs** may deteriorate subsequently while waiting for surgery; during this waiting period the patients care and positioning may cause displacement. The assessment can also considerably be influenced by the quality of films. If the radiograph has been taken in the recommended internal rotation, a severely displaced fracture can appear only as a Garden-III fracture. Once the limb has fallen back into external rotation, a much greater displacement becomes evident. Given these uncertainties the choice of the surgical method should not be based on films taken in one plane only.

The problem with the Garden classification is the fact that it is solely based on a.-p. films. We have seen repeatedly that Garden-I fractures, diagnosed on a.-p. films, show such a major angle of displacement in lateral films that these fractures must be considered Garden-III fractures on account of their displacement. The same problem is encountered when differentiating between Garden-III and Gar-

a

b

Fig. 68. The importance of lateral radiographs. 69-year-old woman. **a.** The a.-p. shows a valgus position corresponding to a Garden-I fracture; **b.** The lateral film shows an obvious antecurvature of 45° (Garden-I–III?). **Note that the femoral head appearing on the a.-p. film as a sphere should be suspicious of a major displacement confirmed by the lateral radiograph**

den-IV fractures. A fracture that appears as Garden-III on the a.-p. film (as in slight varus malposition) may show a major displacement on the lateral film. The femoral head may lie not infrequently posterior to the neck (Manninger et al, 1992) (Figs. 67 and 68).

For this reason the **Alignment-Index,** also described by Garden, is of great clinical value since it takes the a.-p. and lateral view into account. The midline of the compression trabeculae as seen on the a.-p. film forms normally an angle of 160° with the medial border of the diaphysis. On lateral films the compression trabeculae form an angle of 180° with the diaphyseal axis. Both values combined result in the **anatomic Garden Alignment-Index of 160/180** (Fig. 69).

The Alignment-Index does not only allow describing better **borderline fractures,** it also is of use postoperatively **to assess exactly the reduction.** The Alignment-Index of Garden-II fractures, undisplaced in both planes, or anatomically reduced fractures amounts to 160/180. If a smaller or greater angle is present, a reduction is necessary in Garden-I and -II fractures and a correction of reduction in Garden-III and -IV fractures.

Another internationally well known grouping, particularly in German speaking countries is the **AO/ASIF classification** (Müller et al, 1990) (Fig. 70).

Their classification of great use in other body parts can only be adapted to the hip with difficulties. For this reason we do not use it. At the proximal end of the femur (segment code 31) trochanteric fractures are labeled A, **neck fractures B** and intraarticular fractures C (Fig. 71).

Raaymakers (1993) attempted to combine the Garden classification used in the Anglo-American countries with the AO/ASIF classification (Marti and Jacobs, 1993). According to this attempt the medial fractures of Garden type -I and -II correspond to 31-B11, B12 resp. B13 fractures. The Garden types -III and -IV correspond to 31-B22 and B23 as well as to 31-B31, B32, B33 fractures. The 31-B21 (laterobasal) fractures are extracapsular.

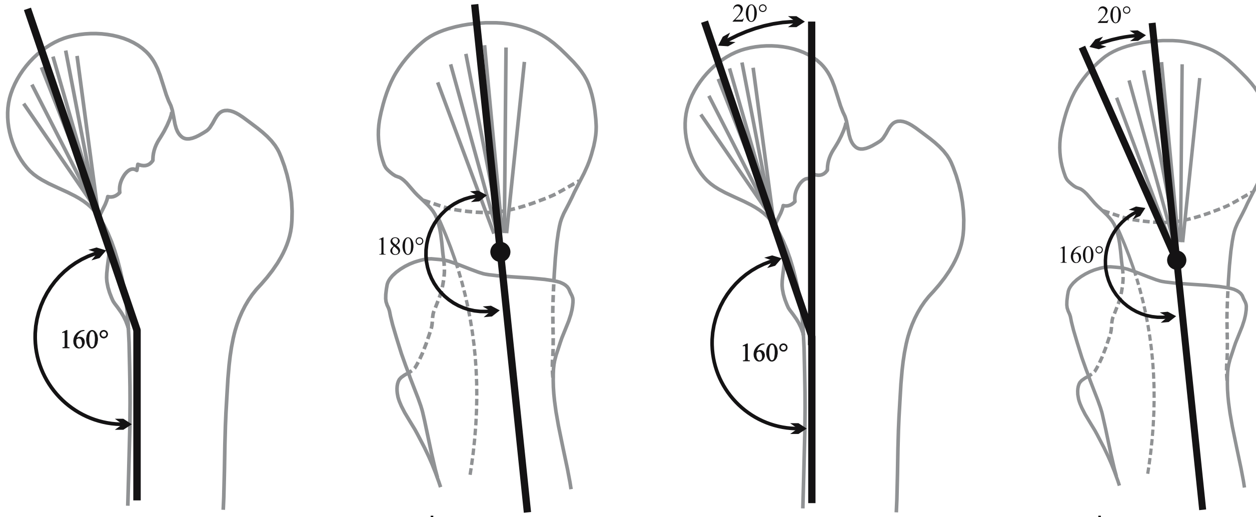


Fig. 69. Garden Alignment-Index (1964), schematic representation.
a. Midline of the compression trabeculae and longitudinal diaphyseal axis (along the medial cortex) form in the a.-p. film an angle of 160°; **b.** In the lateral film going through the midline of the femur this angle is 180°. The anatomical Garden Alignment-Index amounts to 160/180; **c, d.** The index also serves for the intra- and postoperative assessment of reduction: an a.-p. angle varying between 160 to 180° (indicating a slight valgus position) (**c**) and an angle seen in the lateral film of 180 to 160° (**d**) represent an acceptable position

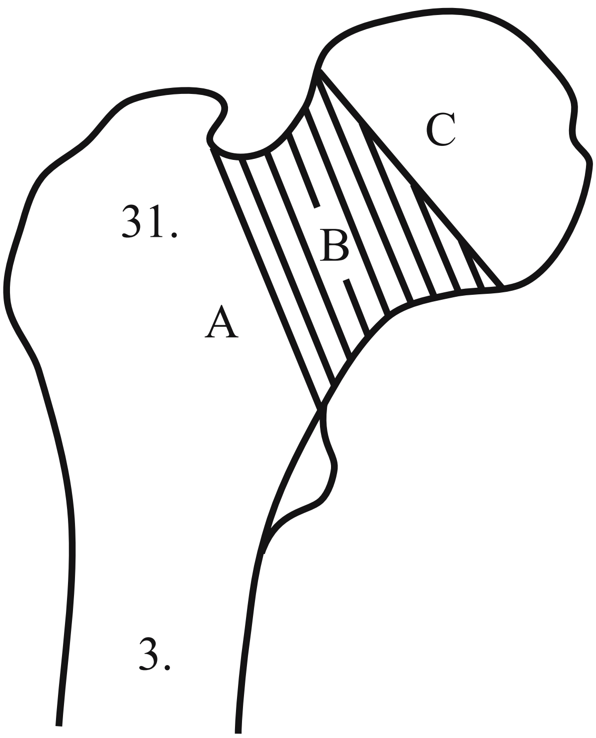


Fig. 70. Basic principles of the AO/ASIF classification (Müller, 1990).
The identification starts with the bone (femur = 3). It is followed by the segment in question (proximal end of femur = 31). Following this the type of fracture is taken into consideration (at the diaphysis the fragmentation and at the epiphysis the involvement of the joint are decisive: extraarticular fracture = A, simple intraarticular fracture = B, intraarticular comminuted fracture = C). Finally, a grouping or subgrouping is added depending on the severity of the fracture

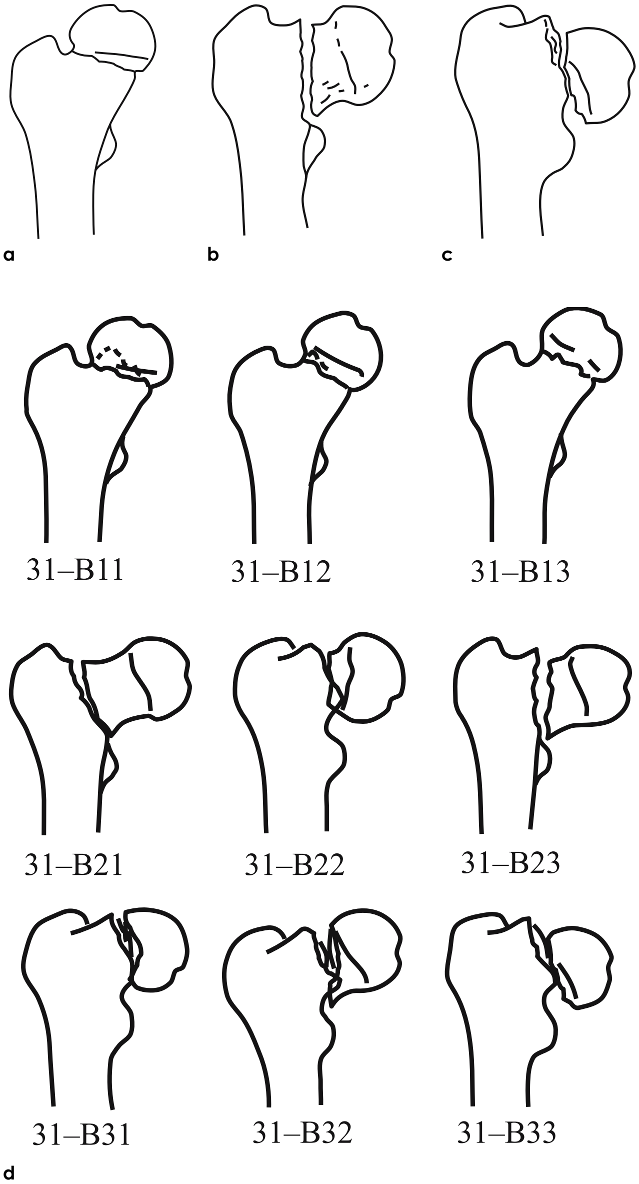


Fig. 71. AO/ASIF classification of neck fractures (Müller, 1990).
a. 31–B1 corresponds essentially to fractures in valgus, without displacement; **b.** 31–B2 = slightly displaced transcervical fractures; **c.** 31–B3 = markedly displaced subcapital fractures;
d. subgroups:
31–B11 = impacted, subcapital fractures, valgus angle > 15° (a.-p. alignment angle > 175°)
31–B12 = 31–B11 but with a valgus angle < 15° (a.-p. alignment angle < 175°). A fracture may also belong to these two types when the angle of antecurvature is < 15° (lateral alignment angle < 165°)
31–B13 = fracture without displacement
31–B21 = basal or lateral fracture
31–B22 = transcervical adduction fracture
31–B23 = transcervical vertical fracture
31–B31 = subcapital, slightly displaced fracture
31–B32 = displaced vertical subcapital fracture
31–B33 = subcapital markedly displaced fracture

2.8 The undisplaced neck fracture (Garden-I and -II)

Linton (1944) considered the undisplaced and displaced neck fractures as two phases of the same injury. Most publications, however, make a distinction and also the International Classification of Diseases attributes to them two different code numbers. This is based on the experience that a great percentage of undisplaced neck fractures heal spontaneously, whereas displaced fractures will not consolidate without surgical intervention. We consider the Garden-I (valgus)-fractures as impacted and the Garden-II as undisplaced. In the interest of a proper classification we also attempt to measure the Garden Alignment-Angle (Fig. 72).

Fractures with an angle of < 160° seen on the a.-p. film (varus, Garden-III) and an increased pos-

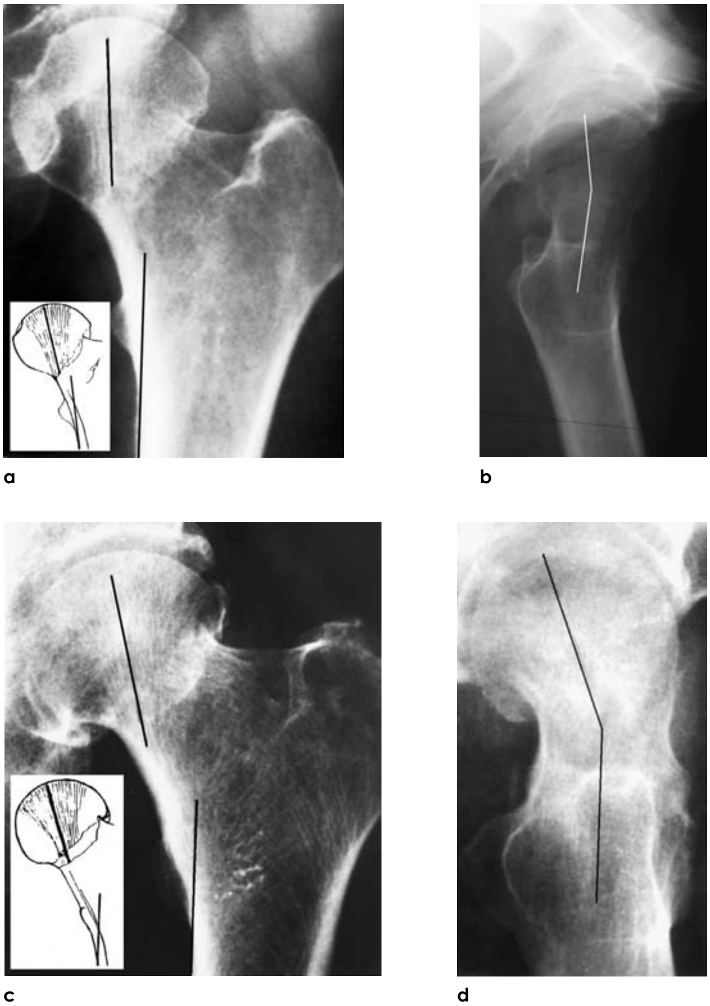


Fig. 72. Garden-I and -II fractures.
Garden-I: **a.** The a.-p. radiograph shows a valgus angle of 170°; **b.** The lateral film shows a posterior angle of 170° (antecurvature). Garden-II: **c.** The a.-p. radiograph shows an angle of 160°; **d.** The lateral film shows a posterior angle of 160° (antecurvature)

terior angle **(antecurvature) in the lateral film** are accompanied by the risk of **increased instability and displacement.** In fractures with **angles exceeding 180° (hypervalgus)** on the a.-p. film and an anterior angle **(recurvatum) in the lateral view** one has to anticipate **circulatory disturbances and necrosis of the head** due to incarceration or stretching of the posterior retinacular vessels (Rösing and James, 1969; Cserháti et al, 1996). For this reason we recommend a **gentle reduction** (Fig. 73).

The **frequency** of undisplaced fractures for all medial neck fractures varies in the pertinent literature between 5 and 40%. Review of our own patients showed repeatedly an incidence between 13 and 16%. In this group Garden-I breaks predominated (Kazár et al, 1959; Zolczer et al, 1970; Manninger et al, 1990; Cserháti et al, 1996).

Linton (1994) assumed that the Garden-I fractures represent the **first phase of a common injury mechanism.** Due to the minor trauma the fracture remains without displacement in a great percentage of patients. The cause of the injury is usually a simple fall or a direct trauma against the hip or trochanter. Some patients **are able to walk directly after the injury;** they seek medical help on account of increasing pain and inability to walk, often only after days or weeks. One can assume that the **displacement of Garden-I and -II fractures had occurred** at the moment when the symptoms are voiced.

The prognosis of undisplaced fractures must be

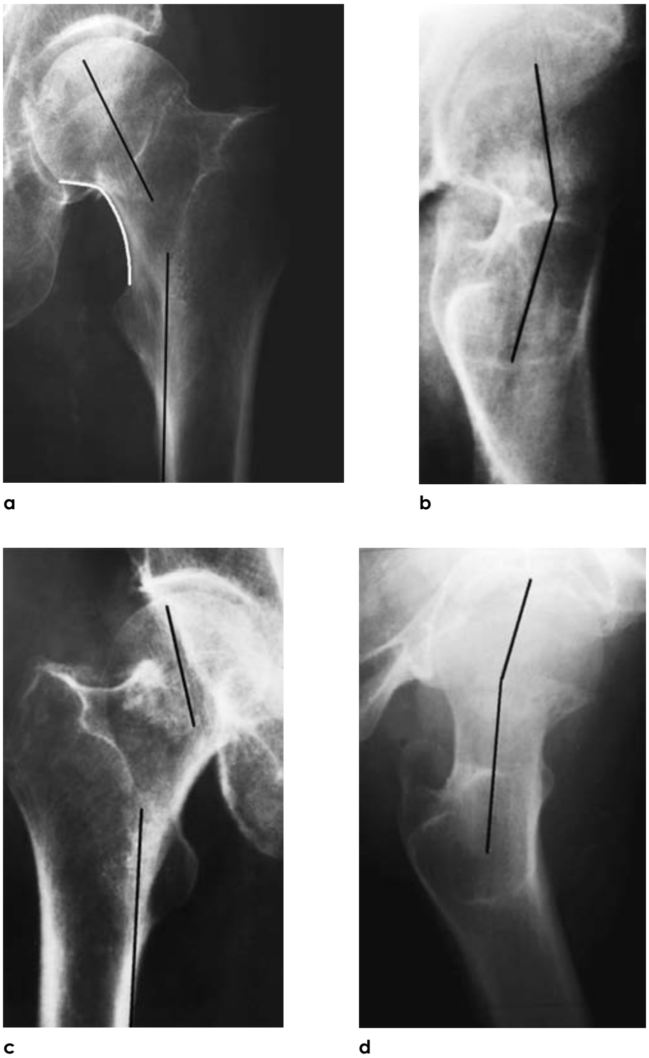


Fig. 73. Borderline problems in undisplaced fractures.
a. An a.-p. alignment angle of 150° is considered by us a varus fracture (Garden-III). Adam's arch is interrupted; **b.** Posterior angle of 150° (antecurvature); **c.** A.-p. alignment angle of 195° (hypervalgus). Well visible is the impaction of the neck close to Claffey's point; **d.** In instances of a rare anterior angle (recurvatum) the lateral alignment amounts to 190°. This has an unfavorable prognosis as the important posterior retinacular vessels are under tension

considered good as the degree of vascular disturbances and thus the risk of **femoral head necrosis** are low **(around 10%).** Since the capsule remains intact, an **intraarticular increase in pressure** may be in fact the consequence. Its little importance is reflected by the low incidence of necrosis (Wingstrand et al, 1986). As a marked kinking or compression of the vessels in the vicinity of Claffey's point is occurring in hypervalgus fractures leading to a **direct damage to the lateral epiphyseal vessels,** the rate of complications is elevated (see Fig. 180).

The patients' data with Garden-I and -II fractures are not markedly different from those with displaced fractures. In both groups women dominate (80%), the average age increases slowly but steadily as does the incidence of concomitant diseases (44% in our patients) (Cserháti et al, 1996).

Chapter 3

DIAGNOSTIC INVESTIGATIONS

3.1 History and physical examination

3.1.1 Anamnesis

In general, the femoral neck fracture in the elderly results from a single trauma after a **simple fall.** Not infrequently it is accompanied by a **fracture of the upper limb** (distal radius, proximal humerus), often due to osteoporosis. In young persons a neck fracture is usually caused by a major trauma. Typically for an **undisplaced fracture** is the preserved or slowly deteriorating ability to walk. The inability to walk may also occur after repeated falls. **Stress fractures** are characterized by slowly increasing pain after prolonged or sudden overexertion. If the anamnesis reveals no trauma but a known systemic disease, a **pathologic fracture** must be suspected.

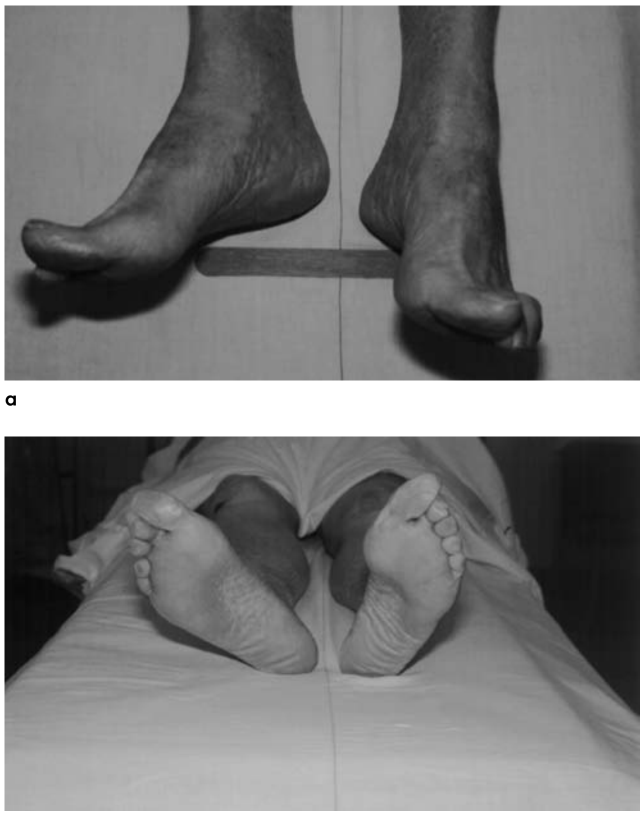
If at all possible, **time and details of the accident, ability to walk and activities** before the injury (could the patient leave his/her house, did he/she use walking aids?) must be documented. It is also helpful to question **relatives,** as the mental condition of older patients often does not permit to obtain **information** concerning the details of the accident. Data must also be gathered as to **systemic diseases and medications.** This information must be used when determining the kind of anesthesia and the operability. It is important for the success of later rehabilitation to gather the past history concerning the mobility and the neurologic status of the patient.

3.1.2 Inspection

The recognition of a displaced hip fracture does not present difficulties. The patient barely moves, is unable to walk and the injured lower limb is usually in external rotation and shortened (Fig. 74).

The clinical examination does **not always allow** to differentiate between a trochanteric and a neck fracture. The externally rotated and shortened limb is characteristic for both. In femoral neck fractures both signs are initially often less pronounced. The trochanteric fractures cause generally more pain. Local swelling is present but hematomas and suffusions occur later. A further typical sign is the marked limitation of hip movements.

If **no external rotation of the limb** is present, the diagnosis of an undisplaced fracture should come to mind. It is also seen in neck or trochanteric fractures where an **anterior angulation at the fracture site,** a recurvatum, is present. This is also of importance during the reduction of the fracture.



a

b

Fig. 74. Position of legs in displaced hip fracture.
a. View from anterior; **b.** View from inferior

No limb shortening is seen in fractures displaced in valgus, the limb might even be slightly longer.

3.1.3 Palpation

The site of maximum pain, exaggerated by palpation or compression, may reveal an important clue. Pain at the trochanteric area speaks in favor of a trochanteric fracture, whereas pain in the groin is typical of a neck fracture. Pain in the groin may also be due to a fracture of the **pubic ramus** that is not infrequently caused by the same injury mechanism in the elderly. Here the exact localization is of value as the patient mostly complains about pain on pressure **over the pubic symphysis.** Pain provoked by tapping against the heel should raise the suspicion for an impacted fracture.

Radiation of pain into **thigh or knee** is not infrequently reported. This may deceive the physician performing only a superficial examination and he may not request the appropriate radiographs.

Of course, examination and documentation must include circulation and innervation of the limb. In the elderly the pedal arteries are often not palpable. Transient damage to the peroneal nerve may occur sometimes during forced internal rotation on the traction table. Damage to the peroneal nerve will cause an inability to extend the foot. If, however, such a damage had occurred during the initial trauma, only a proper preoperative examination can exclude an iatrogenic cause.

3.1.4 Functional examination

Any movement of the injured limb provokes pain at the hip. Once the leg has been elevated, the patient is unable to hold it in that position. This maneuver should be done carefully. As a rule a radiograph of the entire pelvis should be requested, particularly in patients over 40/50 years to exclude a neck fracture. Suspicion of such a fracture is raised by pain in hip and thigh and the fact that the **patient is unable to lift the extended leg from the examining table without pain** (Böhler, 1996).

Patients with Garden-I and -II fractures are often able to bear weight on the involved leg with the knee in extension, **in spite of the fact that this causes pain.**

Not infrequently, often after weeks, the patient is admitted to hospital since during the initial examination the fracture had not been diagnosed but the patient was treated for rheumatic affection or sciatica (Perret, 1964; Pathak et al, 1997). Due to a faulty diagnosis the optimal moment for treatment and the possibility of an immediate, internal fixation less stressful to the patient have been missed. Due to a prolonged bed rest the patient's condition may have worsened to a point where surgery is not anymore possible.

3.2 Radiographic investigation. Special imaging procedures

3.2.1 Standard radiographic examination

3.2.1.1 Conventional radiographs in two planes

In instances of fresh fractures a.-p. and lateral radiographs are usually sufficient for a proper diagnosis and planning for emergency surgery (Böhler, 1963; Williams et al, 1992). **The ultimate fate of the patient depends foremost on the quality of the radiographs. Radiologists and traumatologists are equally responsible for their correct execution. Therefore both must be familiar with the technique and responsible for their proper execution.**

The a.-p. film is taken with the patient supine and the limbs placed parallel to the midline of the body in 10 to 20° of internal rotation. Thus the lesser trochanter is projected over the diaphysis, it overlaps the diaphyseal edge; exceptionally its tip can be seen. Films taken in external rotation lead to an erroneous interpretation as the hip is seen in valgus; Pauwels-II fractures appear as Pauwels-III fractures and the greater trochanter is projected over a "shortened" neck. As a result the fracture is not recognized or fracture type and displacement are wrongly interpreted (Fig. 75).

Internal rotation must be done slowly to avoid unnecessary pain. It is advisable to hold this position with a support or sandbag. The film-focus distance should be 1 m. A Bucky or Lysholm grid is re-

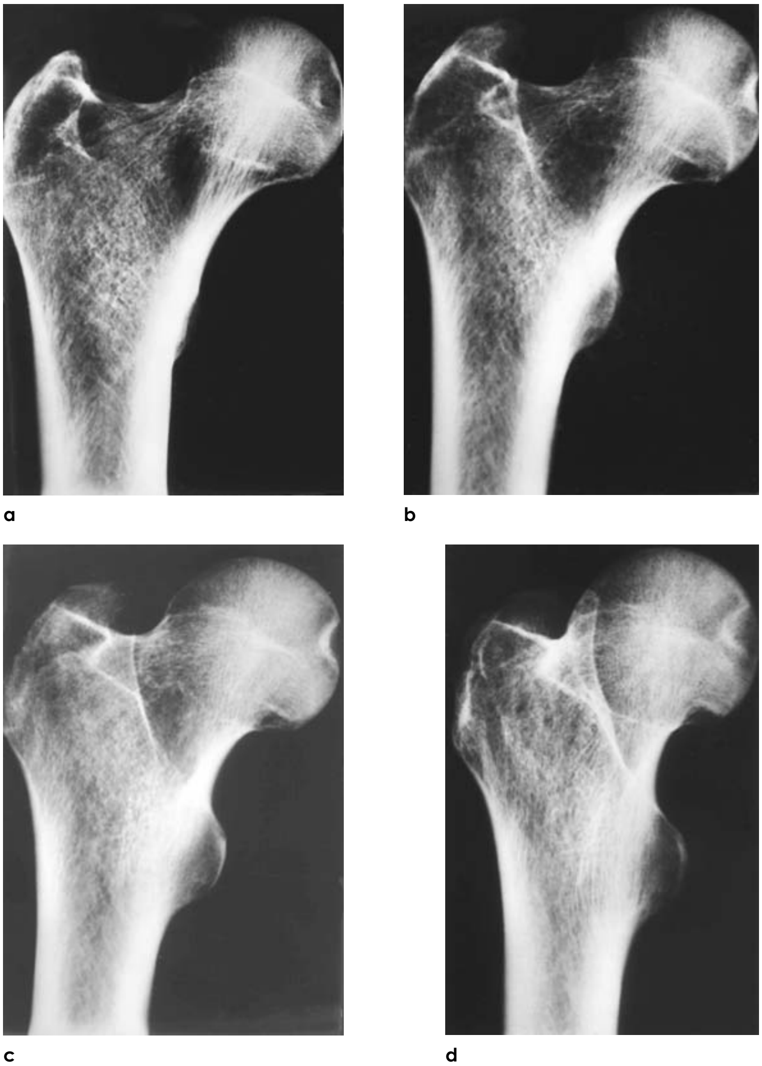


Fig. 75. A.-p. fine grain radiograph of a proximal femoral specimen taken in four different degrees of rotation.
a. Proper a.-p. film taken in 10 to 20° of internal rotation: the lesser trochanter is almost invisible and the femoral neck seen in full length; **b.** Film in neutral position of the leg barely acceptable for proper assessment: the lesser trochanter is seen but the neck is already foreshortened, the fracture cannot be definitely recognized in every instance; **c.** Film taken in external rotation, poor radiographic technique: the greater trochanter is projected over the neck, the neck markedly foreshortened, the picture is almost useless; **d.** Film taken in marked external rotation, very poor radiographic technique: the greater trochanter is projected also over the femoral head, the neck is extremely foreshortened and seems to be in valgus position, the fracture cannot be assessed, the film is useless. Such films often lead to an erroneous diagnosis followed by a wrong decision and treatment

quired. The cassette of 24 x 30 cm is placed longitudinally under the hip, its center should be 3 cm below the center of a line between symphysis and anterosuperior iliac spine. This point corresponds to the center of the femoral head. The X-ray beam must be centered at this point (Fig. 76).

For lateral radiographs the limb remains in the same position as for a.-p. films but it is slightly abducted. The film-focus distance is again 1 m. An 18 x 24 cm cassette with the Bucky grid is pressed laterally over the soft tissues at the level of the iliac crest and its long side parallel to the longitudinal axis of the femoral neck; it is supported by a sandbag. The center of the femoral head (as described in the instructions for a.-p. films) is projected over the midpoint between middle and cranial third of the cassette. The horizontally placed X-ray tube is turned in direction of the neck so that the central beam forms an angle of 40° with the longitudinal axis of the thigh. It thus points to the **midpoint of the neck** (Fig. 77).

The patient bends the opposite leg at the hip and either holds it there or places it on the case of the X-ray tube (Fig. 78). If the patient is unable to lift the leg, the tube can be placed in an opposite direction and the cassette between the thighs. The femoral head is often missed on these films, because the cassette has not been placed sufficiently cranial.

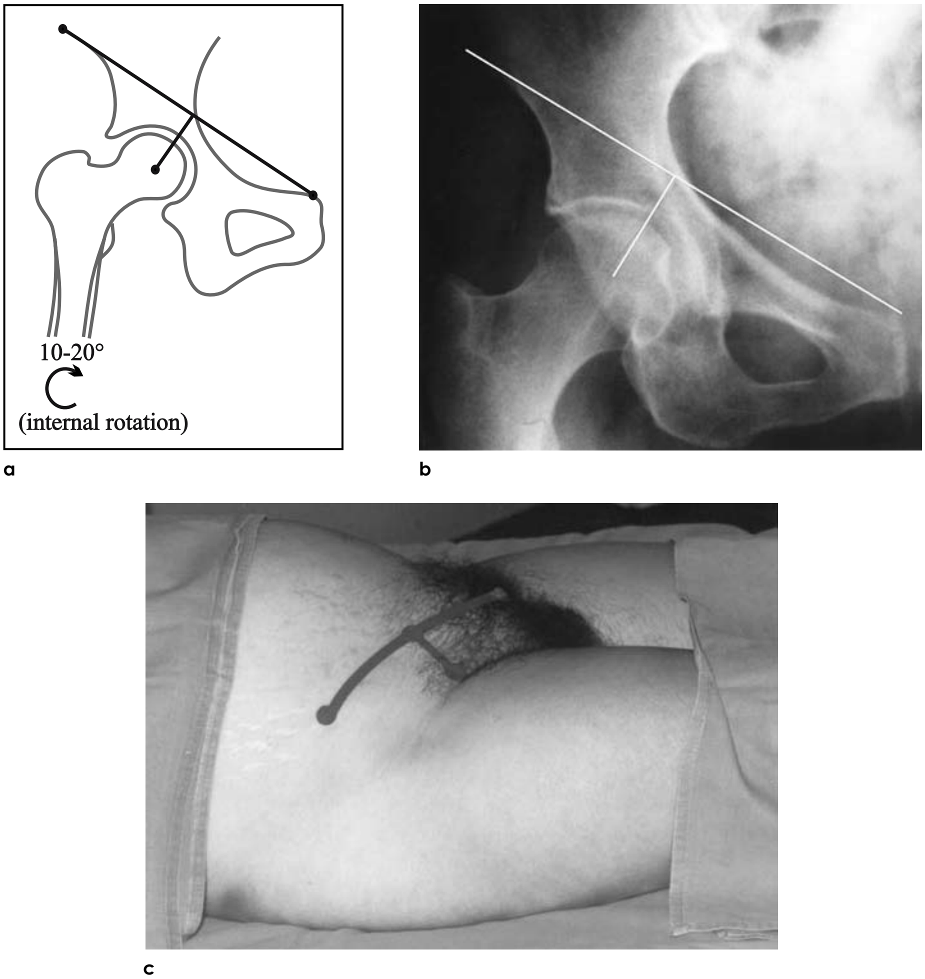


Fig. 76. Determination of the center of the femoral head in average sized subjects.
a. Schema; **b.** Seen in the a.-p. projection and **c.** lines drawn on the body. With the leg in internal rotation of 10 to 20° a line is drawn between pubic tubercle and anterosuperior iliac spine. From its midpoint a 3 cm long perpendicular line is made in a caudal direction. It ends over the center of the femoral head

If the beam has not been pointed perpendicular to the femoral neck, the greater trochanter is projected over the femoral head and the neck is barely or not at all seen or foreshortened. Useless are also lateral films taken with the limb in external rotation (Fig. 79).

Postoperatively, standard films in two planes are mandatory for control of **reduction and internal fixation.** These postoperative films must be compared to the follow-up radiographs for proper assessment. We check our patients regularly after start of weight bearing (before discharge) and at **predetermined intervals** (4 months, 1, 3 and 5 years after injury). In the presence of symptoms, clinical and radiologic examinations have to be done more frequently.

The first postoperative films are usually taken while the patient is still under anesthesia. This allows proper positioning of the tube. Also the follow-up radiographs must be taken in the same position as the original ones. The required internal rotation must be done carefully to avoid pain. We recommend placing the limb temporarily on a splint in optimal rotation.

A comparison of the vascular supply to the femoral head on radiographs taken at different time intervals can be problematic. On one hand, it is often impossible to achieve identical radiographic quality. On the other hand, the positioning of the leg, changes in the general condition of the patient (weight gain), changes in bone density (osteoporosis) or atrophy of the gluteal muscles may render comparison difficult.

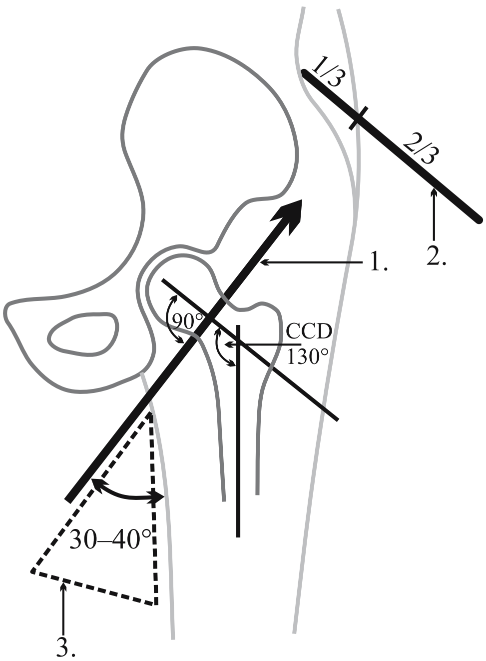


Fig. 77. Schema of the correct positioning of the X-ray tube for lateral films. The proper direction of the beam (1) forms an angle of 30 to 40° to the longitudinal axis of the femur. It runs perpendicular to the femoral neck axis and to the cassette (2). To find the proper direction of the beam a triangular template (3) easily made from Styrofoam is placed on the inner side of the thigh, it is particularly useful in obese patients

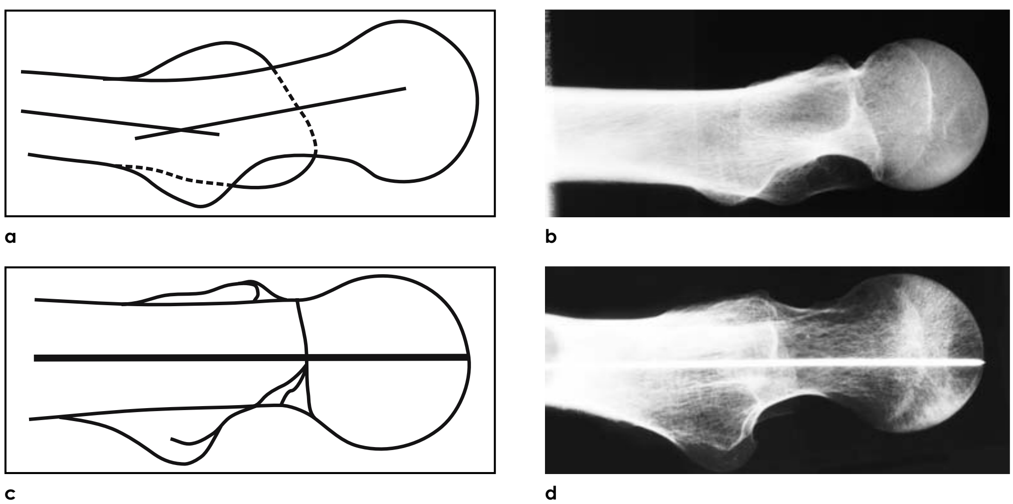


Fig. 78. Standard lateral film: schema and fine grain radiograph of a specimen. **a, b.** In internal rotation of 10 to 20° the neck axis shows the physiologic anteversion, it is inclined anteriorly; **c, d.** A more marked internal rotation abolishes the anteversion, longitudinal axes of neck and diaphysis form a straight horizontal line. This projection is familiar during surgery, it also shows a proper position of a guide wire

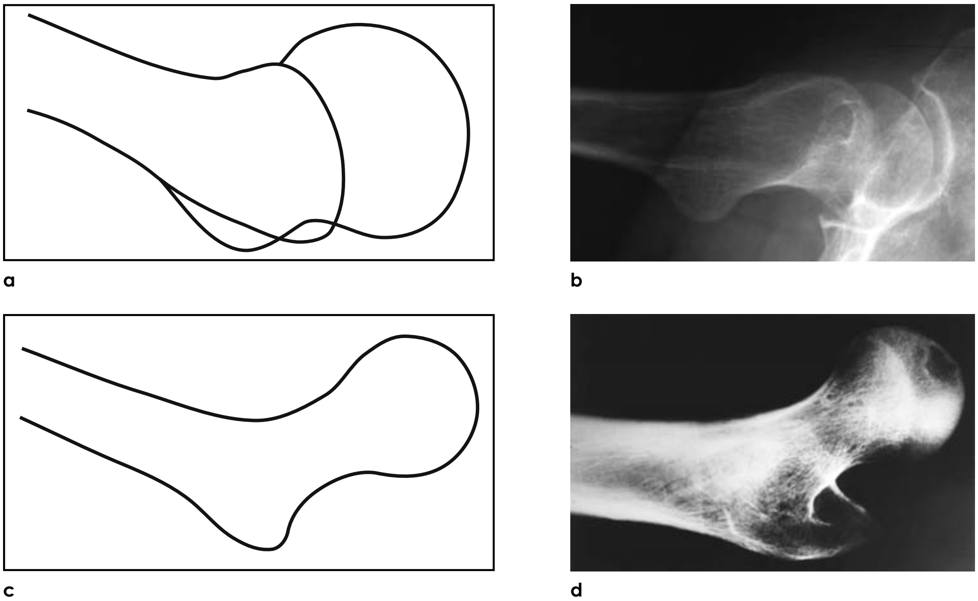


Fig. 79. Poor technique of a lateral film: schema and fine grain radiograph of a specimen.
a, b. The beam has not been centered perpendicular to the femoral neck, the greater trochanter is projected over the femoral head;
c, d. With external rotation the picture looks like an a.-p. film. Course of the fracture line as well as reduction and internal fixation cannot be properly seen with this faulty technique

3.2.1.2 Supplementary radiographs

The diagnosis of displaced fractures is unambiguous on standard radiographs. If the presence of an undisplaced fracture is suspected, we recommend additional films in **internal and external rotation.** Radiographs in two planes of the **opposite hip** in similar positions may also be of help. These additional films may assist in clarifying the degree of displacement in instances of coxa vara or valga and in assessing the reduction.

A.-p. radiographs of both hips together can be taken using the same cassette 15 x 40 cm. Radiographs of the entire pelvis are not well suited as the central beam will be directed to the midline and both hips seen on the edges of the radiograph. Preferable is a more caudally placed cassette. In this position the radiograph will show both coxofemoral joints.

Occasionally **magnified radiographs** can be useful to establish the diagnosis. Fine grain films used together with intensifying screens allow analyzing the bone structure.

Completely undisplaced fractures can be difficult to diagnose (Pathak et al, 1997) but their presence can be suspected by a **kinking of Shenton-Ménard's line (a.-p. film) or a straightened or interrupted S-shape of the head-neck-junction** (see Figs. 73a and 179) (Pannike, 1996).

Suspicions can be raised in certain forms of fatigue fractures that may appear as small folds of the anterior cortex, an interruption of the contours or a minimal axial deviation. Fine grain films may show an interruption in the course of trabeculae. Furthermore, the presence of osteoarthritis may present problems in interpretation in the a.-p. and lateral films, if the marginal osteophytes are erroneously interpreted as a fracture (see Fig. 98).

If a definite diagnosis is still uncertain, special imaging procedures have to be requested. As a basic rule any suspicion of a fracture must be cleared during **the first hospital visit.** Standard radiographs in two planes are sufficient for emergency procedures of fresh displaced fractures. Examination of circulation and other imaging procedures will not change the necessity for surgery and should therefore not be ordered.

Functional films (in ab-/adduction, internal and external rotation) are foremost desirable for surgical planning in instances of avascular necrosis (flexion-, extension-, valgus-, varus-, rotational osteotomies).

3.2.2 Special imaging procedures

3.2.2.1 Conventional tomography

Conventional tomography used to be an important tool in the classic radiologic diagnosis. This technique was done to demonstrate, detect and localize suspected abnormalities that could not or only poorly be seen on standard radiographs. A refined image was obtained on thin slices using a specially designed equipment. This technique has lost its place in the age of modern CT.

Where this method is still available, it is of help to assess **delayed healing and pseudarthrosis.** It is as reliable as scintigraphy and single-photon-emissions-computer-tomography (SPECT) but less invasive.

3.2.2.2 MRI (Magnetic Resonance Imaging)

The phenomenon of nuclear magnetic resonance was described by **Bloch et al** (1946) and **Purcell et al** (1946). Up to the end of the seventies and the beginning of the eighties it has been used for chemical analysis of structures in high frequency spectroscopy. Inspired by the success of the Fourier transformation the computer tomography was developed by **Lauterbur** (2004) and others and initially called "zeumatography".

Prerequisites are atom nuclei with angular momentum, a spin and a magnetic dipole moment. All atoms with an uneven number of protons show these characteristics. In biologic tissue the most frequently found atom is hydrogen. Its atom nucleus having only one proton is perfectly suited for imaging on account of its high dipole moment. The principle of this method is the fact that these atoms align in a strong magnetic field with a almost similar probability parallel or antiparallel to the field strength and form their circular movements in the direction of the outer magnetic field. This thermodynamic distribution of equilibrium can be markedly disturbed by a high radiofrequency stimulating impulse, when its frequency corresponds exactly with precession frequency of the preceding protons. The nucleus turns into a high-energy state. The temporal signal decrease is captured quantitatively. The time the system needs to return to the preexisting distribution of equilibrium is termed the longitudinal or **Spin-Lattice-Relaxation time (T_1).** Other interactions exist inside the MR system. Precession movements occur in the same phase during the initial impulse. After abatement of the impulse the preexisting state returns (phase loss). The time constant is termed transversal or **Spin-Spin-Relaxation Time (T_2).** The T_2 relaxation is determined by the interference of proton signals. The object to be examined is divided into cuts for localization of the captured signals; they are successively stimulated by the nuclear resonance. The traced stationary proton signals are analyzed by computers and transformed into a picture by complex mathematical calculations (Fourier transformation).

Permanent magnets (horse shoe or rod magnets) are used for the generation of magnetic fields. They are very heavy and their magnetic field strength is limited. They are, however, relatively inexpensive and horse shoe magnets with great openings or open rod magnets can be manufactured. Their advantage lies in the fact that contact with patients during the examination is easy, the video surveillance is facilitated, invasive procedures are possible and claustrophobic reactions are limited. For the examination of limbs as in orthopedics and sport medicine the use of specialized magnets (coils) is easy. Only one limb can be placed in its opening.

Two types of **electromagnets** exist: **resistive and superconducting magnets.** The disadvantage of the resistive magnets is the fact that a major part of the electrical input is converted into heat due to the electric resistance of the coil and the ferromagnetic loss of the magnet nucleus. For that reason the newer generation employs low temperature, superconductive coils to generate the magnetic field (4K). The maximal field strength of these magnets for use in humans amounts to 2 Tesla, a tenfold of that of the resistive magnets. More recently, devices have been developed with an even greater field strength thanks to Blood Oxygen Level Dependant (BOLD technique, 3 Tesla) for the functional examination of the brain. Magnets with a field strength between and 6 and 9 Tesla have been used for experimental purposes investigating specimens, their opening being only a few inches.

MRI cannot be used in patients with implants consisting of **ferromagnetic metals** (such as several stainless steels), as the strong magnetic field will cause heating and displacement. Moreover, they influence markedly the distribution of field strength of the outer magnetic field and thus distort the cross-sectional images. If after implant removal **microscopic ferromagnetic particles** remain, they may cause extensive artifacts and thus render impossible an assessment of their surroundings (Fig. 80). Non-ferromagnetic metals such as gold, silver, amalgam and titanium are only seen as localized **metallic artifacts.**

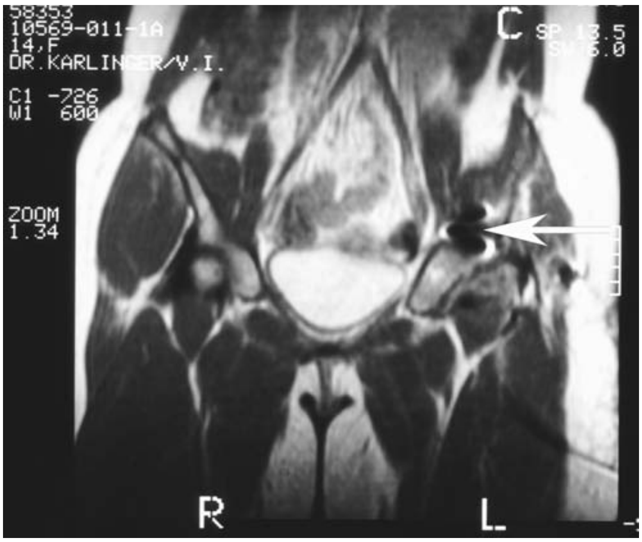


Fig. 80. MRI artifacts.
11-year-old girl. Fracture/dislocation of the left hip treated by internal fixation. Eight months after the injury on account of avascular necrosis and deformity a Chiari osteotomy was performed and fixed with Kirschner wires. After removal of the Kirschner wires, small metallic particles (arrow) remain in the acetabulum. They interfere markedly with the interpretation of the MRI (see Fig. 218)

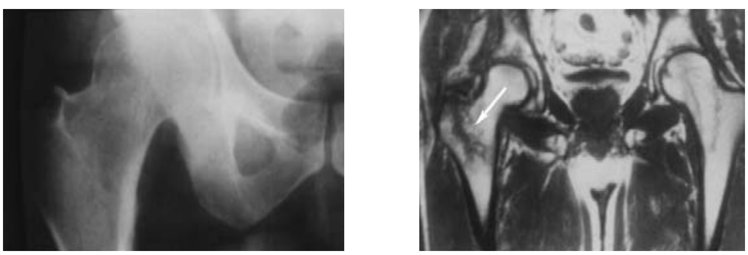
In patients with a **pacemaker** (or any other electronic device) MRI may not be used as it may cause damage to the device. Moreover, the metallic electrode implanted in the right chamber may act as an antenna for radio waves. If the electrode forms a loop, a currency can be induced here.

Patients in whom the limb has been immobilized in a particular position may only be examined with appropriately opened or with open magnets. Plaster casts or fiber glass splints do not interfere with MRI. In patients with claustrophobia a slight sedation or anti-claustrophobic techniques are recommended to prevent an attack.

MRI does not show the cortical bone itself as it does not contain hydrogen in sufficient quantities. MRI visualizes, however, very well bone marrow: the red marrow having a higher water content gives dark signals in T_1 weighted images and bright signals in T_2 weighted images. The fatty bone marrow shows bright signals in T_1 weighted images and dark signals in T_2 weighted images. If the goal of the examination is to diagnose bone marrow pathologies, such as traumatic edema, suffusion, inflammatory edema, changes accompanying deposition of edematous cells, it is recommended to use fat-suppressing sequences allowing the strong signals of water to predominate and fat to be saturated.

T_1 weighted images are advantageous for the demonstration of anatomic details and T_2 weighted images for pathologic conditions.

MRI is the preferred choice for the earliest possible and the least invasive documentation of a fresh, undisplaced femoral neck fracture (Poulsen et al, 1996; Sernbo et al, 1997b; Pandey et al, 1998) On T_1 weighted coronal images one can recognize already **within the first 24 hours** after



a b

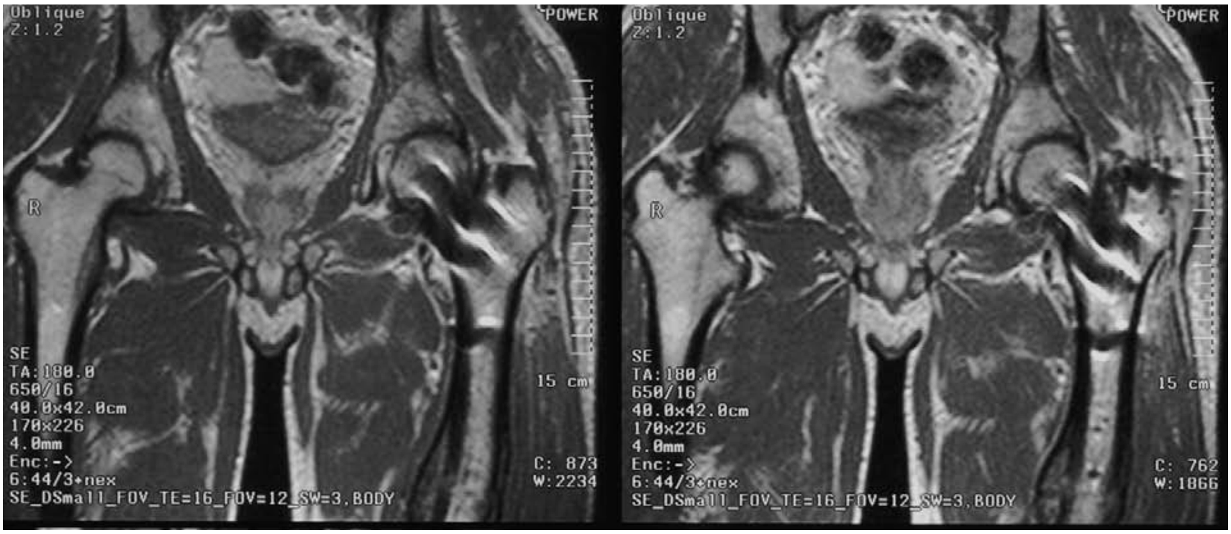
Fig. 81. Undisplaced fracture documented by MRI.
67-year-old woman, fell and hit her right hip; **a.** The standard a.-p. radiograph does not reveal a fracture; **b.** The T1 weighted image shows a radiolucent line corresponding to an edema of a trochanteric fracture (arrow) (film supplied by Dr. Kinga Karlinger)


a


b


c


d



e


f


g

Fig. 82. Early MRI after internal fixation of a neck fracture.
This 31-year-old patient was injured during a traffic accident. His condition was judged serious enough to transport him to our institute by helicopter; **a, b.** Radiographs show a left Garden-IV femoral neck fracture and an undisplaced acetabular fracture; **c. d.** An internal fixation was done within 4 hours: proper reduction and fixation with cannulated titanium screws; **e.** 3 weeks later T1 weighted films taken after contrast injection show a good blood supply to the head. The patient has not been positioned symmetrically; consequently, to allow comparison of the accumulation of the contrast agent in the intact and injured head two sequential images were needed. Little interference by the titanium screws; **f, g.** 4.5 years later the patient is symptom-free, the head contour preserved. Cysts lying anterior to the screws indicate the previous presence of circulatory disturbances

a

b

Fig. 83. Transient ischemia of the hip as seen in MRI.
a. This 55-year-old patient was sent for assessment of possible avascular necrosis of the right hip after an initial MRI was taken on account of recurrent pain. We diagnosed a transient ischemia based on the diffuse extent of the circulatory disturbance; **b.** After conservative treatment lasting for 8 months the MRI was repeated. Identical status of both sides, the patient was symptom-free

the injury a darker, poorly defined stripe at the site of the fracture and its immediate surroundings (Fig. 81). On T_2 weighted images a strong signal can be detected.

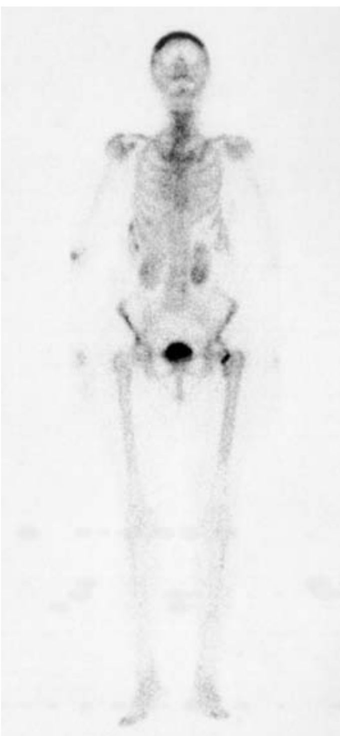
In Hungary, at the present, MRI for hip examination is employed mostly for an **early proof of femoral neck necroses** following a femoral neck fracture in younger patients or in non-traumatic avascular necrosis, as its availability in emergency cases is limited. Visible are edema of the bone marrow, stasis and definite necrosis. During the examination for avascular necrosis one is able to make a conclusion regarding the prognosis of the bone vitality thanks to an increased collection of the contrast medium (Gadolinium).

In younger patients, (in our practice persons under 50 years of age) having undergone an internal fixation with **cannulated titanium screws** for a femoral neck fracture an early proof of necrosis by MRI is possible. This will allow performing a timely intervention (decompression of the focus, osteotomy, pedicled bone grafts) that will avoid an early arthroplasty. The standard MRI will not indicate the extent of the necrosis during the first two weeks following the internal fixation. Starting with **the third week** the MRI after use of a contrast medium (Gadolinium) indicates without being invasive a circulatory disturbance, just as well as with DSA. The intensity of the contrast agent in the femoral head is less than in the distal femoral fragment, contrary to the situation when the circulation is preserved and the intensity in the head-neck area and in the diaphysis is equal (Fig. 82).

MRI is one of the most specific imaging procedures. In spite of this, there are pathologic changes in the hip area that can cause diagnostic problems such as **transient ischemia and transient osteoporosis.** Thanks to the increased availability of MRI machines in Hungary we see more and more patients who undergo an MRI examination for long lasting hip pain and in whom we can prove the presence of circulatory disturbances in the proximal end of the femur. Typical is a diffuse edema that after a conservative treatment will not or only faintly be seen anymore on the follow-up images (Fig. 83).

3.2.2.3 Scintigraphy (Bone scan)

In Hungary it is easier to make use of intravenously administrated radioactive agents than to obtain an MRI. However, undisplaced femoral neck fractures and stress fractures can only be identified later and with a lesser degree of certainty. Generally, Technetium (99 mTc) phosphate compounds are employed for examination of the skeletal system. They have the advantage of giving a functional, dynamic picture and exert less background or renal activities due to their fast blood clearance. They emit gamma rays of a half-life of six hours, an advantage in view of radiation activity. **72 hours after the injury** a broad stripe of increased activity in the fracture line and its surroundings is visible (Pretter et al, 1977; Brill, 1983; Matin, 1983; Williams et al, 1992; Holder, 1993) (Fig. 84).


a


b

Fig. 84. Bone scan for the diagnosis of concealed neck fractures.
This 60-year-old patient had fallen and injured her left hip. She was able to walk and standard radiographs failed to reveal a fracture. On account of continuing pain a 99 mTc scintigram was done two weeks later and showed a basal neck fracture; **a.** Already on the whole body film an isotope uptake is well seen; **b.** Magnified pictures of the pelvis in a.-p. and p.-a. show the uptake better during the bony (late) phase (pictures done by Dr. Zsuzsa Kopcsányi)

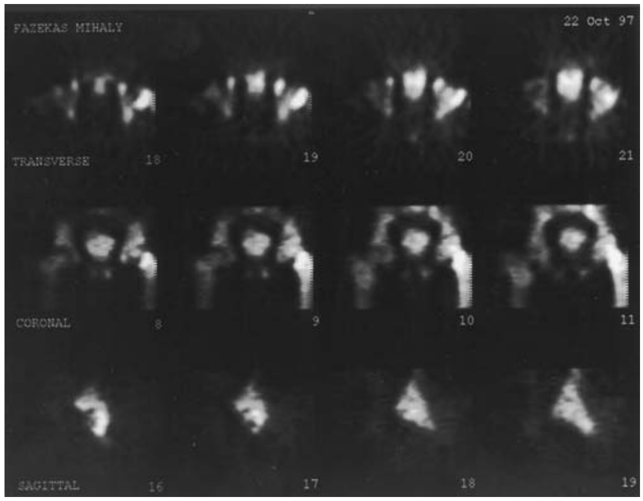


Fig. 85. Clinical application of SPECT.
In this patient, already shown in Fig. 82, a good femoral head circulation is seen after 2 months. The metal screws do not interfere with this examination

False negative results can be found in femoral head necrosis already present at the time of injury, false positive results may appear in the presence of local inflammations. For example, a scintigram made for bursitis complaints may give the appearance of a fracture of the greater trochanter. Scintigraphy for examination of circulatory disturbances after a fresh femoral neck fracture is not very popular on account of the difficulties to obtain in time the isotopes (these isotopes have a short half life!) and because their action is time limited. Moreover, they are not very specific, although several publications dealt with the possibility of employing scintigraphy for this purpose (Bauer et al, 1980; Strömqvist et al, 1984a; Strömqvist et al, 1984b; Strömqvist et al, 1984c; Holmberg et al, 1985). For these reasons we have applied scintigraphy for circulatory disturbances only in about 100 patients.

However, there exists one further application for a scintigram of the proximal femur in absence of the availability of MRI: the proof for a latent inflammation or loosening of nails, screws or metal implants, for a follow-up of progression of an aseptic necrosis or for the results of a revascularization procedure (Strömqvist et al, 1983a; Strömqvist, 1983b; Strömqvist et al, 1987).

3.2.2.4 SPECT (Single-Photon-Emission-Computertomography)

This method is also a part of the diagnostic tools of nuclear medicine. The radioactive tracer corresponds to that used in conventional methods. It is labeled with gamma ray emitting isotopes. The Emission Computertomography producing sequential slices examines the distribution of the radioactive agents in the body. A three dimensional reconstruction is possible with the help of digitalization, analogous to CT. This facilitates the exact anatomic localization of lesions.

SPECT detects the accumulation of the isotopes and thus the metabolism of the radioactively labeled substances by measuring the emitted energy. The computer digitalizes these data and presents them in slices.

During this examination a scintillation camera (scanner) rotating around the patient registers and measures the emission of the radionuclide. An image of the whole body along its longitudinal axis is taken and presented graphically. SPECT's advantage over conventional methods lies in the fact that it delivers **an improved three-dimensional resolution and localization** and differentiates better the emitting isotopes from the background, which means giving a better contrast.

Similar to the conventional planar scintigraphy one can recognize with the SPECT method a fresh, undisplaced femoral neck fracture after 72 hours, however with an improved resolution. At the moment we employ this method as well as MRI to detect femoral head necroses. SPECT has the advantage allowing its utilization even in the presence of a stainless steel implant employed for internal fixation (Greer et al, 1983; Haerten and Hernandez, 1984; Gates, 1986) (Fig. 85).

3.2.2.5 Intraosseous venography

We will deal with the conventional techniques examining the circulation of the femoral head as well as the present day importance of intravenous venography in a special section (3.3).

3.2.2.6 DSA (Digital-Subtraction-Angiography)

The principle of DSA is the creation of a pulsed emission of X-rays by a computer controlled X-ray generator. At each pulse an image is taken and stored. Thus a series of images can be produced. The examination starts with taking a conventional radiograph which serves as a template that is then saved. A contrast agent is now injected, in this case into the femoral head. The obtained images are read by the computer and projected onto the inverted template. The subtraction method allows cancelling against each other the negative and positive images. The result is a subtraction image that shows virtually only the vessels. With an amplifier used in CT it is possible to obtain a reliable, highly amplified picture. Since this method allows to distinguish contrast differences of only 1%, small doses of contrast agents are sufficient. The DSA is particularly advantageous during intraosseous venography as it detects vessels that can barely be seen with conventional methods. The heightened specificity of positive or negative results helps to formulate an indication for surgery with greater accuracy (Figs. 86 and 87).

Another great advantage of the DSA is the fact that one can produce video pictures with this technique. The circulation can therefore be observed in its **dynamic state.** One can also produce single pictures of the most important phases, once the video has been seen repeatedly.

It would also be possible to produce an arteriogram using the DSA technique. However, we consider this technique of little value for examination of the circulation of the femoral head for theoretical and practical reasons. Also it is not widely used in Hungary. On one hand, we believe that the restricted venous drainage is responsible for the circulatory disturbances. The arteries are less vulnerable and it is not certain that there exists a correlation between the condition of the arteries and the severity of the circulatory disturbance. On the other hand, due to the numerous anastomoses close to the joint, even a selective arteriogram will produce such a confusing image that its proper assessment will be very difficult. Finally, one should consider cautiously the increased risk of such a method.

For examinations of larger areas that require repeated injections of the contrast agent because of its rapid clearance, the combination of DS arteriogram and the Seldinger technique (1961) is useful. We apply this technique in instances of avascular necrosis, when we plan an **insertion of a pedicled bone graft taken from the iliac crest** and would like to have an information regarding the course and caliber of the deep circumflex iliac artery that will be used as a pedicle (Salacz et al, 1993; Hankiss et al, 1997).

Several times in the past we have employed an **invasive radiologic method** in pathologic, metastatic femur fractures close to the hip. Our goal was to reduce the intraoperative blood loss from vessels supplying the tumor by a **selective DS-arteriography and embolization** 24 hours before resection and arthroplasty or before internal fixation (Baktai et al, 1998).

3.2.2.7 Sonography

Ultrasound examinations have no role in the diagnosis of femoral neck fractures. However, they are helpful for a diagnosis of intraarticular fluid collection. Already a **2 ml hemarthrosis** can be revealed (Poulsen et al, 1996). This may be of importance particularly in **Garden-I and -II or femoral neck fractures in adolescents** when an immediate surgery is not possible. In this instance an aspiration of the hemarthrosis becomes mandatory (Wingstrand et al, 1986).

This cost efficient, noninvasive technique is indispensable in the diagnosis of certain early complications. Location and extent of **wound hematomas** can be recognized. An unlimited **repeated follow-up** of sonography may become helpful in doubtful scenarios as this examination poses no risk to the patient. The interpretation of these images is not always simple as the hematoma often spreads far under the fascia in caudal and posterior directions.

Deep venous thromboses often without symptoms following hip surgery are easily and reliably diagnosed and controlled by **color-Doppler-sonography.** Their diagnosis is dependable and easy to verify.

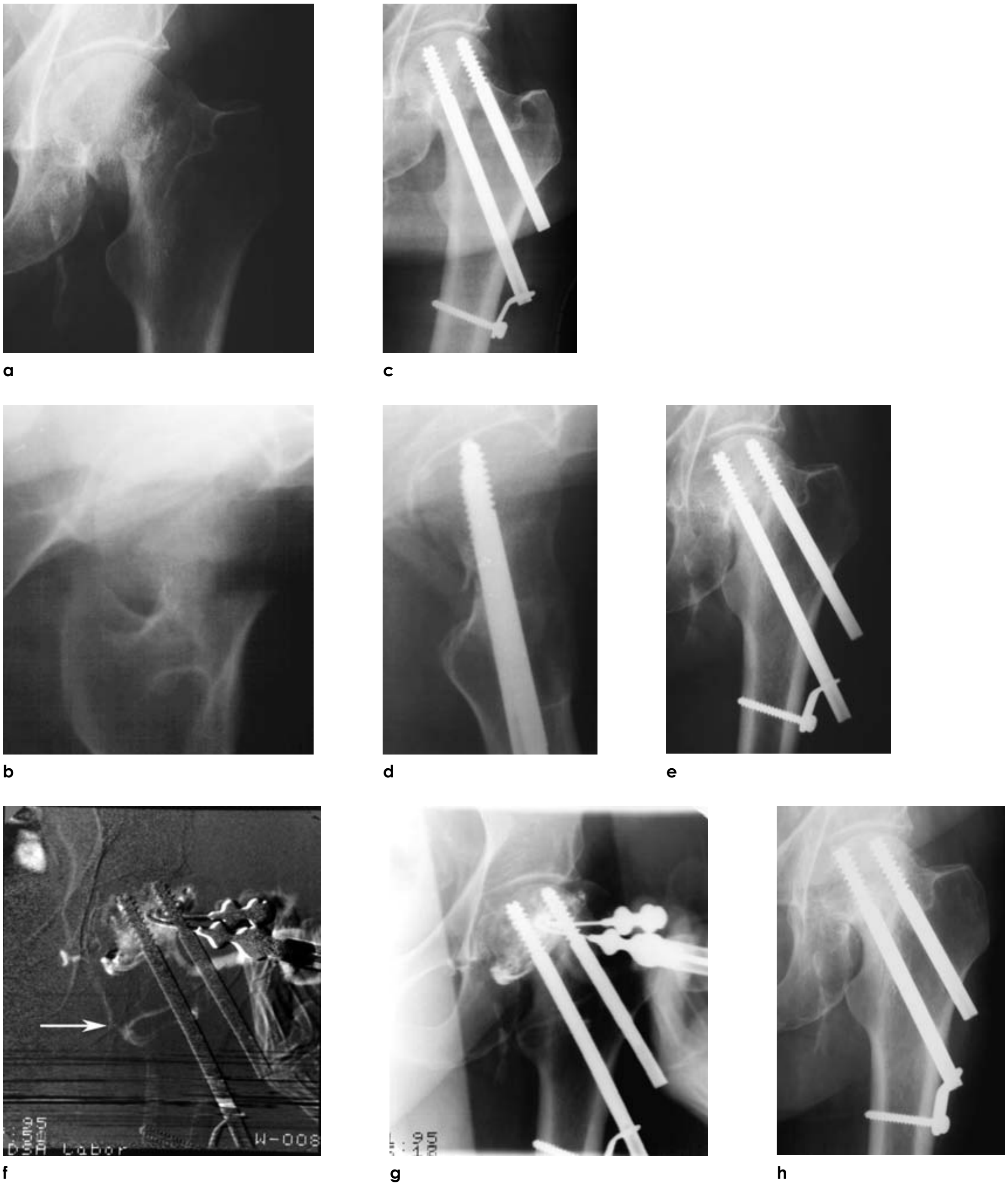


Fig. 86. Clinical application of the Dynamic Subtraction (DS) intraosseous venography I.
74-year-old woman; **a, b.** Left Garden-IV neck fracture; **c, d.** The internal fixation was performed 8 hours after the accident; **e.** The examination done 4.5 months later showed a marked neck resorption, impaction and tilting in varus, the patient voiced uncharacteristic complaints (vascular disturbances?, irritation by screw ends?); **f.** The DS intraosseous venography clearly showed the preserved venous drainage via the medial epiphyseal and the circumflex veins (positive result) (arrow); **g.** A standard radiograph taken at the same time does not show these vessels well. An exchange of screws was performed; **h.** One year later the shape of the head was preserved, the fracture consolidated and the patient symptom-free

Fig. 87. Clinical application of the Dynamic Subtraction (DS) intraosseous venography II.
59-year-old woman; **a, b.** Left Garden-IV neck fracture; **c, d.** Internal fixation with two cannulated screws was performed 10 hours after the accident. Inadequate reduction (varus and recurvatum) besides an unstable internal fixation (screws cranial and posterior to Adam's arch); **e, f.** An early loss of reduction occurred after mobilization of the patient; **g, h.** Due to the young age of the patient a DS intraosseous venography was done to decide whether to perform a revision internal fixation or an arthroplasty: evident congestion in the head without drainage (negative result). A total hip replacement was done

3.2.2.8 CT (Computertomography)

Today CT has rendered the conventional tomography obsolete. The modern fast spiral and multislice CT equipment produces excellent pictures. There is also the possibility of a multiplanar or 3-D reconstruction. For particular purposes a color-coded 3-D or volumetric representation of the digital data block is possible in any plane. Undisplaced fractures can be well seen irrespective of the fracture plane. The speed of this method will replace the entire classical radiographic methods. Of course, the primary condition of the patient has to be exactly established first. All metal implants including titanium interfere with the proper CT examination. The software, developed to eliminate these interferences, has not fulfilled yet our expectations.

In particular, CT has a special importance in staging the femoral head necrosis. The angle of the necrotic sector is determined in the a.-p. and lateral planes. The sum of the angles formed by the lines demarcating the necrosis in both planes is termed **angle of necrosis.** Many authors base their surgical planning on its size. If the sum of angles seen in the a.-p. and lateral films does not exceed 200º, an osteotomy and later a revascularization should be attempted. If the sum is greater, an arthroplasty is indicated (Salacz et al, 1993).

3.2.2.9 DLR (Digital Luminescence Radiography)

Digital luminescence radiography combines images taken with the digital technique and with standard radiography under analogous exposure. The images can be improved thereafter to exclude errors of exposure. Besides, separate soft tissue films become superfluous. For diagnosis of small cracks a change of colors (black for bones, white for soft tissue) can be of great help. Another possibility is the generation of films with sharp borders (Fink et al, 1996; Hofstetter and Voegeli, 1997). This technique is almost never used in Hungary. An exact assessment of the speed of blood flow in tissues may, however, be of value in the future.

3.2.2.10 LDF (Laser-Doppler-Flowmetry)

The LDF method permits the measurement of the speed of blood flow in tissues of more than 6 mm^3. The speed of flow is measured with Laser. The initial signal is a function of the number and speed of the volume of circulating erythrocytes. Well vascu-

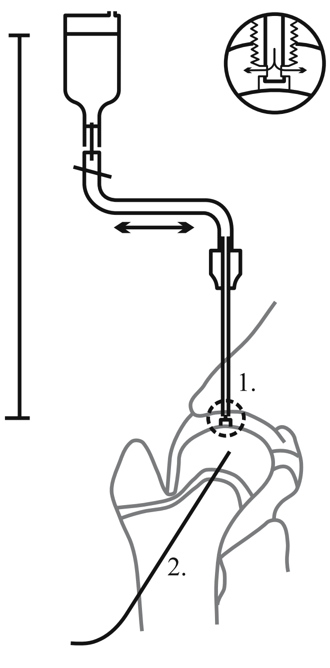


Fig. 88. Laser-Doppler-Flowmetry.
In the animal experiment the sensor is advanced through the acetabulum into the joint (1.) whereas in the clinical situation it is inserted through the greater trochanter (2.) into the subchondral bone of the head

larized tissues emit a stronger signal whereas tissue with a poorer capillary flow give a weaker signal, i.e., a lower tension as measured in mV. The blood flow in the subchondral bone is measured with a sensor allowing an assessment of the vitality of the femoral head. The sensor is introduced intraoperatively through the trochanter into the head or, under experimental conditions, through the joint. This allows measurement of the weight bearing area through the articular cartilage. This technique is very expensive and therefore has not found wide acceptance in Hungary (Fig. 88).

3.2.2.11 RSA (Roentgen-Stereophotogrammetric-Analysis)

This method has been developed by **Selvik** in 1974 and described in detail in 1989. It consists of an implantation of tantalum beads having a diameter of 0.1 to 1 mm into bone around implants under

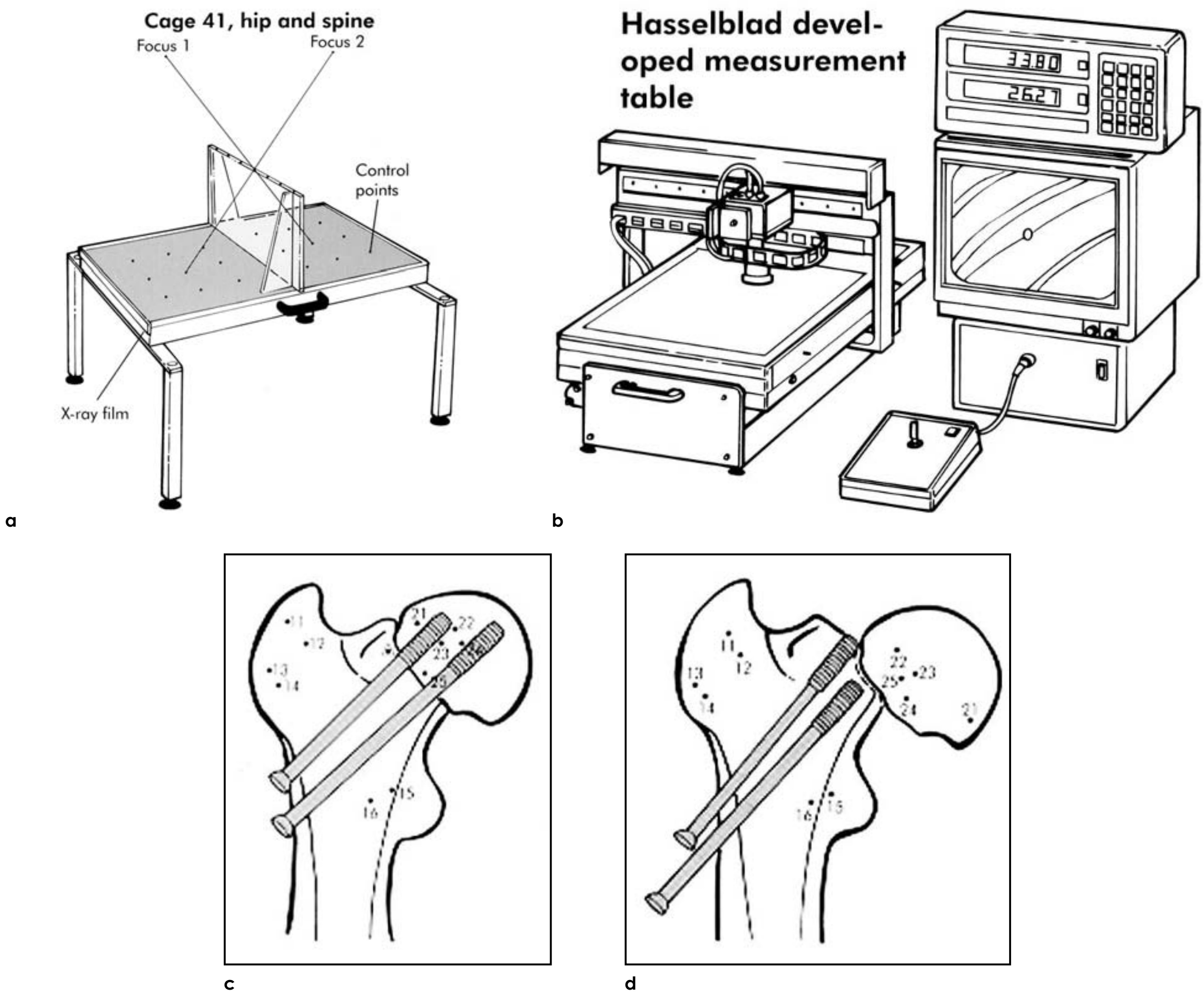


Fig. 89. The RSA technique (Selvik, 1989).
a. Calibration table. Markings identify the places for cassettes and control points; **b.** Special Hasselblad precision table and digitalization. The following clinical examples are shown: **c.** Neck fracture stabilized with screws; **d.** its displacement after one month. Identical tantalum beads identify the femoral head that displaced not only in varus but also rotated by 80°. This example has been published by Selvik. Today even smaller displacements can be detected: loosening of prosthetic components, migration of implants

experimental or intraoperative conditions. Tantalum is a tissue friendly material and its radiodensity permits a distinction from that of other metals or artifacts. After surgery and at set dates during the follow-up **radiographs in two planes** are taken of the area to be examined. The examination is done on a **calibrating table;** its top contains similar tantalum beads for control. The films are digitalized with the help of a special Hasselblad precision table. Specific software allows determining the displaced position of the implanted tantalum beads in relation to the reference points of the calibration table (Fig. 89).

This complex and expensive technique practically eliminates errors of radiographic exposure and permits to follow the migration of fragments or implants over years as the radiographs are always taken under identical conditions (Ragnarsson et al, 1992; Ragnarsson et al, 1993; Nilsson and Kärrholm, 1996).

Summary

Not often enough can we insist on the need to obtain standard radiographs in two planes. Without them the exact assessment of the displaced neck fracture and the planning of proper surgery are difficult. Moreover, without them the classification (determination of the alignment index and the appearance of the fracture surface) is almost impossible.

If an undisplaced fracture is suspected, the patient should not be discharged before the diagnosis has been ascertained. For this, radiographs of both hips, views in internal and external rotation and magnified films should be taken. If these examinations do not result in a definite diagnosis, an MRI should be done 24 hours later and a bone scan (possible SPECT) after 72 hours. If these tests are not available in a given hospital, it is preferable to transfer the patient to a tertiary care hospital where these tests can be performed.

3.3 Examination of the circulation in the femoral head (intraosseous venography)

Intraosseous venography was introduced at the National Institute of Traumatology (Budapest) at the beginning of the sixtieth. After needle insertion into the femoral head a contrast agent is injected allowing a pre-, intra- and postoperative assessment of the circulation. We published our experience in a monograph written in German (Manninger et al, 1979). In 1963, H. L. Boyd visited our institute and after examining our intraosseous venographies he came to the conclusion that our method is superior to isotope examinations and angiographies.

3.3.1 Short description of the method

The intraosseous venography is nowadays combined with the DSA-technique and is performed under a short general or local anesthesia. The method used by **Manninger et al** (1979) is based on the technique published by **Hulth** (1956), and **Herzog** (1962). Since over 30 years we use a modified epidural needle having a double wall and two lateral openings at its tip to prevent clogging (Fig. 90).

With the patient supine and after prepping and draping the mid point of the femoral head is determined (see Fig. 76). The needle is inclined caudally and laterally to avoid the external iliac artery and vein and the anterior rim of the acetabulum and is introduced into the femoral head to a depth of 2 cm with slight hammer blows. We aim at a point slightly cranial to the midpoint of the head and at the apex of the pie-shaped segment of the head (Fig. 91).

5 ml of a contrast agent (early on we used Uromiro®, now Omnipaque® and Optiray®) are injected over 30 seconds. The **filling** can either be followed by serial radiographs or a video camera and the pictures stored. Thereafter, the head is rinsed with 10 ml of saline, thinning the contrast medium; the drainage is documented on films. In the presence of major lack of evacuation the sequence of pictures is repeated after 10 minutes to record the degree of the delayed drainage.

The DSA technique permits also the demonstration of smaller vessels. The dynamics of filling, evacuation, drainage and possible congestion can be fol-

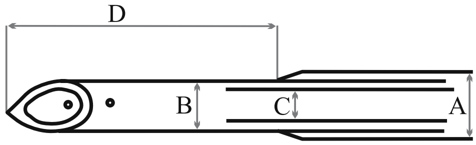


Fig. 90. Modified epidural needle, schematic representation.
For intraosseous venography two lateral holes were added at the needle tip as well as a doubling of the wall. A = 2 mm; B = 1.8 mm; C = 1.3 mm; D = 23 mm

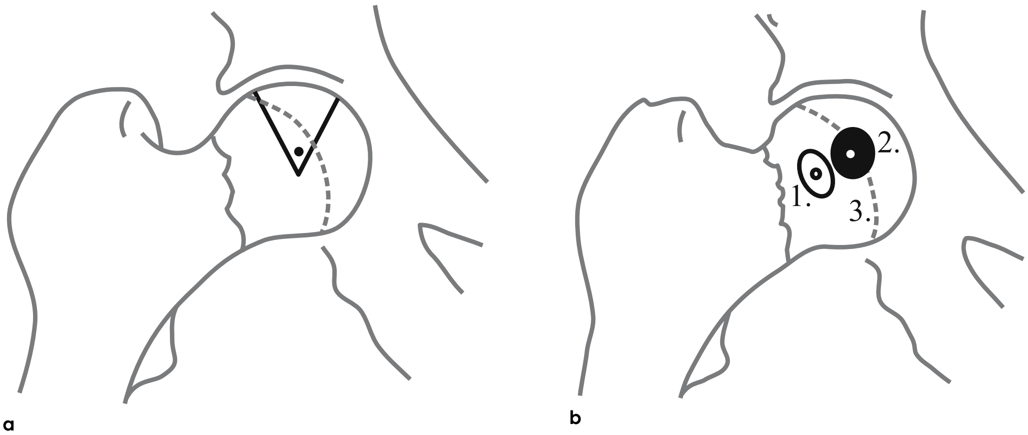


Fig. 91. Schema of correct aiming (Manninger, 1963).
a. The head segment (pie-shaped) where necrosis and collapse occur most frequently; **b.** The point of correct needle entry at the skin (1.) and at the femoral head (2.). The anterior rim of the acetabulum (3.) must not be pierced with the needle

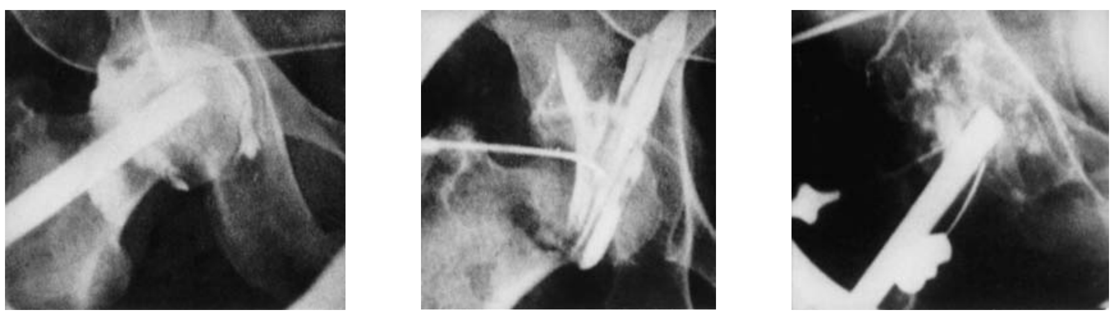
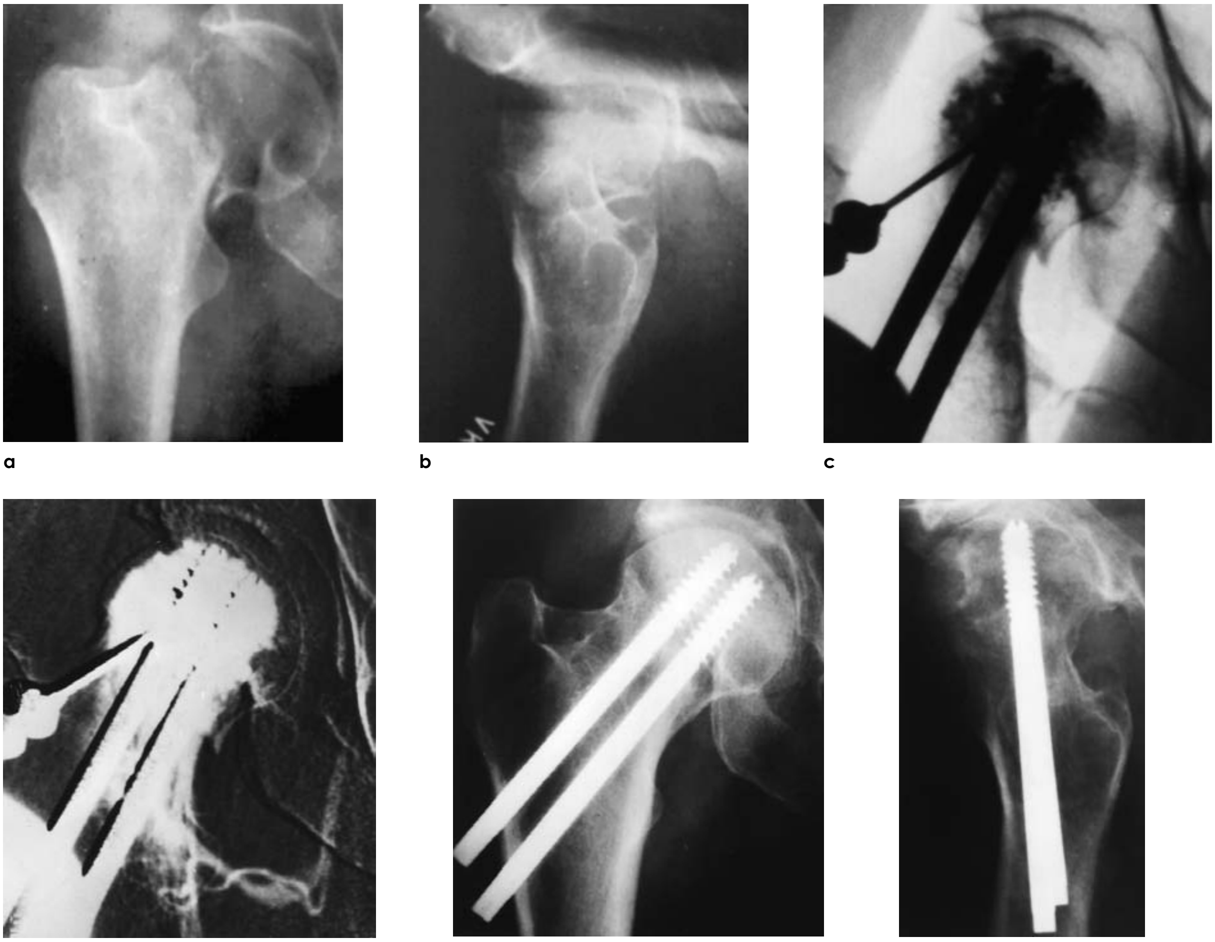


Fig. 92. Technical errors during intraosseous venography.
a. "Arthrography": the contrast medium is not injected into the head but into the joint space, no filling of femoral head;
b. Extraarticular filling: the needle is placed too superficial, the contrast agent is injected into the psoas muscle;
c. Intrapelvic injection: the tip of the needle lies at the anterior acetabular rim. Although the head is filled and a venous drainage seen, the borders of the joint are obscured, spots of the dye are seen in the pelvis

lowed on the monitor by repeatedly playing the sequence. Pictures of the most important moments can be taken. This allows to enhance the reliability of the intraosseous venography. A good venous drainage mostly via the circumflex and epiphyseal veins (see Figs. 41 and 86) is called a positive result and absence of drainage (see Fig. 87) a negative result. Attention should also be paid to the anastomosis (Weathersby, gluteal vessels), the intraosseous flow as well the retention of the contrast agent in the femoral head that increases proportional to the vascular damage.

Meticulous adherence to the technique guarantees a reliable result. Technical errors arising



a b c

d e f

Fig. 93. Positive Dynamic Subtraction (DS) intraosseous venography 3 months after the initial operation.
59-year-old woman; **a, b.** Garden-III fracture of right hip. Reduction and internal fixation 12 hours after trauma. Three months later venogram was done on account of slight tilting in varus and pain at the trochanter area; **c.** Conventional intraosseous venography; **d.** The simultaneous performed DS venography showed clearly a filling of the head and a good venous drainage via the circumflex and femoral veins. Thickening of the lateral cortex was thought to cause the symptoms (see Fig. 149a and b); **e, f.** Five years later normal head contour, anteriorly a minimal partial necrosis is seen that does not involve the weight bearing area. The patient is symptom-free

from a faulty needle placement, injection into the joint or into the pelvis must be avoided at all costs (Fig. 92).

Intraosseous venography is a safe procedure when performed under strict aseptic conditions. No iatrogenic vessel injury has been recorded in the course of 2800 procedures and only one instance of coxitis that occurred in a patient with avascular necrosis during the first year of using this method has been seen.

3.3.2 Indications for intraosseous venography

We believe that intraosseous venographies are not indicated any more for fresh hip fractures as their outcome will not influence the choice of the surgical technique. Our experience taught us that even in instances of a negative result a consolidation without complications is possible (Manninger et al, 1979). This can be foremost explained by the fact that at the time of the intraoperative ex-

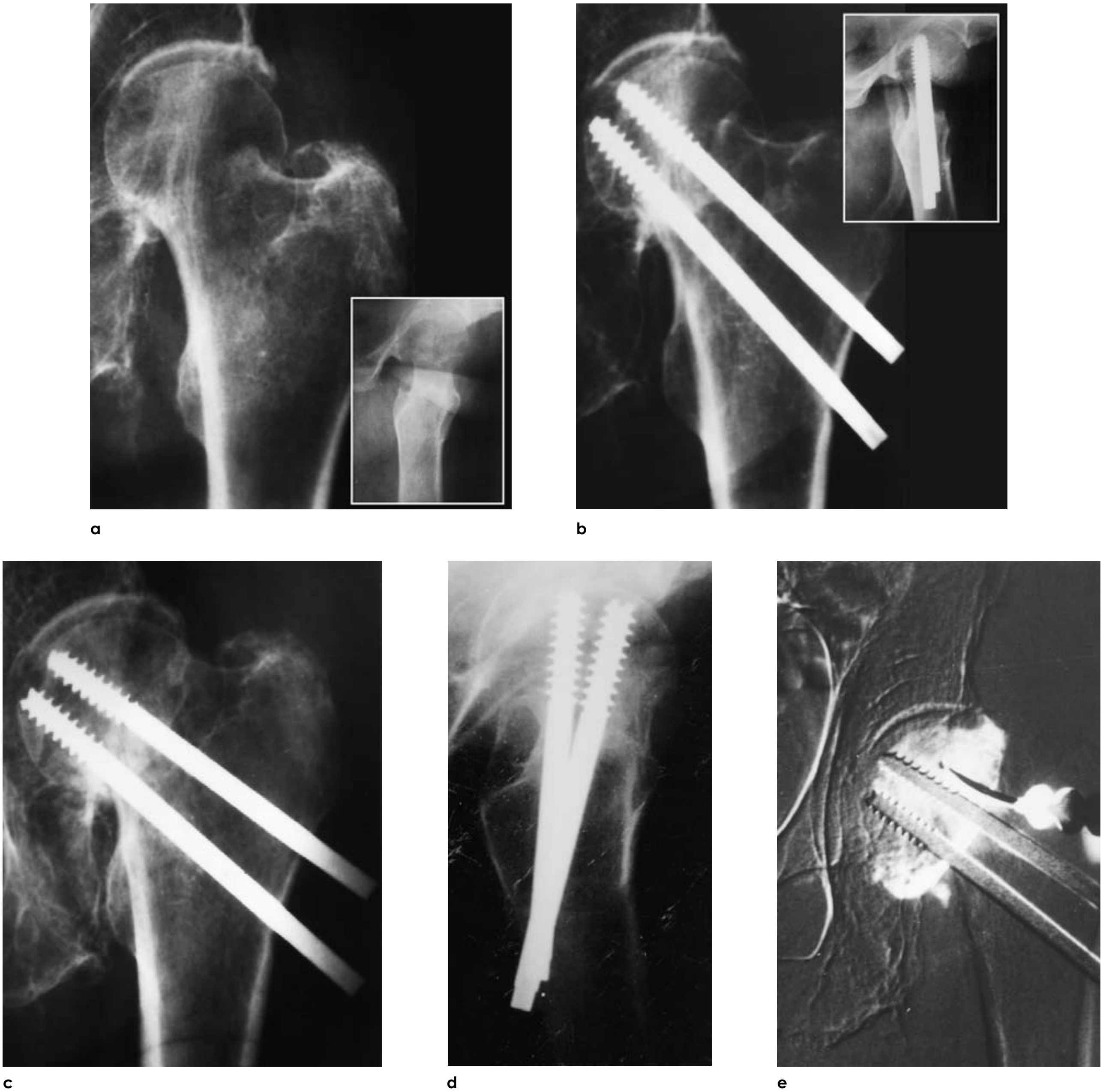
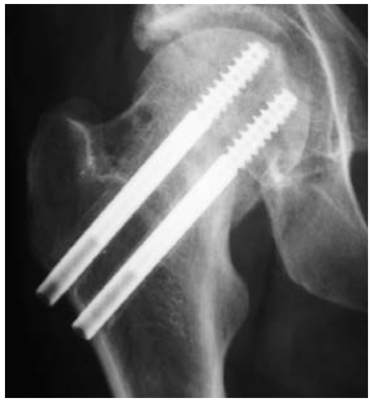


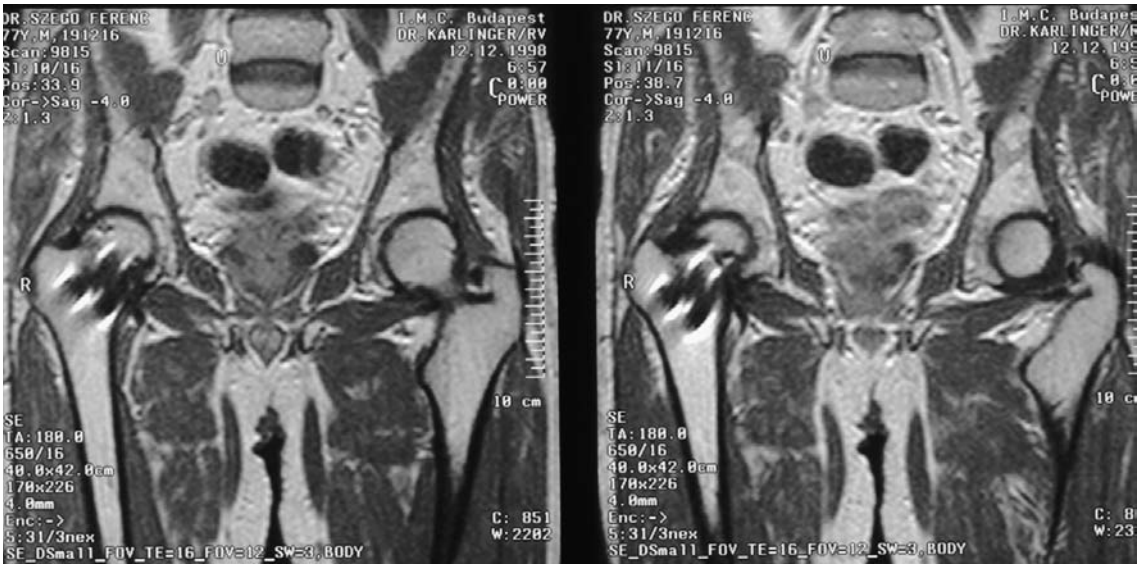
Fig. 94. Negative Dynamic Subtraction (DS) intraosseous venography 2 months after the initial operation (see also Fig. 155).
62-year-old woman; **a.** Garden-I fracture of left hip in hypervalgus (a.-p. alignment angle 190°); **b.** Reduction and internal fixation with cannulated stainless steel screws; **c, d.** 2 months later the patient fell during an epileptic grand mal seizure. The fracture displaced in varus and rotation; **e.** DS intraosseous venography turned out to be negative, a THR was performed. Histologic examination of the removed femoral head confirmed the diagnosis of necrosis. If we had immediately added to the screw fixation a buttressing plate, a loss of reduction would probably not have happened

a

b



c



d

e

Fig. 95. MRI after exchange of titanium screws.
This 72-year-old patient suffered a right neck fracture and was treated elsewhere with cannulated stainless steel screws; **a, b.** 11 months later the fracture had healed in varus with marked shortening of the neck. The patient sought our help on account of increasing pain. After the clinical and radiologic examination it remained doubtful whether the symptoms were due to an impaction leading to backing-out of screws or to an early necrosis; **c.** As the otherwise active patient reported a hypersensitivity to contrast agents we decided in spite of his age in favor of an implant change with shorter titanium screws which would allow later a MRI examination; **d.** 2 months after the exchange the MRI showed a normal circulation in the head, the patient was almost free of symptoms; **e.** 5 years later he was completely symptom-free, the contour of the head was preserved

amination after reduction of a fresh fracture a vessel spasm exists that later will relax. It would be a serious error, particularly in younger individuals, to base the indication for an arthroplasty on a negative result of an intraosseous venography.

Currently there is no method known that can determine safely and reliably the vitality of the femoral head in instances of fresh fractures (to decide whether an internal fixation or arthroplasty should be performed). MRI and bone scan are only of help once 24 to 72 hours have elapsed. Difficulties in interpretation have to be expected when performed as emergency tests. LDF can only be performed during surgery; besides it is costly. An arteriography cannot be performed on account of the problems previously discussed.

For this reasons we currently always perform **emergency internal fixation without prior investigation of the circulatory status of the head.** In instances where the general condition of the patient, concurrent diseases or delayed admission to hospital delays surgery, a venogram may be envisaged.

Even if more modern techniques are now at our disposal, as enumerated in the preceding chapters, the **intraosseous venography performed at later stages** has not lost its importance, particularly when combined with DSA. Given the fact that titanium implants are rarely used in Hungary, a postoperative MRI in younger patients with hip fractures treated with stainless steel implants is not indicated. If a displacement or a pseudarthrosis occurs after internal fixation, the intraosseous venography combined with DSA technique is a reliable procedure for the diagnosis of the vitality of the femoral head and for the choice of the kind of revision surgery (see Figs. 86 and 87).

In patients under 60 years of age, but particularly in adolescents and children, it is of utmost importance to assess and treat early a circulatory disturbance in the femoral head after internal fixation. Already 3 months after the initial operation the DSA-intraosseous venography furnishes a reliable information (Figs. 93 and 94).

If an inadequate blood supply is diagnosed, the duration of non-weight bearing has to be prolonged. If necessary, in adolescents a timely operation is possible to prevent collapse of the femoral head secondary to necrosis (osteotomy, preventive revascularization). If the result is uncertain and if the intervention is not urgent, the examination should be repeated after 6 to 12 weeks. Comparison of both examinations is of great help in the assessment of the vitality of the head. Investigation of the femoral head circulation after implant removal is nowadays done in Hungary with MRI. It is also possible to exchange stainless steel screws for titanium implants and perform an MRI thereafter giving us a reliable picture of the femoral head's vitality (Fig. 95).

3.4 Diagnostic problems (recommendations how to avoid mistakes and errors)

In certain cases problems may arise during the attempt to confirm or to exclude hip fractures in spite of a meticulous examination. Overlooking or recognizing too late a fracture may have serious consequences for the patient. The number of complaints rises steadily, sometimes leading to legal suits. It is for these reasons that we describe in detail instances where diagnostic problems may arise.

A hip fracture may be missed in polytrauma patients; their serious injuries may overshadow a femoral neck fracture causing no or very few symptoms. On account of the **great impact of forces** (being run over, collision, fall from great height) it is essential to take always a **radiograph of the pelvis.** If a hip dislocation, a femoral shaft fracture or bony/ligamentous injury of the knee **(dashboard injury)** have occurred at the same time, a radiograph of the femur in two planes has to be taken. The **proximal and the distal epiphyses must be visible in their entirety** (Fig. 96)!

Some patients with hip fractures do not localize their pain at the hip or groin but at the **medial aspect of the thigh or even at the knee.** If a meticulous clinical examination has not been performed and if radiographs were only taken of the distal femur and knee, a femoral neck fracture may be overlooked. This oversight has led to claims for compensation and even to a conviction of the physician.

The foremost risk of undisplaced fractures is the danger of **misdiagnosing and overlooking the fracture** (Williams et al, 1992; Pathak et al, 1997) (Fig. 97, see also Fig. 138).

It can also happen that a **hip fracture is diagnosed erroneously** in a patient with a history of injury and hip pain. Particularly in elderly persons, marginal osteophytes secondary to osteoarthritis or capsular calcifications may lead to a suspicion of a fracture as they project over the neck. This erroneous diagnosis may result in an unnecessary operation (Fig. 98). **An indication for immediate surgery does not exist under these circumstances.** There would have been enough time to confirm or exclude a fracture with additional examinations (internal and external rotation, magnifying films, comparison with the opposite hip and, if necessary, other imaging procedures).

L. Böhler taught for decades (first in 1951) and followed his own recommendations that in instances of suspected fractures **three radiographs should always been taken (a.-p. films in external and**

internal rotation and proper lateral radiographs) (Böhler, 1996). Even today it is advisable to follow his recommendations in problematic cases (Figs. 99 and 100).

It is possible that the diagnosis is made even when the patient is unable to recall neither the **moment nor the fact of an injury.** Also in this instance a radiograph of excellent quality will be useful to find out whether the fracture is fresh or remote. A high-riding trochanter, a marked shortening of the femoral neck and smooth fracture surfaces may point to a remote injury that might have happened even some weeks ago. The blood supply to the head fragment is preserved in some remote fractures. Months later a cortication of the proximal fracture surface is visible (Fig. 101).

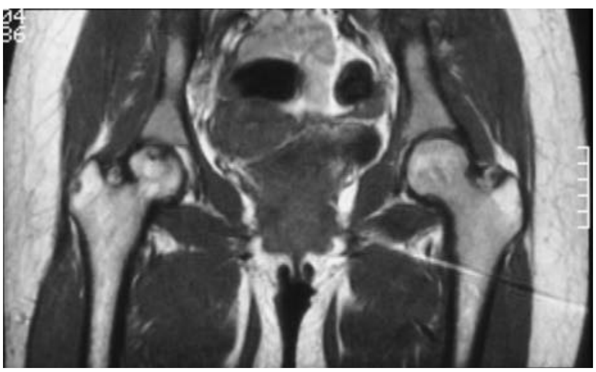
Problems arise in determining the age of a healed or healing Garden-I fracture, when radiographs taken at the first examination show that the fracture is not fresh (Fig. 102).

The occurrence of several hip fractures after repeated falls is rare. In this scenario it is important to decide which of the fractures is fresh necessitating a stabilization (Fig. 103).

Attention should also be paid to **fractures of the pubic ramus.** As the accident mechanism is identical to hip fractures, the symptoms are similar. Often these patients are admitted to a hospital with the provisional diagnosis of a neck fracture. It may also happen that both fractures have occurred simultaneously creating a diagnostic dilemma (Fig. 104).

Finally, Fig. 105 illustrates an unfortunate but instructive example of the sequelae of an unrecognized neck fracture and its faulty treatment.

If a fracture is suspected, a diagnosis must be established. All pertinent examinations are mandatory. The aftercare of problematic and unrecognized fractures is the responsibility of an experienced specialist.



f

g

Fig. 96. Missed femoral neck fracture in a polytraumatized patient due to inadequate radiographs.
This 19-year-old female patient was injured in a motorcycle accident having been a passenger. The clinical picture was dominated by shock, trauma to the chest wall and abdominal organs (ruptured spleen and liver) as well as by a compound, comminuted fracture of the right femoral diaphysis, patella and ankle. These injuries were treated immediately; **a, b.** The already on the a.-p. visible Garden-III neck fracture was missed due to inadequate radiographs; **c.** After the emergency treatment a multiorgan failure set in as well as an infection of the right femur. The leg was immobilized in extension; **d.** For this reason the internal fixation with two cancellous bone screws was only done 34 days later; **e.** 14 months later a MRI performed after screw removal showed a pie-shaped, partial necrosis of the head. The patient had to use crutches for 2 years; **f.** A repeated MRI after 5 years confirmed progressive healing of the necrosis; **g.** The contour of the femoral head was maintained. Since then the patient became a mother, she is free of symptoms

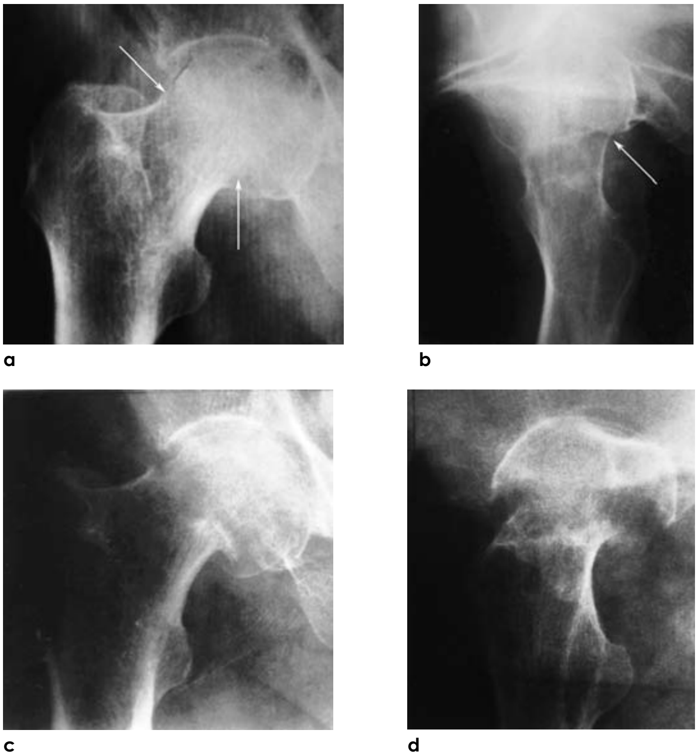


Fig. 97. Unrecognized Garden-II neck fracture.
This 73-year-old female patient had a fall and banged her hip. **a, b.** On account of poorly exposed films in external rotation the injury was regarded as a contusion and the patient was discharged home. Subsequently, the patient was admitted to another hospital and while being mobilized her pain increased; **c, d.** A repeated radiograph revealed a Garden-III neck fracture

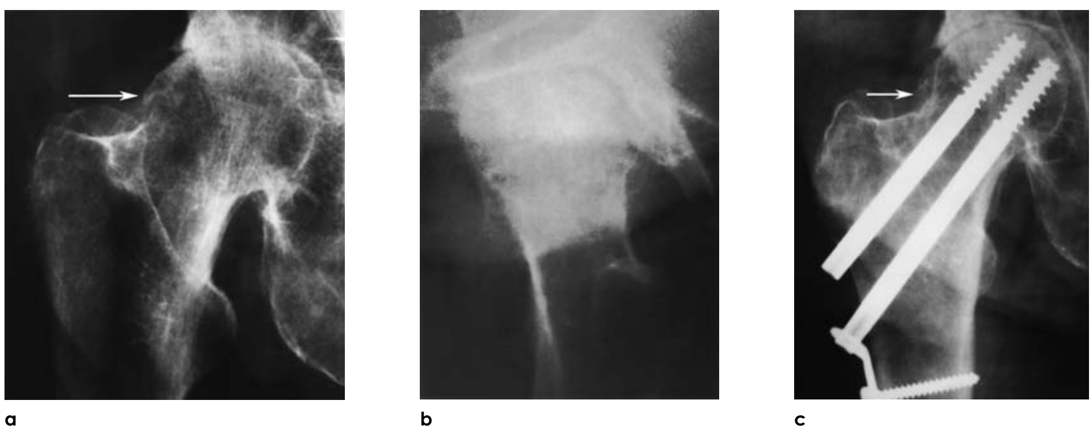


Fig. 98. False positive diagnosis.
The 83-year-old female patient injured her right hip during a fall; **a, b.** Diagnosis of the neck fracture was made; **c.** The patient was treated by an internal fixation with cannulated screws. On the radiograph no fracture could be seen. The examining physician had been induced into error by osteophytes caused be a coxarthrosis. (Trochanteric fractures occur more often than neck fractures in instances of advanced osteoarthritis)


a


b

Fig. 99. Documentation of a neck fracture on a.-p. films with the limb in internal rotation.
This 45-year-old patient fell from a tree and injured his hip; **a.** The initial a.-p. film has not been properly taken as the limb had been placed in external rotation. The greater trochanter is projected over the neck and obscures the fracture; **b.** The fracture becomes only evident with the limb in internal rotation


a


b

Fig. 100. Documentation of a neck fracture in a film taken in external rotation.
This 82-year-old woman fell and injured her right hip. After the fall she was able to walk; **a.** On the initial a.-p. film correctly taken in internal rotation no fracture was apparent; **b.** The fracture became evident two days later when the radiologist recommended a radiograph to be taken in external rotation. An internal fixation with cannulated screws was done


a


b

Fig. 101. Radiographs of a patient with a cortication of the proximal fracture surface (Kazár, 1963). 51-year-old patient; **a.** 10 months after the injury the femoral neck holds the in varus tilted head due to impaction of the calcar femorale; **b.** 10 years later a tight pseudarthrosis has developed. The head is vascularized, its density is identical with that of the surrounding bony structures, the fracture surface has sealed off. The contour of the head and the coxofemoral joint are almost unchanged. The greater trochanter is high riding. The pseudarthrosis has been caused by the wear of the calcar and the fact that the head is in contact with the lesser trochanter. The patient has used a cane for all these years, but his symptoms have increased over the past year. In the presence of a living femoral head an internal fixation would still have been possible after 10 months after the original injury, at the time when the chance for consolidation of the pseudarthrosis was still good (See Figs. 120. a–d and 140)

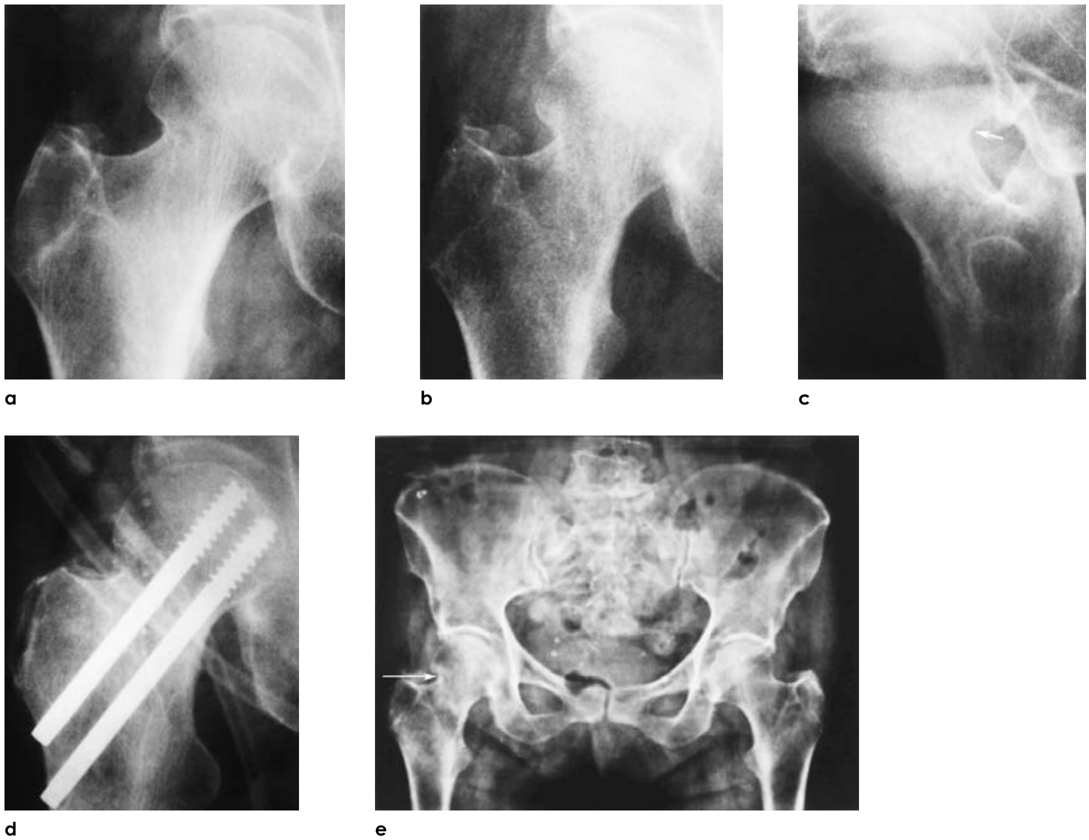


Fig. 102. Remote Garden-I fracture.
This 69-year-old woman injured her right hip during a fall 6 weeks ago. She continued walking; **a.** A specialist interpreted the radiographs taken in an ambulatory facility as being negative; **b, c.** 6 weeks later the patient was admitted to a hospital on account of increasing pain; **d.** The fracture was interpreted as being a Garden-I and was fixed with cannulated screws. It is debatable whether the internal fixation after such a long time was still indicated; **e.** Radiograph of the pelvis shows the right neck in a valgus position when comparing to the left. The lateral film (**c**) shows a posterior tilt with a posterior step (arrow). Posteriorly the S-shape is interrupted (arrow), becomes crescent shaped. The fracture surfaces and the corners are rounded off. One cannot exclude that this fracture had been older than 6 weeks (For explanations of "S" shapes see Fig. 179)

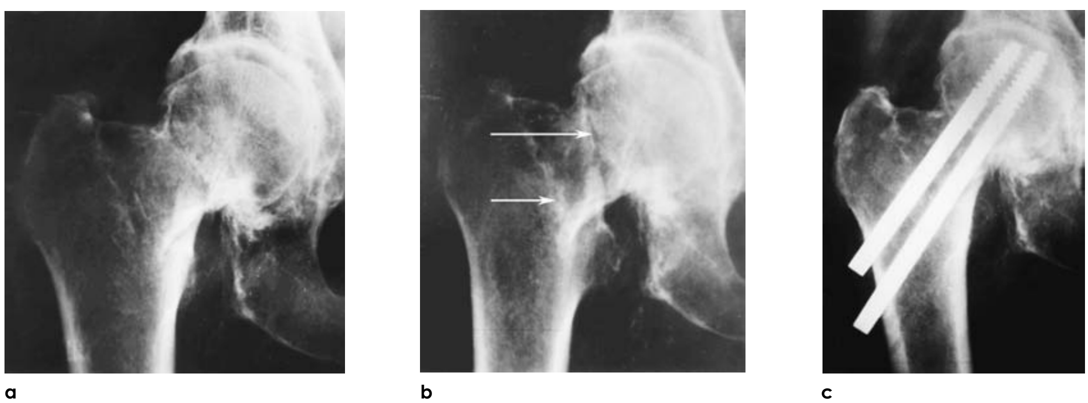
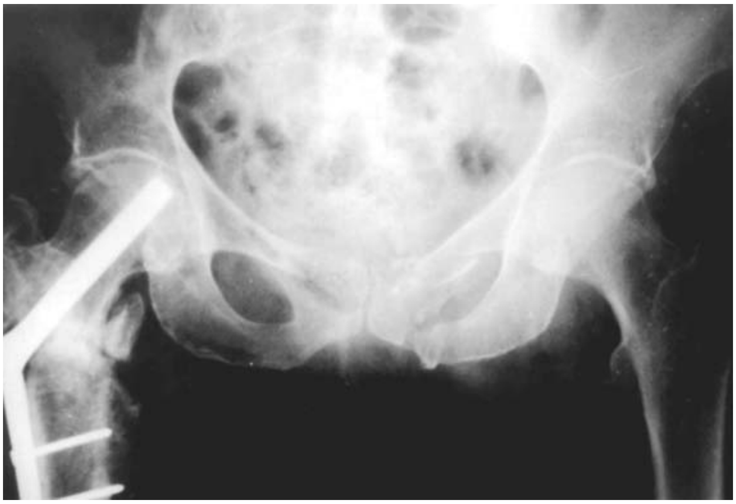


Fig. 103. Two separate fractures of the femoral neck.
84-year-old woman, her history could only be given by relatives stating that the patient fell on the day of admission and injured her right hip; **a, b.** The initial radiographs show two fractures, one mid neck and one basal neck fracture (arrows). The basal fracture is in varus and partly obliterated and caudally remodelled, therefore remote. However, the mid neck fracture is fresh; **c.** 4 months after internal fixation with cannulated screws the mid neck fracture consolidated



a

b

c

d

Fig. 104. Concomitant femoral neck and pubic ramus fracture.
75-year-old woman had a fall and injured her left hip. 3 months previously she had been treated for a right per-subtrochanteric fracture with a Jewett nail; **a.** On the basis of the original radiographs a pubic ramus fracture was diagnosed; **b, c.** At the 6 week follow-up examination the patient was symptom-free and no neck fracture was recorded. 3 weeks later she was admitted being unable to walk; **d.** Radiographs showed a remote left neck fracture with smooth surfaces (arrow). She was treated with a hemiarthroplasty. Reevaluation of the original a.-p. radiographs (**b**) raised the suspicion of a fracture in spite of the external rotation: interruption of the cortex medially as well as laterally and varus kinking of the Adam's arch and a flattening of the lateral contour (S) (upper arrow). Also in the lateral film (**c**) an anterior step (arrow) is visible; it should have led to a suspicion of a fracture. Additional examination would have most probably led to a diagnosis of a fracture. It is possible that the right sided not yet consolidated per-subtrochanteric fracture and a break of the left pubic ramus may have distracted the treating physician. The per-subtrochanteric fracture had rendered difficult a comparison of both hips and the pubic ramus fracture interfered with the assessment of Shenton's line


a


b


c

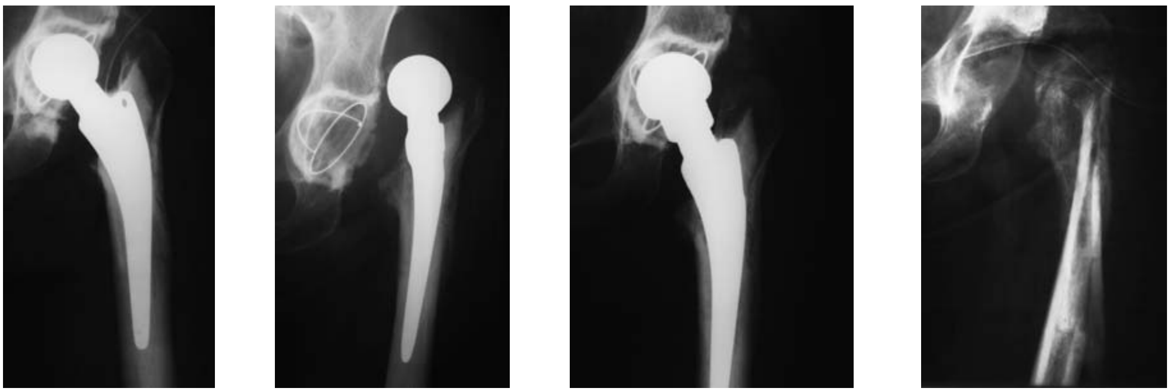

d


e


f


g

h i j



k l m n

Fig. 105. Overlooked and incorrectly treated Garden-II fracture.

This 60-year-old woman injured her left hip during a fall; **a, b.** Based on the radiographs taken at the time of admission the radiologist voiced a suspicion of a neck fracture. This led to additional examinations; **c.** Only conventional tomograms were done and interpreted as being negative. The patient was mobilized. At the day before discharge (5th day after injury) the hip pain increased considerably; **d, e.** Radiographs showed a displaced fracture (a.-p.: evident varus position, lateral: slight antecurvature). In retrospect, the original a.-p. film (**a**) show a slight intraosseous condensation at the cortex. The trabecular structure is interrupted on several places corresponding to the later visible fracture line, particularly cranially; **f, g.** In spite of the fact that only a displacement in varus was present, a forceful maneuver at reduction was also performed in the sagittal plane. Forced internal rotation led to a recurvatum and a faulty internal fixation was done (screws lie too posterior); **h, i.** An early loss of reduction was the consequence followed by a septic arthritis. The treatment of the undisplaced fracture ended with a Girdlestone resection!

4 years later the patient was admitted for a different condition; **j.** During examination necessitated by the symptoms due to the Girdlestone resection, the examiner was able to pull the femur distally under fluoroscopy; **k.** Based on this finding a THR was done; **l.** Repeated dislocations occurred in the postoperative period; **m.** The patient was reoperated (exchange of head component). The septic process recurred; **n.** At the end all components were removed

Chapter 4

HISTORICAL RETROSPECTION

4.1 History of the treatment of hip fractures

4.1.1 The beginnings

The first proper description of proximal femur fractures was done by **Ambroise Paré** in the 16th century. Up to this time they were thought to be dislocations (cited by Cordasco, 1938).

During the ensuing centuries many unsuccessful treatment attempts have been described. **Cooper** (1822) distinguished between extracapsular fractures having a favorable prognosis and intracapsular fractures that failed to consolidate; he attributed this failure to the poor blood supply to the femoral head. This perception prevailed during the entire century although already in 1858 **von Langenbeck** (cited by Böhler, 1996), later **Senn** (1889), and then **Nicolaysen** (1897) and **Delbet** (1919) attempted an open reduction and internal fixation with nails, screws and fibular strut grafts. **Senn** undertook investigations in animals. He was one of the few surgeons who insisted that intracapsular fractures would heal when properly reduced and stabilized. Inadequate asepsis, absent or unsatisfactory biocompatibility and insufficient mechanical stability of the implants associated with these procedures precluded a successful outcome. No wonder, therefore, that **Kocher** (1896) recommended resection of the femoral head.

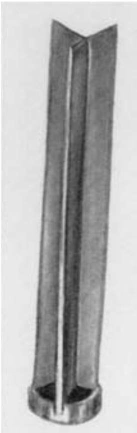
A consolidation of the fracture was achieved in some patients for the first time by **Whitman** (1925) who reduced the fracture and then placed the patient in a spica cast, a cast that included trunk, pelvis and lower limb. At the same time successful results were achieved in some instances of extracapsular fractures by **Codevilla** (1904) and later **Steinmann** (1919) who employed skeletal traction by means of a transosseous pin inserted either through the distal femur or proximal tibia. On account of the prolonged immobilization for six months, be it in the cast or in bed, most patients succumbed to an intercurrent complication. In 1936, **Hohenegg** summarized the situation as follows: "The hip fracture is an injury affecting elderly persons and is often the beginning of the end. The demise of most patients is due to pneumonia, urinary sepsis or decubitus. To avoid this bitter end, physicians should do their utmost to get patients out of the bed" (cited by Ehalt, 1967).

4.1.2 The development of internal fixation

Axhausen (cited by Manninger et al, 1960) was the first to submit a counterevidence to the assertion of Cooper. During an autopsy he could document that a fracture with a totally necrotic head consolidated. Subsequently attempts were undertaken to improve the process of consolidation. **Smith-Petersen** in 1925 undertook the first major step in this direction with his three-flanged nail (Smith-Petersen et al, 1931; Smith-Petersen, 1937). The nail was inserted after an arthrotomy. A more exact placement of the nail became possible thanks to **Johansson** (1932); he used a nail with a central bore and a guide wire that obviated an arthrotomy. The procedure gained fast acceptance in Europe and permitted surgery even in elderly persons. At the same time **Jerusalem** (cited by Manninger et al, 1960) designed a similar nail; the bore for the guide wire was placed at the base between two flanges. **Felsenreich** (1938) and **Böhler** (1996) improved the stability of fixation by broadening the flanges and by adding a small spike at the nail's neck to decrease the risk of backing out (Fig. 106).

The introduction of the **Jeschke** mesh helped to improve the placement and the control of position of the guide wire (Böhler, 1996). This technique necessitated serial radiographs and thus lengthened markedly the operating time.

Already in 1940 **Bauer** (1941) ameliorated the stability of internal fixation of non-unions by adding a second nail. The high rate of early and late complications induced several authors to look for means to enhance the design of implants and the surgical



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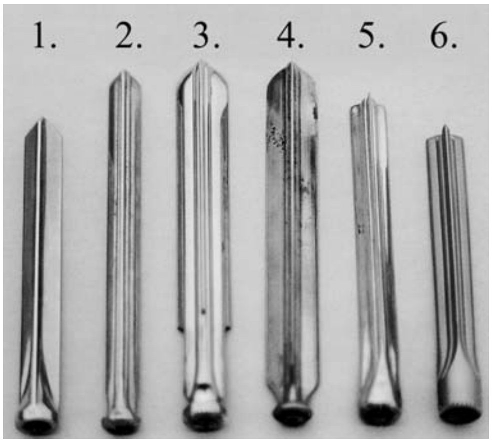
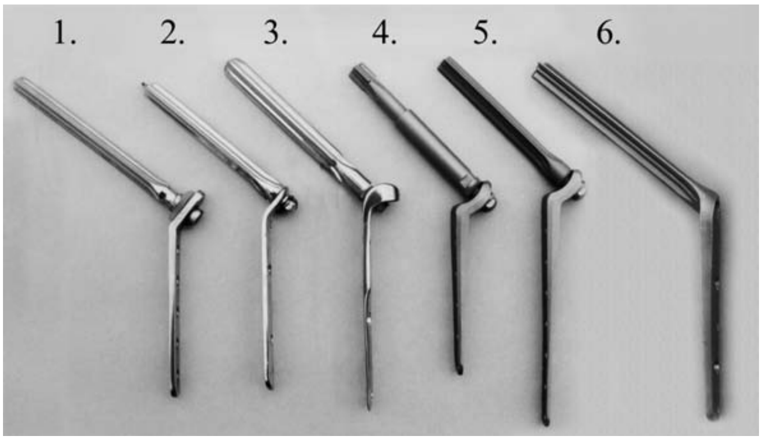


b

Fig. 106. Three-flanged nails.
a. Photograph of the first flanged nail taken from the publication of Smith-Petersen (1931). Nail and head were manufactured separately and then welded together. The junction gave rise to corrosion; **b.** The subsequent nails were made in one piece: (1) non-cannulated nail similar to the Smith-Petersen nail; (2) small, cannulated nail designed by Johansson in 1932; (3) broad flanged nail of L. Böhler with spikes that were supposed to prevent backing-out; (4) Felsenreich nail with broad flanges; (5) Aesculap® SP-nail with inner threads at the end; (6) Thornton nail made from vitallium



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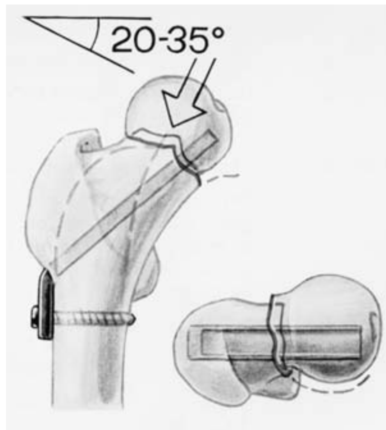
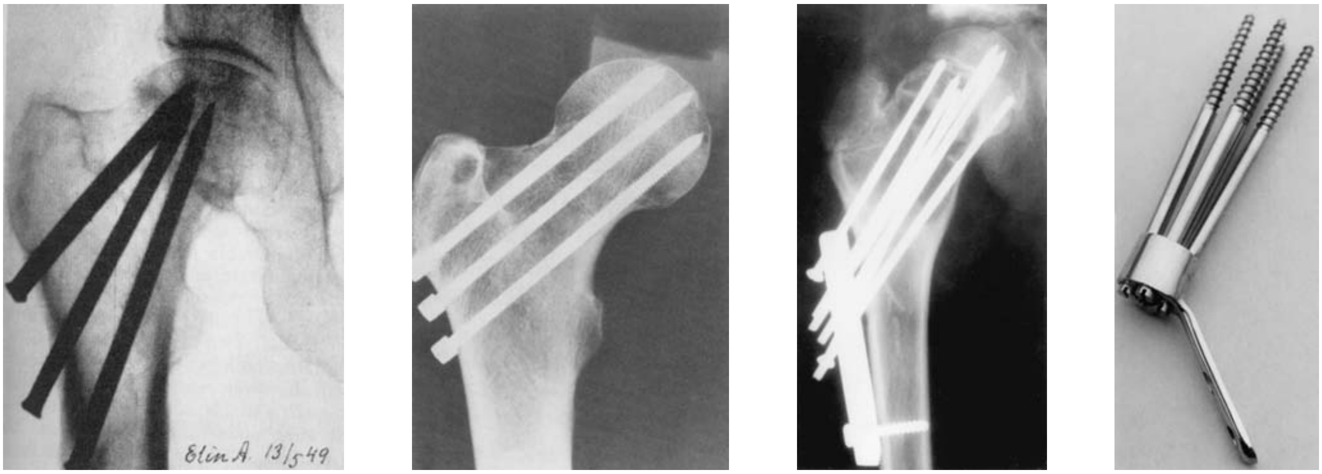


b

Fig. 107. Various plate-nail systems.
a. Combined plate-nail systems: (1) Szilágyi nail made in Hungary in 1960; (2) Aesculap® nail with plate; (3) nail made in the former German Democratic Republic; (4) Pugh telescoping nail made from Vitallium allowing a settling; (5) McLaughlin nail with side plate made either from Titanium or Vitallium; (6) Jewett nail-plate; **b.** AO 130° blade-plate (Müller et al, 1977)

technique. The well-known book by **Pauwels** (1935) contributed to a better understanding of biomechanical conditions. **Böhler** (1996) was the first to describe the migrating non-union. **Freund** (1930), **Trueta and Harrison** (1953), **Judet and collaborators** (1955), **Trueta** (1957), **Sevitt** (1964), **Catto** (1965a, 1965b), **Judet and colleagues** (1981) contributed to the study and elucidation of the pathology of fractures, the investigation of the blood supply and the refinement of diagnosis. **Brittain** (1942) as well as **Küntscher** (1953) and **Maatz** (1950) advocated the vertical position of the nail.

Thornton (cit. Bonnaire, 1998) was the first to add a plate to the caudal end of the nail. Using the same principle **McLaughlin** (1947), **Massie** (1958) and **Böhler** (1996) designed side plates attached to the nail. **Jewitt** (1941) developed his nail-plate and the researchers of the **AO/ASIF** group their blade plate (Müller et al, 1977); all these designs increased considerably the stability of the implants. Further modifications were made; they improved the treatment of trochanteric fractures considerably (Fig. 107). These devices did not prove worthwhile in the treatment of neck fractures. Due to the



a b c d

Fig. 108. Examples of the use of multiple implants.
a. Nyström's nails; **b.** Knowles pins; **c.** Deyerle method using several 3 mm wires with thread on their tip and a strong angle-stable plate; it was used repeatedly in our institute; d. Internal fixation according to Forgon with four neck screws and an angle-stable lateral buttressing plate that allowed backing out

impaction/resorption (settling) at the fracture site and thus the shortening of the neck the nail often perforated the femoral head particularly in elderly patients. In younger patients this caused a distraction as the nail had found a solid purchase in the strong subchondral bone. This led to a non-union and then to a fatigue fracture of the nail (see Fig. 118).

To counter this problem **Pugh** (1955) designed a telescoping nail with a fixed angle side plate that permitted to compensate for impaction/resorption (settling) of the fracture (Fig. 107a). **Putti** (1942) was the first to introduce screw fixation instead of rigid nailing. In 1951, **Pohl** invented a telescoping screw (Laschenschraube) that allowed to compensate for a settling of the fracture. This sliding hip screw, later refined in U.S.A. (Schumpelick and Jantzen, 1955), permitted an auto-compression of a neck fracture. Thanks to a small compression screw the fragments were impacted (Richards compression screw). The **AO** flattened the caudal end of the screw and squared the hole in the side plate to prevent any rotation of the femoral head. This lead to the design of the **Dynamic Hip Screw (DHS)**.

The disadvantage of these methods was that a single implant did not protect sufficiently against a rotational displacement and thus did not stabilize adequately the femoral head. For this reason several authors recommended a combination of two, three or more nails, screws or pins (**Nyström**, 1959; **Knowles**, 1936). **Deyerle** (1980) introduced many thin screws through a thick plate. **Forgon** (1975) achieved dynamic internal fixation with four screws and an angulated side plate. Thus he could early on prove that a combination of several implants, settling of the fracture and lateral fixation are equally important (Fig. 108).

Other improved the purchase of the implant in the head: **Rydell** (1964) added to his four-flanged nail a spring, **Hansson** (1982) used different hook pins (Fig. 109).

The methods of internal fixation underwent internationally an enormous development.

4.1.3 The history of joint replacement

The high incidence of complications after internal fixation led already in the first half of the 20th century to ideas to replace the fractured femoral head (**Hey-Groves**, 1930). **Moore and Bohlmann** (1943) were the first to replace the proximal femur with a stainless steel prosthesis for a malignant giant cell tumor in Baltimore 1940. The **Judet**

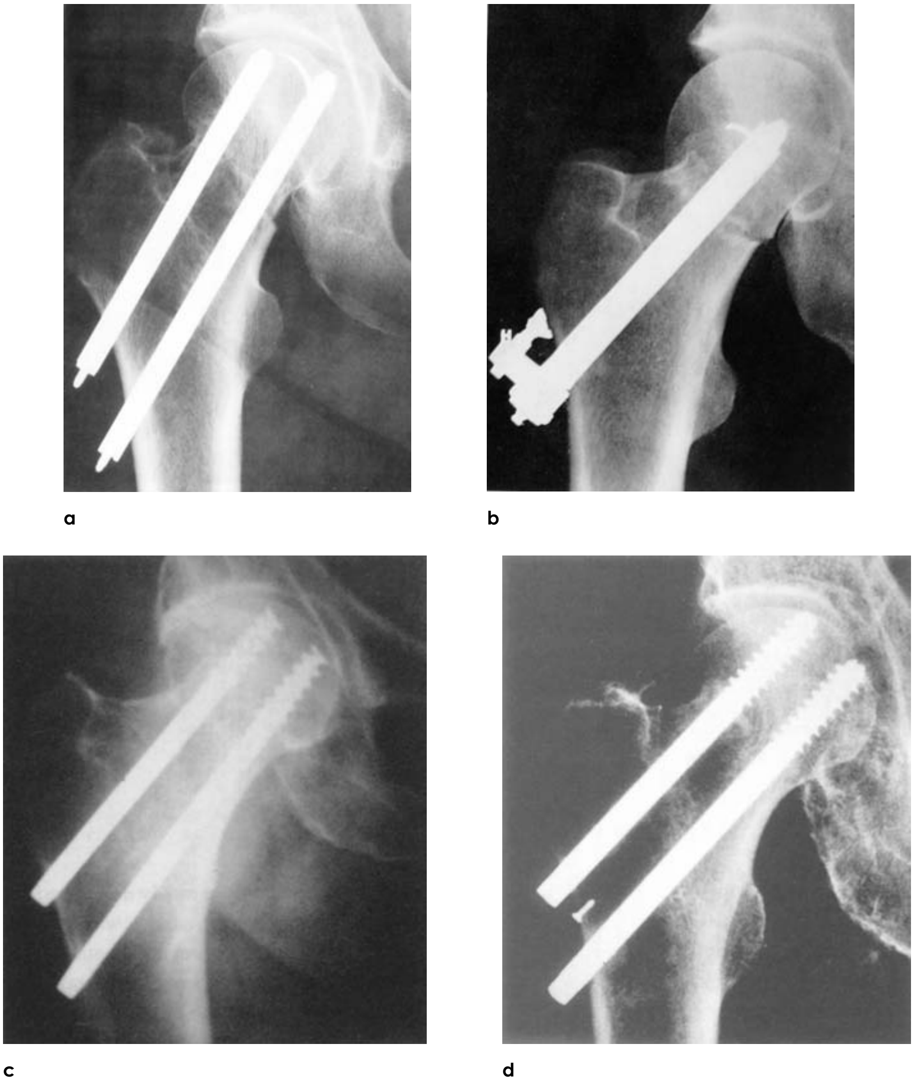


Fig. 109. Different designs of implants to improve purchase in the femoral head.
a. Double hook pin according to Hansson; **b.** Four-flanged nail with spring according to Rydell; **c.** Non-cannulated cancellous bone screws according to von Bahr; **d.** Cannulated cancellous bone screws designed by Rehnberg (1977)

brothers (1950) published a series of 300 patients that since 1947 had undergone a femoral head replacement with a short stemmed head component. **Thompson** (1954) and **Moore** (1957) implanted a head component with a longer stem for the first time in 1950. The development of a total joint replacement as an alternative for internal fixation started with **McKee and Watson-Farrar** (1966), **Charnley** (1961; 1970b) and **Müller** (1963; 1970). To improve the fixation of the components **Charnley** (1960; 1970b) was the first to use bone cement.

In countries where fresh fractures in elderly patients were treated with primary replacement, the hemiarthroplasty was the method of choice. This procedure similar to internal fixation went through major steps in the development with the goal to reduce complications (dislocation, protrusion); for example, the double cup components (Duokopf®) known for their minimal friction.

4.1.4 Beginnings of operative treatment of femoral neck fractures in Hungary

In Hungary, thanks to the influence of Lorenz Böhler who had learned the method in U.S.A. and was the first to execute it in Europe, the three-flanged nail was used to treat femoral neck fractures (**Monspart, Neuber, Dániel,** cited by Manninger et al, 1960).

Following the inauguration of the first Hungarian accident hospital (Magdalena Hospital) in 1940 the surgeons in charge – **Dániel, Elischer** and from 1945 up **Hedri** – performed hip nailing as a routine procedure. Even before the foundation of the National Institute of Traumatology in the same building (1956) we created a study group to investigate femoral neck fractures (1953). During the scientific sessions of the Hungarian surgeons in 1954 we presented for the first time an analysis of results reaching back to 1940. In 1960 we published an exhaustive study (Manninger et al, 1960) in several parts listing our experience in more than 1000 patients that had been treated in our institute between 1940 and 1955. In this study we emphasized the widening range of surgical indications, the importance of early surgery, the increasing age of patients and the improvement of results. However, at the same time we drew attention to two serious complications.

Loss of reduction was noted in one fifth of our patients that without revision surgery usually led to a nonunion. Avascular necroses of variable extent were the most frequent complication that occurred in one third of healed fractures, an observation also confirmed by other authors. This led to a search for means of achieving increased stability of internal fixation and to look for ways to preserve the vitality of the head. We hoped to prognosticate the occurrence of femoral head necrosis in order to arrive at a scientifically based decision to opt either for an internal fixation or a joint replacement. Among the known methods to investigate the circulation in the femoral head we chose the intraosseous venography as the optimal procedure, not lastly on account of our limited financial means. Already in the mid-sixties results were at our disposal justifying an international trauma congress in Hungary. Many participants from abroad presented their experiences at the symposium organized by us. With our study we were able to contribute to the elucidation of current problems of femoral neck fractures (Ehalt 1968).

4.2 The stages of development of internal fixation for femoral neck fractures at the National Institute of Traumatology (Budapest)

4.2.1 Nailing of femoral neck fractures

From the opening of the Trauma Hospital (1940) (belonging to the largest insurance company in Hungary and which preceded our institute) to the end of the fifties all displaced neck fractures were treated with the **Smith-Petersen** (1931) and the **Johansson** (1932) nails (Manninger et al, 1960).

This surgery was always considered a major intervention. Only the most experienced surgeons with two assistants were allowed to execute this procedure. The first assistant stood beside the surgeon; the second assistant stood opposite on a stool and bent over the Sajgo traction table and over the patient while holding the retractors. At least three radiographic examinations were done in two planes with two sphere-shaped mobile units (for the control of reduction, for the position of the guide wire and of the nail). Taking the radiographs including the development of the films (three pairs of pictures) took half an hour in spite of the fact that the dark room was beside the operating room. Not infrequently the films had to be repeated once or twice during a given phase. This led to an average of four to five pairs of films bringing the operating time to 1 1/2 to 2 hours.

Younger colleagues were only allowed after two years of assistance to nail a fracture. Meticulous reduction on the traction table preceded the suturing of a Jeschke wire mesh to the skin. If the radiographs in two planes revealed a correct reduction, the center of the femoral head was determined with the help of the mesh and the entry point of the nail into the lateral cortex determined as well. With two percutaneous needles the entry point and the center of the head were marked (Fig. 110). Under local anesthesia a transmuscular approach was done. At the lateral cortex, at the site of the needle, a small hole was chiseled. With a telescopic drill bit according to Kirschner a guide wire was driven in the direction determined by the two needles. Very often this maneuver had to be repeated until the guide wire was properly positioned in both planes.

The hole in the lateral cortex was enlarged with a chisel to accommodate the three-flanged nail. This nail was then driven over the guide wire (Fig. 111). Starting in 1949 we placed the nail steeper as recommended by Dániel (see Fig. 110). If the nail position was correct, the fracture was impacted with a special impactor before wound closure.

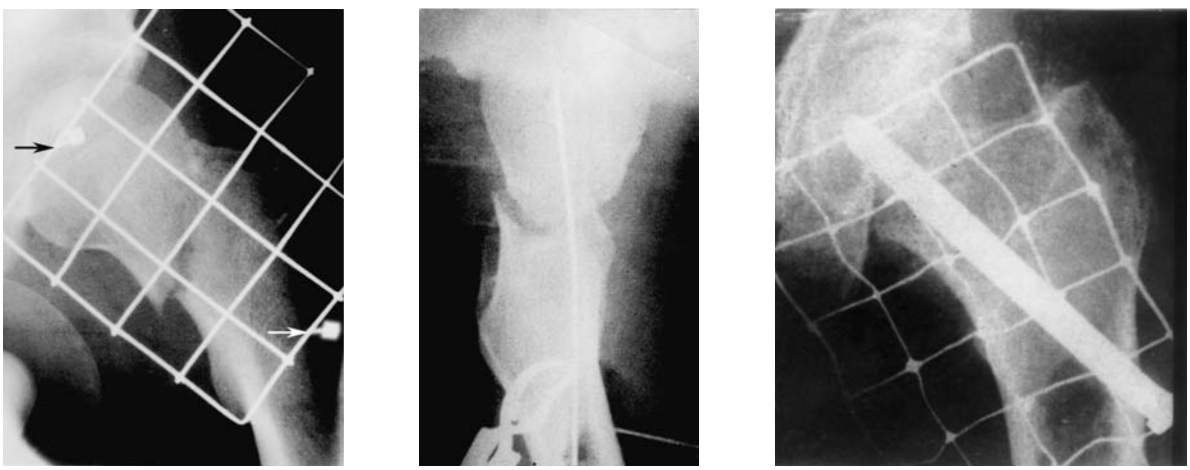
After a period of studies at the hospital of Lorenz Böhler in Vienna in 1957 we changed to the Böhler nail with broader flanges ensuring a greater stability. We used this nail for a long time and could observe a decrease in the incidence of loss of reduction (Fig. 112). At the same time we introduced a modified retromuscular approach as performed by Jörg Böhler, which diminished the blood loss.

With the event of the rapid x-ray developer the operating time decreased. We also experienced a shortage of films (shortly after 1956); they were replaced by photographic paper for economic reasons. This entailed a higher exposure to radiation and poorer picture quality. Films were only available for the final documentation.

Besides the experiences gained with Lorenz and Jörg Böhler (Vienna and Linz) the introduction of the **Müller image intensifier** and of the **Maquet operating table** in 1958 and 1959 (Szabó et al, 1964) constituted a real step forward. Initially these devices met considerable opposition as they did not posses a monitor and only occasionally could the images be seen when looking into the beam thanks to the prismatic objective (fluoroscopy). However, the marked decrease in operating time was convincing. With the introduction of the C-arm and a digital memory, image intensification was universally accepted.

Since the sixties anesthesia also has made a remarkable progress; most patients are now operated under a general or epidural anesthesia.

A three-month-use of crutches was obligatory, a requirement that caused great difficulties for elderly patients. After three months radiographs were taken and depending on the outcome a gradual weight bearing was permitted. To prevent backing out of the nail, often followed by loss of reduction, a Sherman screw was placed beneath the nail head. A backing out of the nail not infrequently caused a bending of the implant or the nail slid beside the screw (Fig. 113, see also Fig. 30b) (Manninger et al, 1961).



a b c

Fig. 110. Radiographs of a femoral neck nailing taken from our archive.
a, b. After reduction the entry point of the nail is marked with the help of a Jeschke mesh and two needles (arrows); ***c.*** Steep angled nailing according to Dániel

Fig. 111. Consolidated fracture after Smith-Petersen nailing.
16 years postoperatively a normal femoral head contour is seen

a

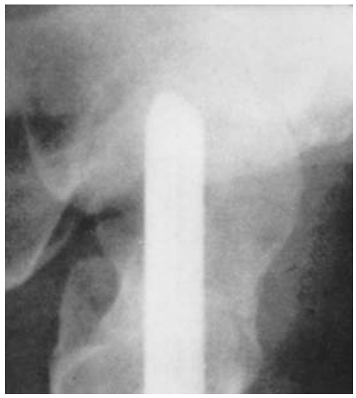


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Fig. 112. Nailing of a displaced neck fracture according to Böhler.
a. A.-p. film showing the correct position of a Böhler flanged nail placed close to the Adam's arch; **b.** lateral radiograph showing a central position of the implant

Fig. 113. Buttressing of a Smith-Petersen nail with a Sherman screw.
During backing out of the nail the screw did bent

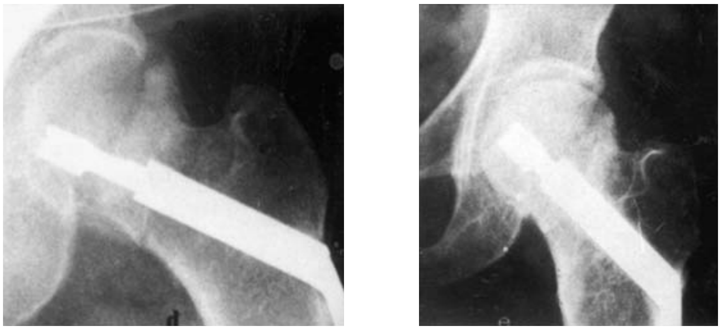

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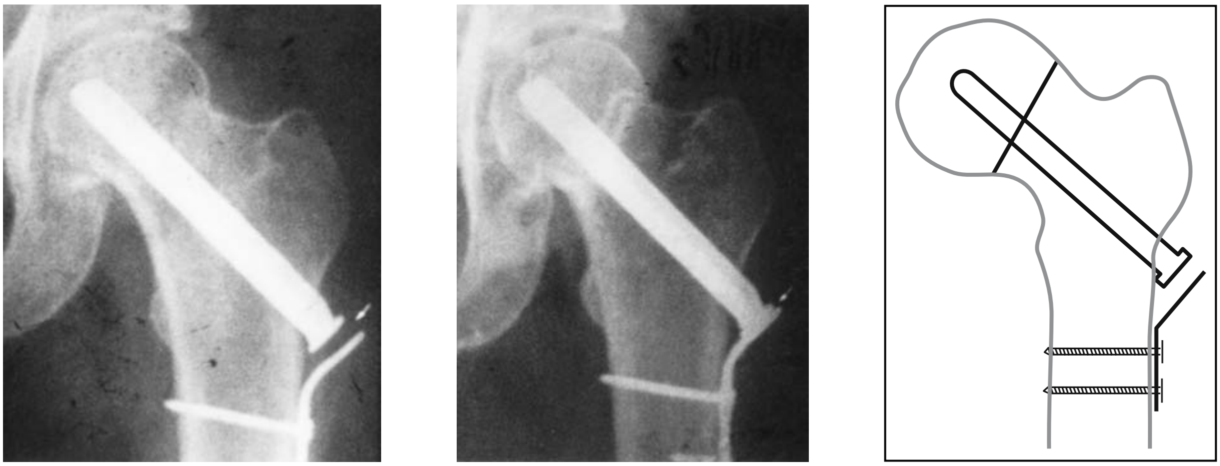
Fig. 114. Treatment of a neck fracture with a Pugh telescoping nail.
a. A.-p. film after internal fixation, normal neck length. The fracture line is still visible caudally;
b. A.-p. film one year postoperatively, the fracture has healed with shortening of the neck by 1 cm due to settling of the fracture



a b c

Fig. 115. "Distant" buttressing plate.
a. Early postoperative a.-p. film showing a correct position of the implant; (the arrow points to the gap between end of nail and plate);
b. A.-p. after fracture healing. The neck has shortened at the fracture site by 5 mm, the position of the nail in the femoral head remained unchanged (the arrow points to a contact between the nail end and the plate); **c.** This schematic drawing was taken from a publication of our technique in a German monograph (Nigst, 1964) with the caption "Manninger's method to allow a limited backing out of the nail"

To solve the problem of backing out dynamic nails and screws were introduced. These implants were not freely available to us on account of their high costs (Fig. 114).

In 1959, we replaced the Sherman screw by a small buttressing plate ("distant" buttressing side plate, according to Manninger) at a slight distance from the nail head (Manninger et al, 1961). The principle of this method was the result of our experiences and observations made during the follow-up study of 1057 patients operated between 1940 and 1955. We discovered that the majority of fractures treated by only one Smith-Petersen nail had consolidated after a backing out of the nail by 3 to 8 mm without any positional change of the implant in the femoral head.

We concluded that for an uneventful consolidation of a neck fracture the buttressing of the nail must be done in a way that preserved the stability in spite of the impaction/resorption (settling) of the fragments by 3 to 8 mm (Fig. 115). According to our experiences settling occurred already during the first postoperative days. If the nail is attached directly to the buttressing side plate, a diastasis of

Fig. 116. Buttressing side plates.
Right: the former buttressing plate (Aesculap®). Left: the plate later designed by us giving a better protection **against** backing out thanks to its socket

a

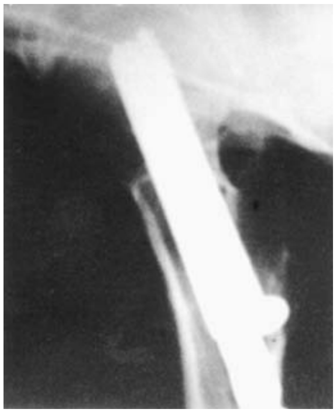


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Fig. 117. Böhler flanged nail in combination with a cranially inserted cancellous bone screw.
a. A.-p. film; **b.** Lateral film

the fracture may occur in younger patients causing a delayed or non-union. In older patients one has to expect **a perforation of the femoral head** (Fig. 118b).

The incidence of backing out of a single Smith-Petersen nail was approximately 20% in patients treated between 1940 and 1955. The use of the "distant" buttressing side plate reduced this incidence by half. Although this had been a major improvement, incidences were observed where the nail backed out above or beside the buttressing side plate. To prevent this complication we designed a small buttressing side plate with a socket at the proximal screw hole. This led in the 1960s to a further reduction in the incidence of complications (Fig. 116).

To increase the stability (particularly rotational stability) **two implants** of various designs were introduced. At the end of the sixties we frequently placed a cancellous bone screw cranial to the Böhler nail (Fig. 117).

Another possibility to increase stability was the nail-plate (see Fig. 107, 6. Jewett nail). This implant proved its value only in the stabilization of

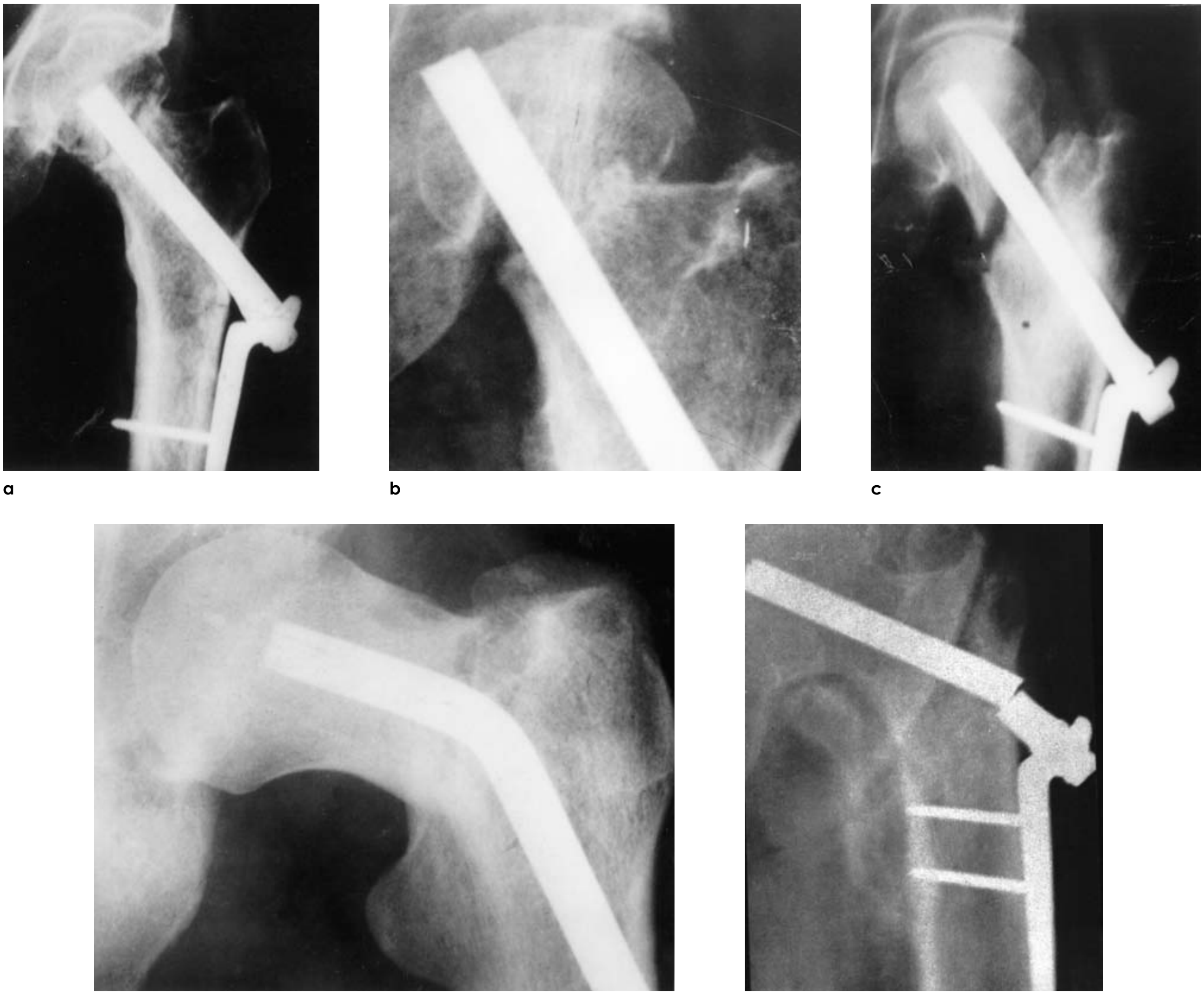


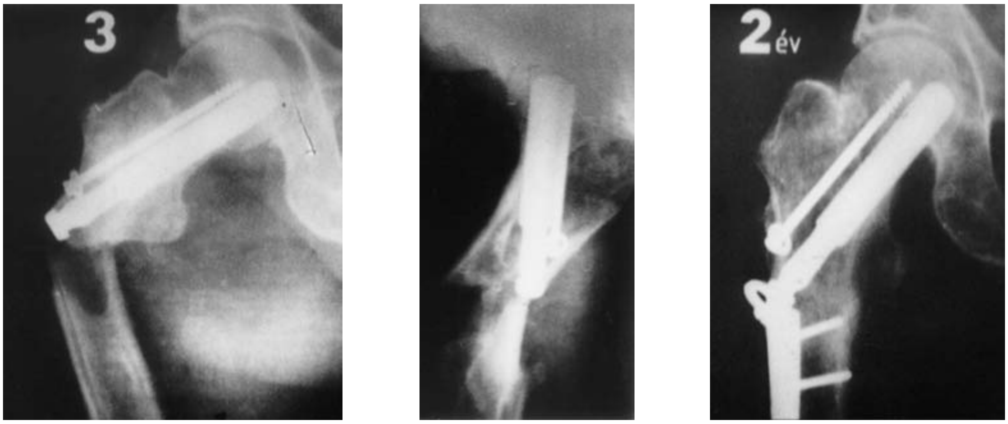
Fig. 118. Complications after internal fixation with a plate-nail for femoral neck fractures.
a. Delayed healing. Five months postoperatively the fracture gap is clearly discernable; **b.** The nail perforates the femoral head; **c.** Gap between the fragments, diastasis of the fracture; **d.** Bending of a nail of poor quality; **e.** Fatigue fracture of an implant

trochanteric fractures as the rigid buttressing prevented a backing out of the nail. When used for femoral neck fractures this implant caused complications (Szabó et al, 1961) (Fig. 118).

It happened rarely that a **diaphyseal fracture** developed at the insertion site of the flanged nail. In these instances the use of the buttressing side plate was advantageous (Fig. 119).

The additional application of **homologous bone grafts** inserted parallel to the screw led to a better consolidation when used for revisions after loss of reduction, delayed union or even nonunion (Manninger, 1959) (Fig. 120).

To further reduce the incidence of loss of reduction we employed occasionally in the sixties and regularly in the seventies an **internal fixation**



a b c

Fig. 119. Complications after internal fixation of femoral neck fractures. Shaft fracture at the level of the insertion of the nail.
a, b. Three months after internal fixation with a Böhler flanged nail and screw. The patient suffered a fracture during a fall just distal to the lesser trochanter; **c.** Two years after reinforcement of the nail with a buttressing side plate, the fracture consolidated

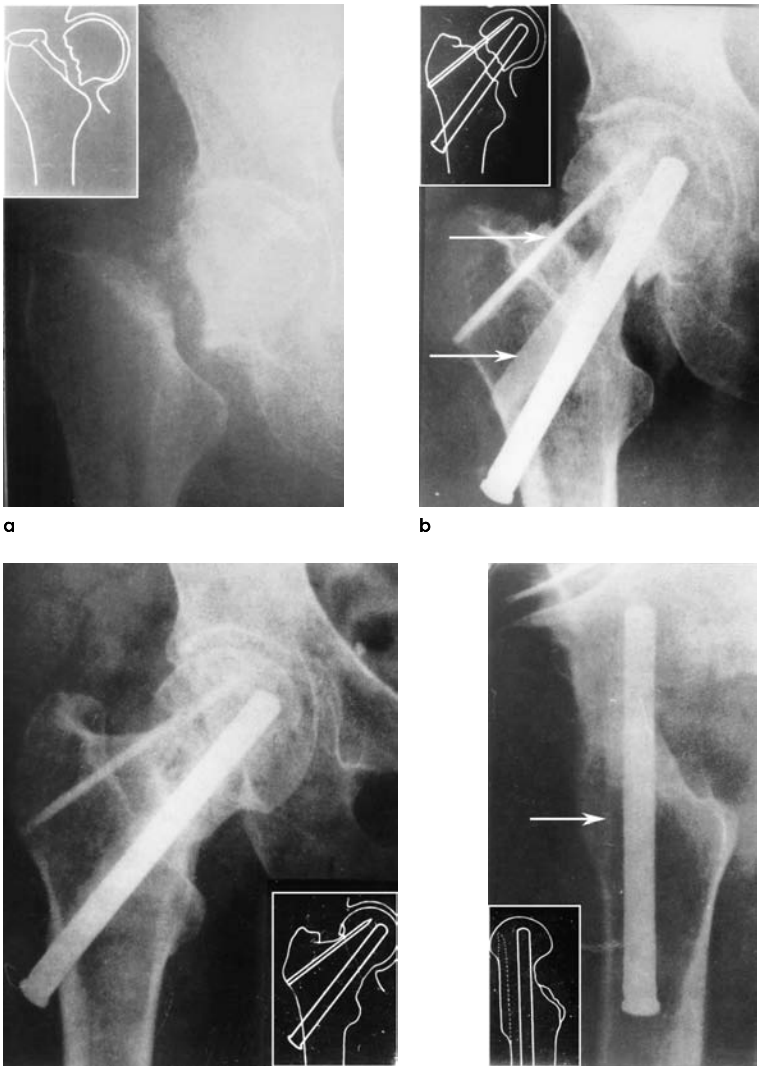
with two Smith-Petersen nails. This increased considerably the rotational stability without preventing the problem of backing out of the nails (Fig. 121).

Even the use of the buttressing plate with a socket did not prevent a backing out of the nail. Therefore, we **connected the nail to the plate with a sliding screw**. This sliding screw was inserted through the hole in the plate into the inner threads of the nail end. Before surgery the threads of the sliding screw close to the screw head had been removed so that the screw would not get stuck in the plate. This solution had two advantages: the nail slid in the direction of the plate and the application of the tension band principle prevented a varus tilting of nail and femoral head and thus no loss of reduction could occur. For the same reason it was important to buttress the nail against Adam's arch. In this way we transformed the one-arm lever into a two-arm lever leading to a more reliable stability. From 1983 on we combined the Böhler nailing with a sliding screw buttressing (Fig. 122).

The second important factor, beside the supplementation with a "distant" buttressing plate, was the reinforcement of the lateral fixation: the **meticulous preparation of the entry point of the nail in the lateral cortex**. During the sixties we first drilled a hole and then prepared the channels for the three flanges with a chisel (in the shape of a "Mercedes Star"). This laborious and time consuming procedure was later facilitated by the use of a three flanged stepped chisel. In spite of the use of this instrument fissures occurred or great fragments broke out during hammering of the nail into the cortex. This decreased the lateral purchase of the nail end. Even fractures of the femur occurred. A further disadvantage was the prominence of the buttressing plate, a design necessary to accommodate the backing-out of the nail. Particularly in slender patients this prominence caused serious complaints and sores. Therefore the plate had often to be removed later.

An ensuing modification eliminated this disadvantage. The new Smith-Petersen nails made by Aesculap® having a cylindrical end rendered unnecessary any chiseling. A 13 mm hole was drilled without causing any fissures. This allowed to countersink the nail end and therefore the corresponding buttressing side plate **was less prominent**. In addition, the even surface at the lateral cortex improved the bony buttressing of the nail end.

The preparation of the lateral entry point thus became easier, faster and better; fissures or fractures occurred rarely. At the same time the stability of internal fixation was increased by the lateral but-



a b c d

Fig. 120. Implantation of a homologous bone graft during revision surgery.
a. 6 months after the femoral neck fracture a diagnosis of a defect pseudarthrosis accompanied by a cortication of the fracture surfaces was made; **b.** Treatment with a nail and two cortical strut grafts, one cranial and one anterior (arrows); **c, d.** Two years later the pseudarthrosis has consolidated and remodeled

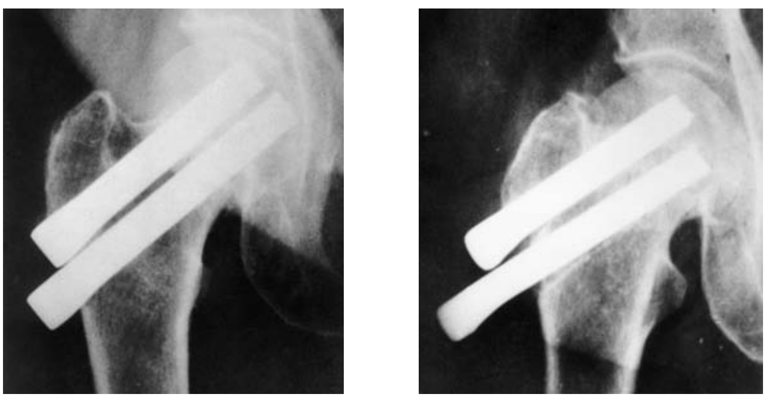


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Fig. 121. Internal fixation with two Smith-Petersen nails.
a. Immediate postoperative a.-p. radiograph; **b.** Film taken after two weeks. Due to a shortening of the femoral neck and the nails' displacement in the femoral head the nails backed out. The loss of reduction was caused by the backing out of the nails from the femoral head and not due to settling

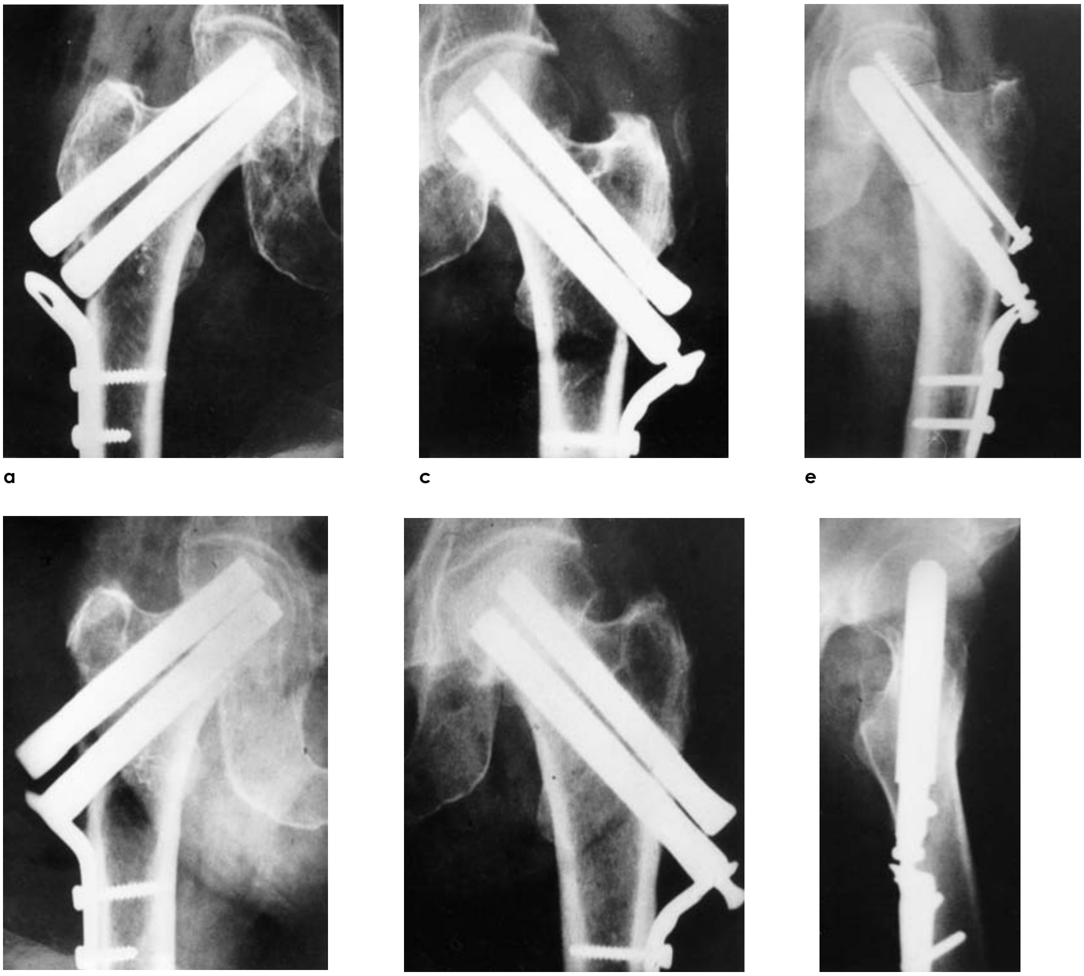


Fig. 122. "Distant" buttressing of the implant.
a, b. The caudal Smith-Petersen nail backed out and is in contact with the plate; **c, d.** The same buttressing supplemented with a sliding screw; **e, f.** Addition of a sliding screw and plate to a Böhler nail

tressing. Nevertheless, the 13 mm hole weakened the strength of the involved bony segment leading occasionally to secondary (usually subtrochanteric) fractures.

For this reason the sliding screw was connected to a **stronger plate** that was fixed to the femur with two screws. The proximal screw was bicortical and the distal screw found purchase only in the lateral cortex (Fig. 123).

With this modification we obtained such a stable internal fixation that starting in the eighties we could **omit the use of crutches and allowed the patients weight bearing with a walker**. As soon as the patient could leave the bed and the wound pain had subsided, weight bearing was allowed. In light of the fact that elderly patients could rarely use crutches and often put weight on the operated limb against our advice, this was a tremendous advantage.

The early mobilization made possible by the internal fixation and the weight bearing had a beneficial effect on the patients' physical and mental conditions. The danger of complications due to prolonged confinement to bed (pneumonia, thromboem-

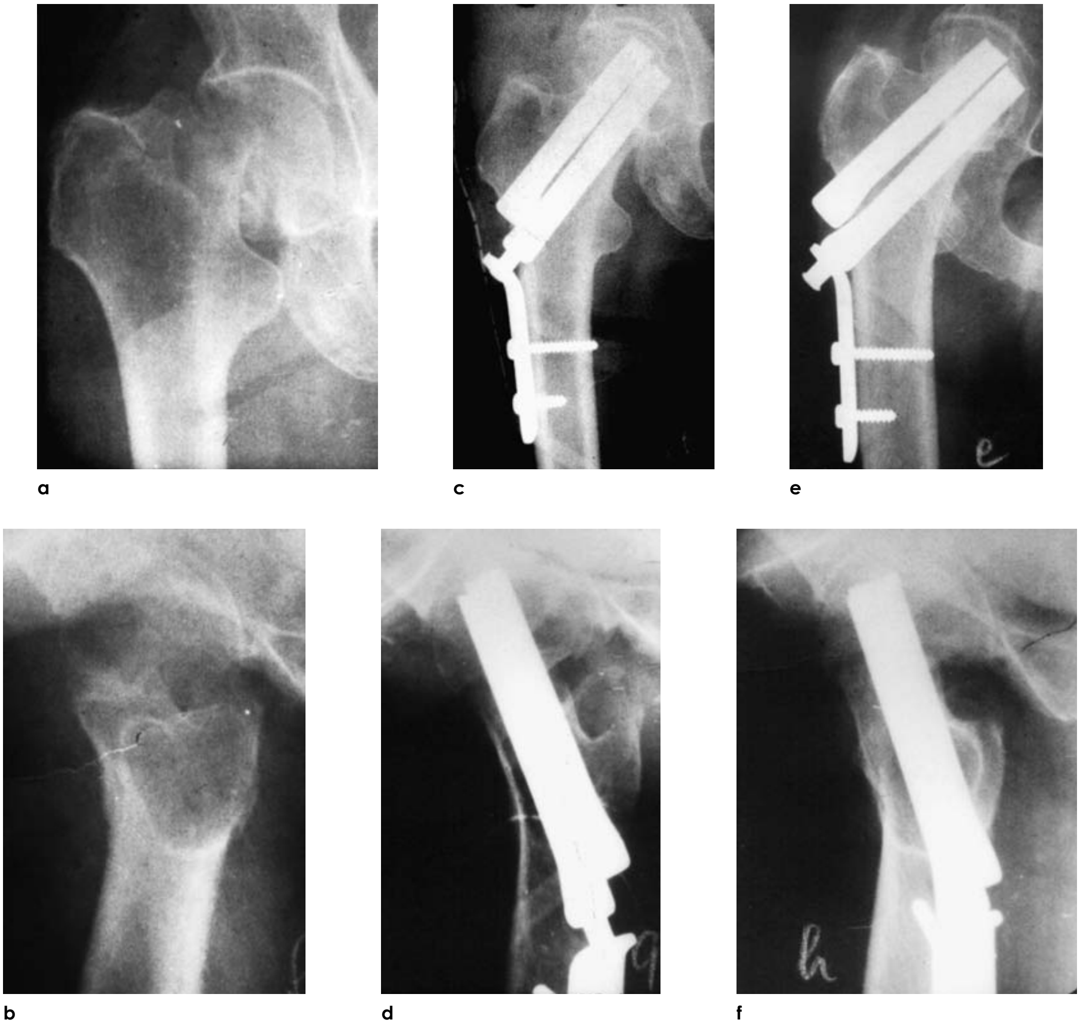


Fig. 123. Results of improved internal fixation after a lengthy process of development: internal fixation with two Smith-Petersen nails, distal sliding screw and buttressing side plate.
a, b. Garden-IV neck fracture; **c, d.** Postoperative radiographs. Good demonstration of the countersunk cylindrical nail end and the buttressing side plate fixed to the cortex with two screws and only slightly separated from the femoral cortex; **e, f.** One year later the fracture has consolidated after settling of the fracture

bolism, decubitus, urinary infections) decreased and the incidence of mortality secondary to these complications also diminished. People using crutches are often regarded to be invalids, whereas elderly patients circulating with a walker feel less being an invalid because they can weight bear and walk safely.

4.2.2 Summary of the basic principles gained during 40 years of experience

(1) The femoral head has to be fixed with **two (or three) nails or screws**, mainly to increase the rotational stability.
(2) The internal fixation must be done in such a way that an **impaction/resorption (settling) of 3 to 8 mm should be** possible, otherwise a diastasis at the fracture site or perforation of the head will occur.

Table 1. Incidence of loss of reduction as seen in our analyses during different time periods (Manninger et al, 1960; Manninger et al, 1985; Manninger et al, 1989)

Year	Number of patients	Number of loss of reduction	% of loss of reduction	Internal fixation	Mobilization
1940–55	300	60	20	One Smith-Petersen nail	3 month with crutches
1962	50	5	10	One Smith-Petersen nail + "distant" plate	3 month with crutches
1981–83	70	2	2.9	Two Smith-Petersen nails + "distant" plate	Walker after a few days
1985–87	127	4	3.1	Two Smith-Petersen nails + "distant" plate + sliding screw	Immediate weight bearing with walker

(3) **The caudal implant must rest on Adam's arch.** Only in this way can the implant prevent a loss of reduction in varus because of the implant's two-arm lever effect.

(4) **It is important to properly drill the hole in the lateral cortex and to use a buttressing side plate.**

(5) The dimension of the applied metal implant should be kept at an optimal minimum necessary for a reliable internal fixation. The distance between plate and buttress (Adam's arch), that is the lever arm to which the force is applied, is considerably greater than the distance between the center of the head and Adam's arch that is the load arm. For this reason, a **small buttressing side plate** is sufficient for **an adequate tension band effect** in the majority of neck fractures and it is therefore not necessary to use a massive plate as in instances of trochanteric fractures, where the plate compensates foremost for the broken Adam's arch.

(6) The goal is to obtain a stability that allows the elderly patient **an early postoperative mobilization with weight bearing**. Consequently, the barely enforceable use of crutches can be omitted. In this way the internal fixation shares all the advantages of a joint replacement, but with a considerably lesser surgical trauma.

Internal fixation with two Smith-Petersen nails combined with a "distant" sliding screw side plate meets all these requirements. This combination was the result of the above described development and was used for one decade as a standard intervention. **A marked decrease in the incidence of loss of reduction** resulted from this modification (Table 1).

4.2.3 Internal fixation with screws

Already in the sixties the treatment of neck fractures in 50 to 60 year-old patients and also in adolescents and children was done by screw fixation. Driving nails into the compact bone is difficult and is accompanied by a very extensive damage to the bone. On the other hand, screws can be introduced with less damage thanks to predrilling and tapping. The screws are sufficiently stabilized in the relatively solid bone. The introduction of cancellous bone screws further increased the stability (Manninger et al, 1970; Manninger et al, 1985).

The rule also applies here that a single implant does not protect sufficiently against loss of reduction in rotation. However, the insertion of several screws has its own problem in that it is difficult to place the screws in a parallel fashion in the narrow neck using a free-hand technique. Any divergence or convergence of screw placement precludes impaction/resorption (settling) and thus leads to a delayed or nonunion.

In the eighties we introduced in our institute a **parallel guide for parallel placement of three screws** to counteract this problem. This guide is fixed to the lateral cortex with a guide wire placed in the center of the neck. Holes in the guide ensure a parallel drilling, tapping and later insertion of the screws after removal of the guide. To reinforce the lateral buttressing of the screw head we designed **a plate with "reversed keyholes"** that was inserted from cranial over the screw heads and pulled down before tightening the screws. This plate was attached to the femur with one cortical screw. Thanks to the caudal cancellous screw lying in contact with Adam's arch a tension band effect was obtained and protected against loss of reduction in varus. The three screws together with the plate protected against a loss of reduction in rotation (Fig. 124).

We used this technique foremost for the treat-

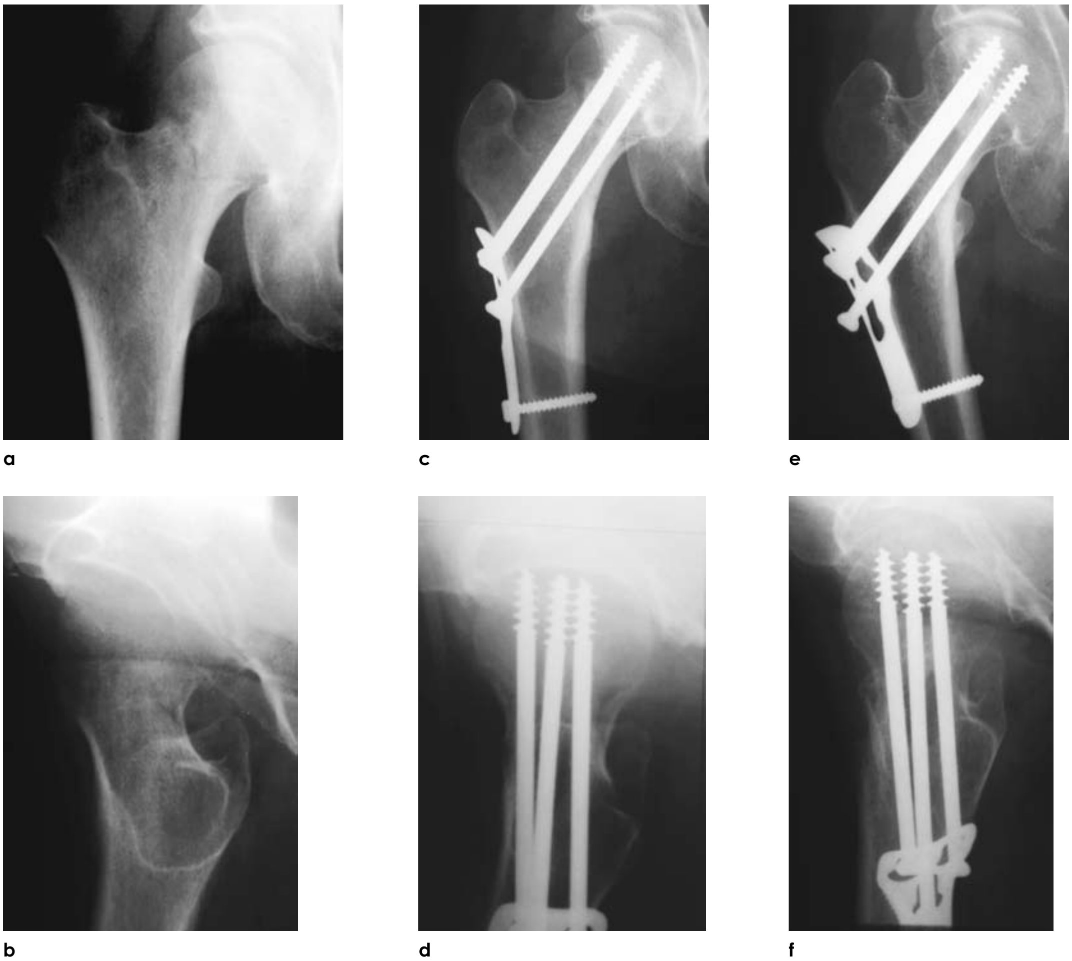


Fig. 124. Internal fixation with three cancellous bone screws and plate with reversed keyholes.
50-year-old patient who suffered one year previously a left hemiparesis secondary to occlusion of the internal carotid artery. She fell on the day of admission and hit her right hip; **a, b.** Films in both planes show a Garden-I fracture with slight valgus position and anteversion. A small bony fragment is also seen at the posterior aspect of the neck. Since the right hip was exposed to greater weight bearing due to her stroke, we decided in favor of surgery; **c, d.** The fracture was stabilized with three cancellous bone screws and a keyhole plate. The patient was mobilized after a few days; **e, f.** 5 years later the fracture healed with a shortening of the neck, the function was good

ment of displaced fractures in younger persons or for the stabilization of Garden-I and -II fractures. In several studies we could prove that well placed screws produce a reliable stability; no loss of reduction was observed (Manninger et al, 1990; Cserháti et al, 1996).

The greatest advantage of this technique in instances of undisplaced fractures in the elderly was the elimination of the aggravating **three-week confinement to bed and the three-month use of crutches, both being part of the conservative treatment**. Similar to the patients treated for displaced fractures with the Smith-Petersen nailing, these patients can weight bear with cane or walker a few days after surgery without running the risk of loss of reduction.

From the static standpoint our methods, double nailing or fixation with three screws, has also responded to the requirements of internal fixation. Chiseling, insertion of the nail by hammering, application of the parallel guide and insertion of the plate with key holes were time consuming and could only be executed by a precise retromuscular approach. This led to a lengthening of the operating time and an increased stress for the older patient. Consequently, a longer preoperative preparation became necessary (availability of blood transfusions) and forced us frequently to exceed the 6-hour limit before surgery.

A percutaneous insertion of screws could constitute the method that would also be advantageous for the patient from **the biologic aspect**. However, the screws available up to this moment did not seem to guarantee the necessary parallel insertion. Besides, the stability obtained, particularly in rotation, could not match that of two Smith-Petersen nails that allowed also a reliable fixation of displaced fractures. This situation changed dramatically with the introduction of **cannulated cancellous bone screws**. Their parallel insertion was guaranteed by using guide wires.

4.2.4 Percutaneous insertion of two screws

In 1987, Professor C. Olerud presented the use of two percutaneously inserted cannulated screws at our institute. Screws and instruments were designed by his group (Rehnberg and Olerud, 1989; Olerud and Rehnberg, 1991; Olerud and Rehnberg, 1993; Olerud et al, 1995). This so-called Uppsala technique, known to us from the thesis of **Rehnberg** (1988) resembled in some aspects the techniques developed by us: the nailing with two Smith-Petersen nails and the fixation with three cancellous bone screws combined with the keyhole plate. Also in these techniques the strictly parallel insertion of screws and the importance of compensation for resorption had been emphasized. The new method was a step in the right direction for two reasons: a less invasive approach and a more stable internal fixation. On one hand, parallel guide and guide wires allowed a reliable **parallel insertion of the cannulated screws through a smaller incision**. On the other hand, advancing the screws into the **subchondral bone** of the femoral head led to a better purchase also in the hope of a better hold in severely osteoporotic bone.

In November 1990, we performed the first two insertions of the original Swedish implants. In the following year we added another ten implantations. In our opinion the subchondral stability of the screws and the shorter operating time are two outstanding advantages. We attempted from the beginning to use our past experience in the development and clinical use of earlier methods to incorporate them into the new technique.

The **lateral buttressing** was not part of the original Swedish method. In the first two cases we attached the lateral screw ends to a modified one third tubular plate. As its placement met technical difficulties, we constructed a small side plate exerting a tension band effect, mostly to prevent a tilting in varus (see Fig. 241a). Rectangular holes contributed to a certain rotational stability. During the development of the plate we perfected the **percutaneous insertion** and the relevant **instruments**. Up to the moment of the introduction of this plate we performed the internal fixation only with two screws. During that time we observed on radiographs in a considerable number of these patients a slight displacement in varus and rotation after mobilization of the patient (Fekete et al, 1992).

The necessity arose to adapt the screw shank to the rectangular holes of the small plate and to flatten its end over a longer distance to preserve the stability without interfering with the sliding. To compensate for this flattening we increased the shank diameter to 7 mm. This stronger shank also allowed to insert larger compression screws. At the same time this prevented a migration of the cannulated screw in a superomedial direction (see Fig. 192d). We also **deepened the threads** and removed the spikes at the tip of the cancellous bone screw to increase the subchondral purchase. In addition, we designed **holes** between the threads and two **longitudinal grooves** at the surface of these screws to improve the drainage of the congested blood in the femoral head (see Fig. 57).

We also modified considerably the surgical technique. During the earlier performed open reductions we observed that the tip of the guide wire slipped off the bone and displaced the femoral head, particularly in younger patients. For this reason we perform now a **predrilling** with a 3.2 mm spiral drill bit.

For a more stable fixation of porotic, certain subcapital or vertical fractures (Pauwels-III) as well as for basal neck fractures we use screws with **a greater thread diameter** (9.5 mm) and **thread lengths of 18, 34, and 44 mm** (standard length 24 mm) (Fekete et al, 2000b; Fekete et al, 2000c). For the internal fixation of neck fractures in younger patients where MRI and CT follow-up examinations are necessary, we also use titanium implants (Melly et al, 1999) (see Fig. 189).

We discussed repeatedly certain modifications with representatives of the manufacturer. We wanted to make sure that our wishes based on experience are respected permitting us the introduction of cannulated screws. As our efforts were not successful we approached the Hungarian company Sanatmetal. Over many years this company had manufactured for us numerous implants of reliable quality with the result that our cannulated femoral neck screws are made in Hungary from imported cannulated steel rods (Sandvik®).

We tested the majority of developed implants before their clinical use in **cadaver specimens at the Department of Material Science and Mechanics at the Budapest University of Technology and Economics (BUTE)** (see chap. 5) and patented them (Patent number 85256, valid to 2007).

The collaboration of medical doctors and engineers at the National Institute of Traumatology (Budapest), the members of the BUTE and the development engineers of the manufacturer led to numerous new and considerably modified implants and instruments. Our research and development was also supported by grants from the Hungarian Ministry of Health (ETT) and the Hungarian Academy of Science (OTKA) (Project Nr. ETT 140/1993, 103/1996, 426/2000, 254/2003, 344/2003, OTKA 970/1991, F6193/1992, T016341/1995, T024006/1997, T034680/2000).

The following short summary lists the most important new models and modifications for the internal fixation with standard screws:

(1) Screws:

- The shank of the neck screw was increased to 7 mm to ensure that the flattening of the shank's end would not weaken the implant. This, in turn, allows a dynamic auto-compression secondary to impaction/resorption (settling) as well as fixation ensuring rotational stability thanks to a small straight side plate having a tension band effect.
- The tip of the screw is blunt; the threads reach the tip and are self-cutting.
- The other end of the cannulated screw has a bore (∅ 5 mm) with threads in the metric system. Another long screw is inserted into the T-handle and screwed into the cannulated screw. This allows a secure hold of the T-handle. The 5 mm bore can also be used for a stronger compression screw.
- The accumulated intraosseous blood can drain through four holes made between the threads and two longitudinal grooves in the shank. This is the principle of the "draining screw".
- The length of threads is available in four lengths: 18 mm, 24 mm (standard length), 34 mm and 44 mm.
- Thread diameters of 8 mm and 9.5 mm are available.
- The slotted screws can be introduced exacter, faster and simpler through the 10/8 mm sleeve.

(2) Instruments:

- To ensure a parallel insertion of the guide wires two 300 mm long spiral drill bits have been included in the set (∅ 3.2 mm).

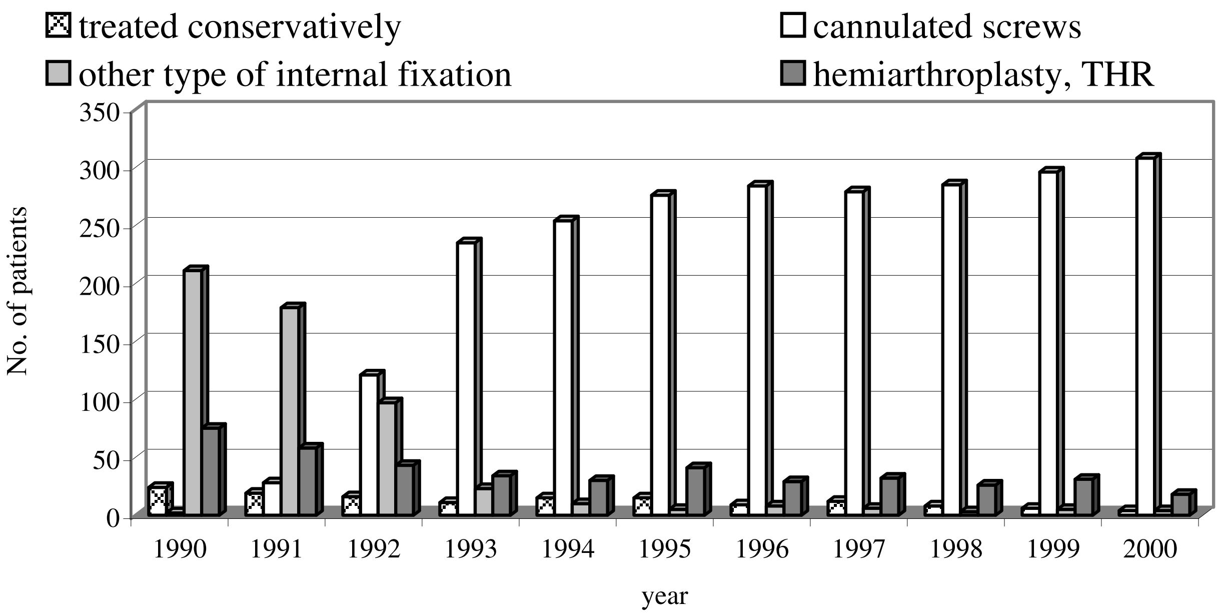


Fig. 125. The treatment of femoral neck fractures at the National Institute of Traumatology (Budapest) between January 1, 1990 and December 31, 2000.

- Instead of the reamer a stepped drill bit of two lengths (250 and 300 mm) has been manufactured.
- The T-handle can be attached to either of the two 300 mm long taps (∅ 8 mm and 9.5 mm).
- The new parallel guide and the new 10/7 and 10/8 mm drill sleeves render screw insertion more precise.
- For precise insertion of the third screw an additional device can be attached to either the left or right side of the parallel drill guide.
- The sleeve of the soft tissue protector with handle (∅ 10 mm) has a beveled end that fits the femur's surface and two little spikes for better hold on the bone. This allows a precise drilling and insertion of guide wires while at the same time protecting the soft tissues.
- At the end of surgery a new instrument for proper seating of the side plate permits a fast percutaneous insertion of the straight side plate.

Thanks to these additions and while respecting the requirement for emergency intervention, it was possible since 1993 to treat the majority of patients with fresh neck fractures with two cannulated screws (Fig. 125) (Cserháti et al, 1999).

Chapter 5

BIOMECHANICAL ASPECTS OF CANNULATED SCREW FIXATION. EXPERIMENTAL INVESTIGATIONS AND DEVELOPMENTS

Use a minimum of material to get maximum of stability (van Vugt et al, 1993)

5.1 The importance of three-point buttressing

In Sects. 1.3 and 1.5, we have discussed the **anatomical and biomechanical characteristics** of the proximal femur that determine the optimal position of the stabilizing implants during internal fixation (three-point buttressing: lateral cortex, Adam's arch/calcar femorale and subchondral bone in the femoral head). In Sect. 4.2.2, we summarized **the fundamental biomechanical principles** as they are **related to the design of the implant** in respect to the internal fixation with two Smith-Petersen nails. These principles are still valid:

– Necessity of two or more implants;
– Protection against tilting in varus and rotation of the femoral head;
– Allowing settling of the fracture.

The percutaneous fixation with cannulated screws meets these requirements in many ways. The percutaneous technique not only proved less stressful to the elderly patient, but also was a biologically more favorable approach. In the course of the analysis of results of our first patient collective we discovered some biomechanical problems that necessitated a comprehensive **engagement in experimental investigations and new developments**. The practical realization of our ideas became possible with the general **progress in fields of traumatology** and medical technology. **Improved implant material** and its processing but in particular the use of image intensifiers giving ever better and refined images were the basis of technical improvements for the demanding internal fixation.

Osteopenia and weakening of bone at the proximal end of the femur are not distributed evenly: the atrophy of the trabeculae progresses faster and more pronounced than the loss of cortical bone. Moreover, osteopenia is more marked in the neck than in the head (Józsa et al, 1998). If one takes into consideration this fact, one realizes that even during advanced stages of osteoporosis zones exist where a well-placed implant finds a stable purchase. While planning properly the implant's shape and its application, **potential problems and possible loss of reduction** have to be considered.

(1) In general, the varus displacement is most frequent and most pronounced due to body weight and muscle pull. The less frequently occurring valgus displacement is caused typically by a fall, the first stage of the injury. It arises generally from a fall on the side, a direct impact on the trochanter. Only in some instances the femur head remains in its original position (Garden-I fracture) (Linton, 1944). A secondary displacement or loss of reduction in valgus occurs very seldom. In one of our patients we observed it after reduction of a fracture that was displaced in hypervalgus.
(2) After the fall and due to the muscle pull an **antecurvature** occurs (an angle open posteriorly). A recurvatum is seldom due to the fact that the femoral neck is anteriorly convex and posteriorly concave leading to a posterior displacement of the head (Scheck, 1959; Kazár, 1963). In addition, the very strong iliofemoral ligament (Bertini) that lies anteriorly and is under tension protects against the recurvatum. A secondary recurvatum occurring as a loss of reduction after internal fixation is so rare that it did merit a publication (Flóris, 1996).
(3) Once a femoral neck fracture has happened, neither muscles nor ligaments can stabilize the cranial fragment (head) (the very thin and relatively long round ligament cannot protect against rotational displacement). If no asperities of the fracture surfaces are present such as spikes that could prevent a rotational displacement, the femoral head can turn freely in the acetabulum around its axis. This applies also to the presence of comminuted fractures; a rota-

tional displacement is the consequence (Backmann, 1953).

Ad (1) **The position of the implant** plays an important role in the prevention of loss of reduction in varus.

Pauwels noted that distraction moments are operative in the fracture line cranial to the implant, whereas compression moments are prevalent caudal to the implant. For this reason, a more **cranial positioning of the implant** seems more advantageous (Pannike, 1996). This advantage, however, is countered by many disadvantages: the implant placed under the zone of loading endangers markedly the circulation in the femoral head leading to an increased incidence of avascular necrosis (Brodetti, 1960; Manninger et al, 1961a). In addition, in such an instance and in the presence of porotic bone, one has to fear a cranial migration of the implant through the joint surface (cutting out).

If the implant is placed in the **center of the neck along the longitudinal axis of the neck**, it does not find sufficient support in the elderly patient due to the loss of trabeculae in Ward's triangle. Without this buttressing a one-arm leverage is present, the resulting compression moments lead to an overloading of the already thin lateral cortex (the tension trabeculae at this site have already branched off medially).

If the implant is positioned on Adam's arch, one obtains a three-point buttressing effect instead of a two-point loading and a two-arm lever instead of a one-arm leverage. This reduces considerably the loading of the implant. At the same time, the direction of the forces is changed laterally, instead of compression distraction moments are operative. If Adam's arch of the caudal fragment remains intact (as it happens in the majority of neck fractures), the use of a **thick, rigid plate (as with DHS) is unnecessary. A 2 mm two-hole plate exerting a tension band effect is sufficient.** It can be inserted percutaneously and causes therefore less soft tissue trauma.

A precise placement of the screw in the subchondral bone constitutes foremost the first point of buttressing (in the caudal third of the head) and is the prerequisite for an adequate stabilization. The stability can be increased by **a greater screw diameter or the use of several screws**. If the fracture is more vertical (Pauwels-III), it is advisable **to use a caudal screw with a longer thread section** that results in an improved purchase in the cranial fragment (see Fig. 144).

Protection against tilting in varus (and rotation) can be further increased by **the design of the implant end** (see hook pin, Rydell nail). In our experiments we have increased the rotational stability of cannulated screws by **inserting a plate (acting as a flange) in a longitudinal groove made in the cannulated screw; the groove ends short of the last thread**. This flanged screw was designed in analogy to flanged nails (see Fig. 138 and 241k, l).

Ad (2) **The intact calcar femorale** plays the same role of support in the sagittal plane in avoiding the secondary antecurvature as the Adam's arch does in the frontal plane. As seen in a lateral view the slightly anteriorly placed caudal screw lies in the gutter between Adam's arch and calcar femorale and prevents not only a tilting in varus but also an antecurvature (see Figs. 10 and 11).

Ad (3) Smooth or fragmented fracture surfaces cannot prevent rotation. Only the use of two or more implant can do so. Number and size of implants are not trivial, as they increase the bony defect and thus interfere with the circulation to a greater extent (Brodetti, 1960; Nyiri and Rupnik, 1998). If after a placement of the screws a visible fracture gap remains, an impaction (approximation) of the fracture surfaces is mandatory. On one hand, a bony consolidation of the neck that is not covered by a periosteum cannot occur even when the gap is narrow. This may lead to delayed or non-union. On the other hand, with an early perfect approximation the drainage into the metaphysis can be restored already during surgery (see Fig. 55).

The approximation must be done very carefully as too great a force may block the intraosseous drainage. Moreover, a great force may break off bony spikes resulting in an increased instability. Careful approximation will improve the contact between the fragments and facilitate the desired sliding of the screw shank. This sliding will continue during the ensuing settling.

At first we will deal with the three-point buttressing: femoral head, Adam's arch/calcar femorale and lateral cortex discussing problems of secure stability. We will describe results of investigations and developments that helped us to solve these problems. Questions relating to the displacement in rotation, the approximation of fragments and the settling of the fracture will be dealt with in separate sections according to their importance. We will conclude this chapter with a presentation of our current and future investigations and developments.

5.2 Reinforcement of the first point of buttressing – improvement of the purchase in the femoral head

5.2.1 Problems of stability concerning the femoral head

The inadequacy of the first point of buttressing may have two causes: **(1) faulty placement of the implant; (2) advanced osteoporosis**

In a publication dealing with our results of the first 1000 femoral neck fractures between 1940 and 1955 we analyzed the importance of the nail position in the femoral neck (Manninger et al, 1961a). We noted that the placement of the implant in the cranial part in the head is wrong. We determined the limits of nail placement in a.-p. and lateral films (as a rule the outer third of the head). Placing the nails beyond this limit is questionable as the stability is insufficient. We also analyzed the importance of the distance between the tip of the screw and head contour. We found that a distance exceeding 15 mm leads to a marked increase in the incidence of complications. Distances ranging between 1 and 15 mm did not influence the incidence of complications regardless of the length of the distance. In the aforementioned study we did not investigate the correlation between stability and age, neither the importance of osteoporosis.

In the last half of the 20th century the **average age** of our patients with femoral neck fracture increased by **10 to 15 years**. Due to the age related increase in osteoporosis the attainment of a stable internal fixation in the femoral head became a much bigger problem. In the compact and homogenous bone of adolescents a distance between screw tip and head contour of 10 to 15 mm has no serious consequences. With increasing age, however, the trabeculae at the center of the femoral head become thinner and therefore the purchase of the screw is decreased. For this reason internal fixation with the standard screw is insufficient. Already 40 years ago we found that insertion of the nail up to the femoral head contour influenced favorably the stability of internal fixation (Manninger et al, 1961a). However, only after the investigations by Rehnberg (1988) did we recognize the importance of **subchondral fixation** and accepted it. As the subchondral bone is the last to be affected by the age-related regressive changes, the tips of the screws have to be placed here while avoiding perforation of the femoral head. This ensures a reliable first point of buttressing.

5.2.2 Modifications of the screw threads to improve stability

Early on we proceeded with several minor modifications to improve the hold of cannulated screws in the femoral head. **At the screw tip we decreased the depth and the width of the cutting threads by half** (see Fig. 127). In addition, the **screw tip was blunted** to ensure that already the first thread would find a good purchase in the most precious subchondral zone thanks to an increased thread surface. Such a purchase had been more difficult to obtain with earlier models having a tapered tip; it decreased the purchase while increasing the risk of joint perforation (Sundgren and Persson, 1994; Adolphson, 1995; Olerud et al, 1995).

This danger was less with the modified screw. The blunted end could be easier identified on the monitor. A perforation of the subchondral bone is not a catastrophic error as the layer of hyaline cartilage is thick. Admittedly, the interpretation on the monitor is not easy and one can be easily deceived. A position that seems acceptable in both views can prove to be a serious joint perforation in oblique views. Damage to the cartilage of the acetabulum may be the consequence (Fig. 126).

It is for this reason that we recommend checking on the monitor the position of the screw tip in the subchondral bone by moving the lower limb through

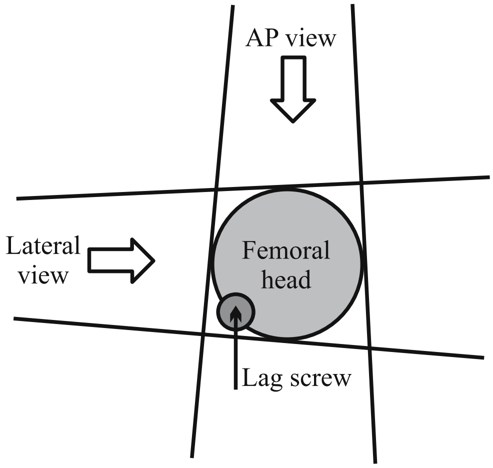


Fig. 126. Explanation of the erroneous assessment of screw position in the femoral head (Parker and Pryor, 1993).
The tip of the screw lies outside of the head contour although its position appears intraosseous in both views

a full range of motion and proceed with corrections, if indicated before attaching the 2 mm two-hole plate.

5.2.3 Comparative avulsion test of femoral neck screws possessing various thread qualities and thread diameter

Various types of cannulated screws were tested **pulling them in direction of the femoral neck axis**. The force of avulsion is a characteristic feature of the implant and its stability. Obviously, this feature not only depends on the screw but also on the quality of the bone and the way of insertion.

For testing, femoral heads were removed at the time of autopsy through an osteotomy at mid-neck and preserved deep-frozen. The measurements were executed at the Department of Material Science and Mechanical Technology of the Budapest University of Technology and Economics (BUTE) in 1995. The force of avulsion was tested in a 10-ton electromechanical device similar to the Instrom machine type TTDM. In total 12 measurements were done, twice one femoral head only was harvested from two patients and in five instances, both heads were removed.

We compared one screw manufactured by Olmed to three different screws developed by us and made by Sanatmetal from stainless steel of the Swedish firm Sandvik (ISO 5832-1:1987) (Fig. 127 and Table 2).

After drilling and tapping the screws were inserted up to the subchondral bone under direct vision and palpation. The femoral heads were embed-

Table 2. Characteristics of cannulated screws

Type of screws	Shank diameter (mm)	Thread diameter (mm)	Lenght of threads (mm)	Number of threads	Shape of screw tip
Olmed®	5	8	25	9	Pointed reamer
Sanatmetal 1®	5	8	24	8	self-cutting
Sanatmetal 2®	5	8	24	8	Threads up to the tip, little self-cutting
Sanatmetal 3®	6	9.5	24	8	Threads up to the tip, little self-cutting

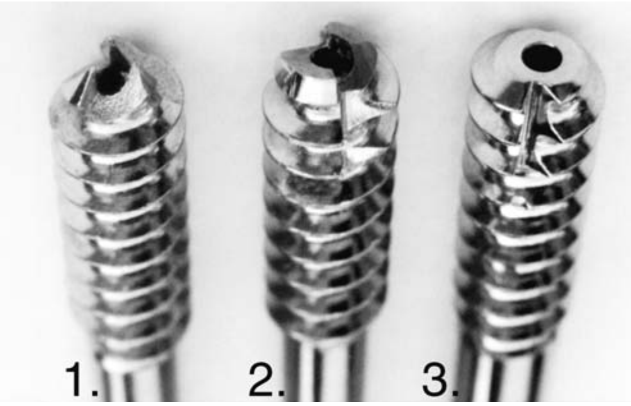


Fig. 127. Magnified views of the experimentally tested cannulated screws.
(1) Olmed®; (2) Sanatmetal®1; (3) Sanatmetal®2. The tip of the 9.5 mm screw (Sanatmetal®3) is identical to the tip of screws still used today of the type Sanatmetal®2

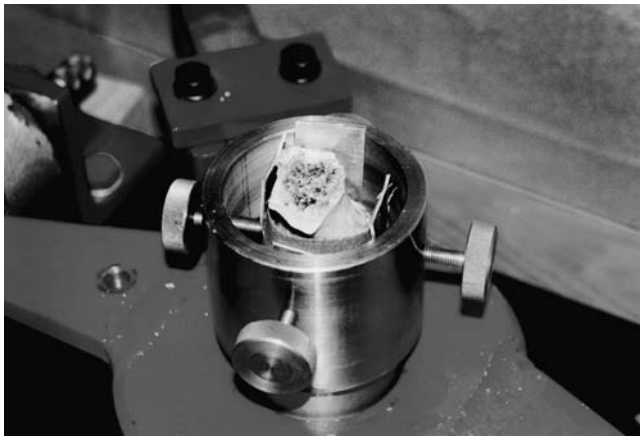


Fig. 128. Fixation container used for avulsion testing.
The femoral head has been fastened in a specially designed cylinder

ded in a specially designed fixation container (Fig. 128) and the screw ends fastened in a chuck with a universal joint. The speed of loading amounted to 2 mm/minute. The force was measured as a function of displacement.

The force of avulsion did not show a substantial difference between screws having an identical thread diameter (8 mm) and different forms of their tips (Fig. 129).

The force of avulsion of screws with a greater thread diameter (9.5 mm) was **twice as great** as for standard screws (thread diameter 8 mm) (Fig. 130).

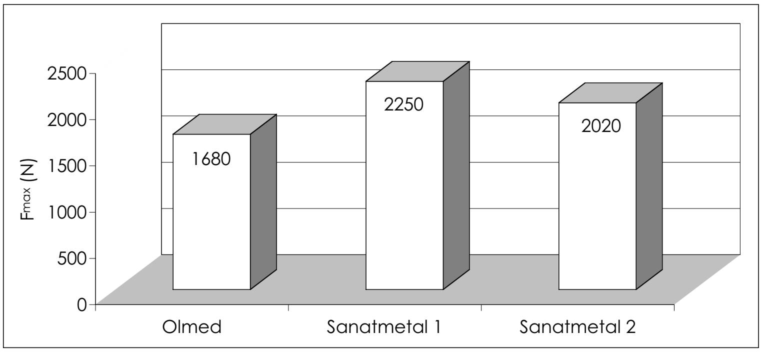


Fig. 129. Comparison of the avulsion force after implantation of various implants having different screw tips into the femoral head. Average value of the force (F max.), measured in Newton (N) that has been necessary for the avulsion of the screws from both femoral head cadaver specimens of a 48-year-old and a 59-year-old man

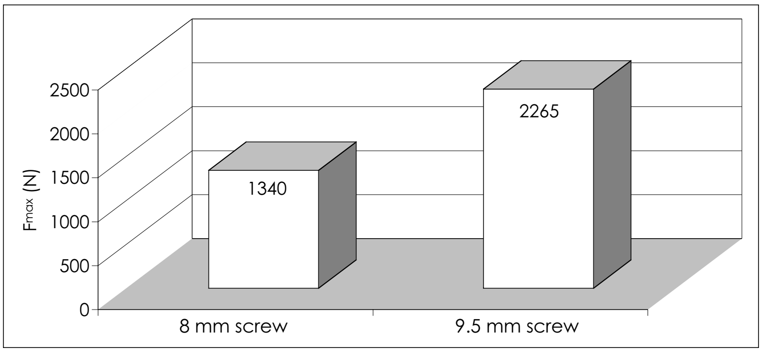


Fig. 130. Comparison of the avulsion force after insertion of a 9.5 mm screw and of a 8 mm screw. Average value of the force (F max.), measured in Newton (N) that has been necessary for the avulsion of the screws from both femoral head cadaver specimens of a 48-year-old man

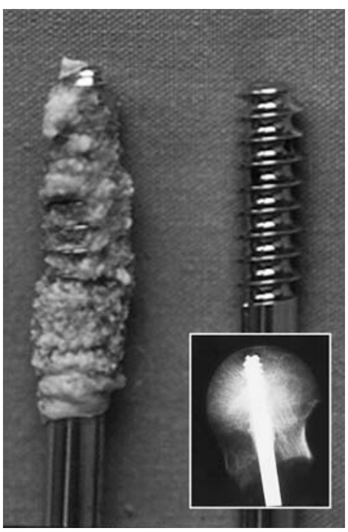


Fig. 131. Bone cement injected into the head around the screw threads and its radiologic appearance (inset).

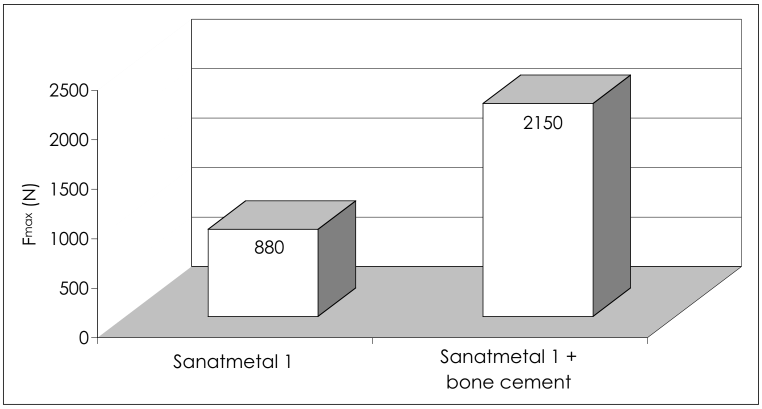


Fig. 132. Avulsion force of identical screws (Sanatmetal®1) for standard screw insertion and after addition of Palacos® cement.
Average value of the force (F max.), measured in Newton (N) that has been necessary to avulse the screws from both femoral head cadaver specimens of a 92-year-old man

5.2.4 Testing of avulsion force of neck screws enforced by bone cement

For this test the same experimental conditions were applied. After drilling and tapping 1 ml of liquid bone cement (polymethylmethacrylate) was injected through a small drain into the femoral head and then the screw inserted. After settling of the cement (10 minutes) the test was started (Fig. 131) (Bagi et al, 1996; Dévényi et al, 1996; Soltay et al, 1998).

The effect of the cement required **more than twice** the force of avulsion (Fig. 132).

5.2.5 Assessment of results

The results must be interpreted with caution given the small number of specimens:

(1) The force of avulsion of Olmed screws®, Sanatmetal (1) screws® and the further developed Sanatmetal (2) screws® **did not show a marked difference**. The shape of the screw tip does not seem to be an important factor. The reason for this might be explained by the fact, that although the last thread improved the purchase of the screw in the subchondral bone, the strong purchase of the following seven threads in cancellous bone did not allow to detect this effect. The advantage of the blunted screw tip was mainly reflected by the fact that perforations could be prevented.

(2) **The increased thread diameter and the supplementation with bone cement is of much greater importance.** It is for this reason that we recommend to use the 9.5 mm screw for internal fixation of fractures in patients over 80 years and for pathologic fractures involving the femoral head.

The technique of injecting bone cement into the drill hole should be considered for the initial surgery in **elderly patients with severe osteoporosis or for revisions after complications** (loss of reduction). This technique is particularly advantageous, as it does not cause an additional stress to the patient in instances where a cavity has formed around the loosened screw and when a total joint replacement is contraindicated on account of poor health. This technique that will decrease pain and facilitate patient care as the purchase of screws in damaged cancellous bone is more reliable, can be added without being more invasive.

The supplementation of bone cement to the internal fixation of hip fractures has also been tried by other authors (Goodman et al, 1998). Their method, however, is markedly different from ours as they used the cement **to fill the fracture gap, the bone defect and to reinforce the medial femoral neck cortex**. Our goal for the injection of bone cement into the implant bed is the **improvement of cancellous bone strength** around the screws in the **senile, markedly osteoporotic femoral head**.

Goodman used the biologically more favorable hydroxyapatite instead of polymethylmethacrylate. In spite of its high cost its use in **small amounts** seems indicated.

Recently another research group has reported on experiments with bone cement. To increase the purchase of the implant they injected bone cement through the bore of the cannulated implant (modified DHS with perforations between the threads) into the femoral head (Kramer et al, 2000).

5.2.6 Investigations into the rotational stability of flanged screws

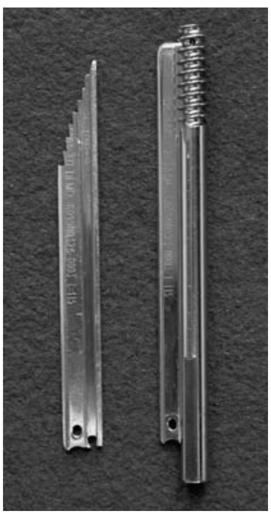
The rotational stability of three-flanged nails in comparison to screws is greater whereas the force necessary to avulse the screws is greater when compared to nails. To combine these two favorable characteristics we designed the **flanged screw**: A slit has been added longitudinally reaching into the bore but sparing the two last threads. A plate is inserted into this slit. The dimensions of the flanged screw and its technique of insertion are similar to that of an 8 mm standard screw. After drilling and tapping a groove is made for the plate (flange) into the lateral cortex and into the cancellous bone with a **toothed chisel**. After screw insertion the plate is inserted percutaneously with the help of a driver and slight hammer blows (Fig. 133, also Fig. 241k, l).

In collaboration with the Department of Material Science and Mechanical Technology of the Budapest University of Technology and Economics (BUTE) we investigated ways to improve the rotational stability in 1998. Subcapital osteotomized femoral head specimens of human cadaver were clamped in a special device. Either a three-flanged Smith-Petersen nail (width of flange 3 mm) or screws with one 5 mm broad plate (flanged screw) were inserted into the specimen and tested in rotation. The moment of rotation was measured as an electrical signal through a load cell, the data recorded as moment of rotation-time-function, stored and graphically represented.

The measurements were done on paired head specimens of younger (37- and 47-year-old) and older (69-, 78- and 86-year-old) subjects. We attempted to insert the two different implants into the specimen pairs in an identical position during subsequent measurements.

We could show that the resistance against rotation of a **flanged screw** equaled that of the Smith-Petersen three-flanged nail (Fig. 134).

The advantage of inserting the flanged screw is seen in the fact that the rotational stability is comparable to that of femoral neck nailing but its insertion can be achieved without exposing the femur (see Fig. 138).



a

b

c

Fig. 133. The flanged screw and its instruments.
a. Toothed chisel and the screw with inserted plate; **b.** Close up of the screw and the plate end; **c.** Screw with driver and inserted plate

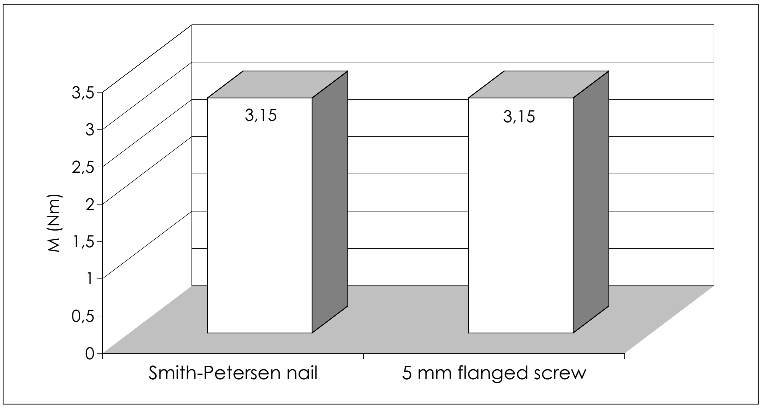


Fig. 134. Comparison of resistance against rotation of Smith-Petersen nail and flanged screw. Average value of resistance against rotation of Smith-Petersen nails with three 3 mm broad flanges and the flanged screw with one 5 mm broad flange. Both were symmetrically implanted into paired femoral head specimens. The rotational moment (M) was measured in Nm

5.2.7 Improvement of stability with three screws

The disadvantage of the above described solutions lies in the fact that different implant series must be available, if internal fixation is planned with screws of different thread widths or with special flanged screws. It would be simpler to use **three cannulated standard screws**. The problem here is to insert the screws in a parallel fashion. Similar to the procedure with cancellous bone screws described in Sect. 4.2.3, we designed an **aiming device (called parallel guide) for the parallel insertion of three screws** and a 2 mm **four-hole plate**. This plate is broader cranially and pointed caudally resembling an **isosceles triangle**; it exerts a tension band effect on the screws (Fig. 135b).

The exposure of the lateral femoral cortex is a disadvantage of this procedure. Another disadvantage is the technical difficulty to insert three cannulated screws into an oval femoral neck. Based on the analysis of measurements of transverse cuts of the femoral neck and on CT serial images we feel that the entry points of screws should be placed in **a triangular fashion, two anteriorly and one posteriorly** (Fig. 136, also Fig. 241g). The caudal screw is placed in the gutter slightly anterior to Adam's arch whereas the posterior screw rests on the calcar femorale. The third screw placed cranially and anteriorly rests and finds support on the **always present crest like cortical thickening** directly under the iliofemoral ligament (see Fig. 28) (Booth et al, 1998).

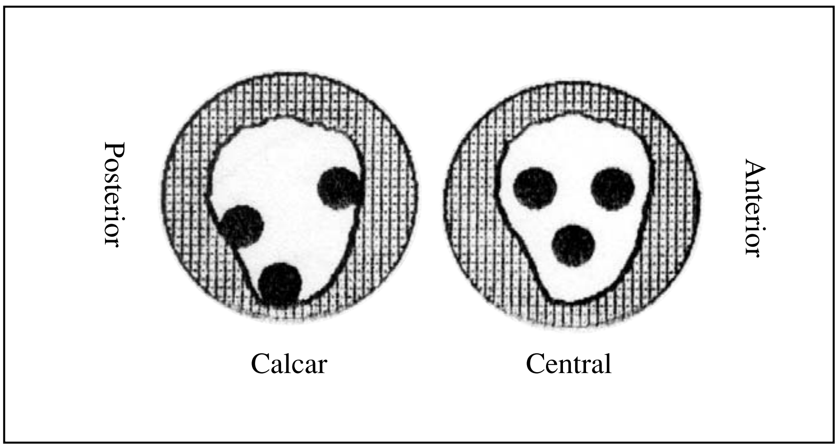
If the 2 mm two-hole plate is only connected to the caudal screw, a major exposure of the bone is not necessary.

a

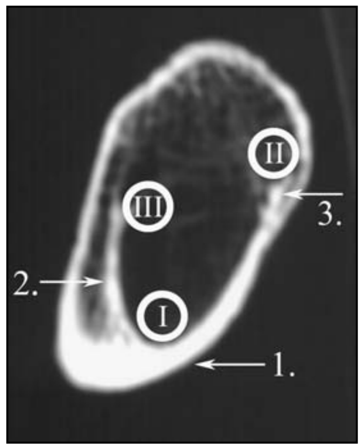
b

c

Fig. 135. Internal fixation with three cannulated screws and exposure of the lateral femoral cortex (earlier method, see Fig. 139).
a. Aiming device and short sleeves for the parallel insertion of three screws; **b.** Plate for the fixation of the three cannulated screws (2 mm four-hole plate); **c.** For comparison: plate for the fixation of one (standard 2 mm two-hole plate) or for fixation of two cannulated screws (2 mm three-hole plate)



a



b

Fig. 136. Modified position of the three cannulated screws inserted percutaneously.
a. Booth and collaborators (1998) designed a similar experimental model: schematic representation of the conventional and the modified position; **b. This sagittal CT image of the femoral neck shows the position of the three cannulated screws** in their sequence of insertion (I–III) as well as the three important zones for stable buttressing: 1. Adam's arch, 2. calcar femorale, 3. anterocranial cortical thickening of the femoral neck (isoscele)

5.2.8 Improvement of stabilization – clinical examples

Screws with thread diameter of 9.5 mm have been used by us regularly since 1994 for the treatment of fractures in patients older than 80 years or for revision surgery (Fig. 137).

Since 1999, after requesting the patent, we used the flanged screw in nine patients inserting the plate always into the caudal screw (Fig. 138).

Already years ago we used three screws in a few instances (Figs. 139 and 140). Since 2001 we performed the screw insertion employing the new parallel guide (see Sect. 5.7, point 2 and Fig. 162).

Fig. 137. Use of the 9.5 mm screw for revision surgery.
78-year-old patient; **a, b.** Garden-IV fracture (very poor a.-p. film); **c, d.** 14 hours after the accident the fracture was treated with cannulated screws. Minor mistakes happened during the reduction (inadequate traction) and during internal fixation (the caudal screw does not rest on Adam's arch, both screws are placed cranially); **e, f.** 8 months later the caudal screw is in contact with Adam's arch, non-union with marked tilting in varus and extreme settling have developed. As the DS intraosseous venography was positive, we exchanged the caudal screw that caused the symptoms for a 9.5 mm screw after repeated drilling of the pseudarthrosis (with a special drill bit). The stronger screw that is buttressed by the Adam's arch finds purchase in the vital head in good position; **g, h.** 3 years later, the head contour is preserved, Adam's arch remodeled and the patient has no important symptoms

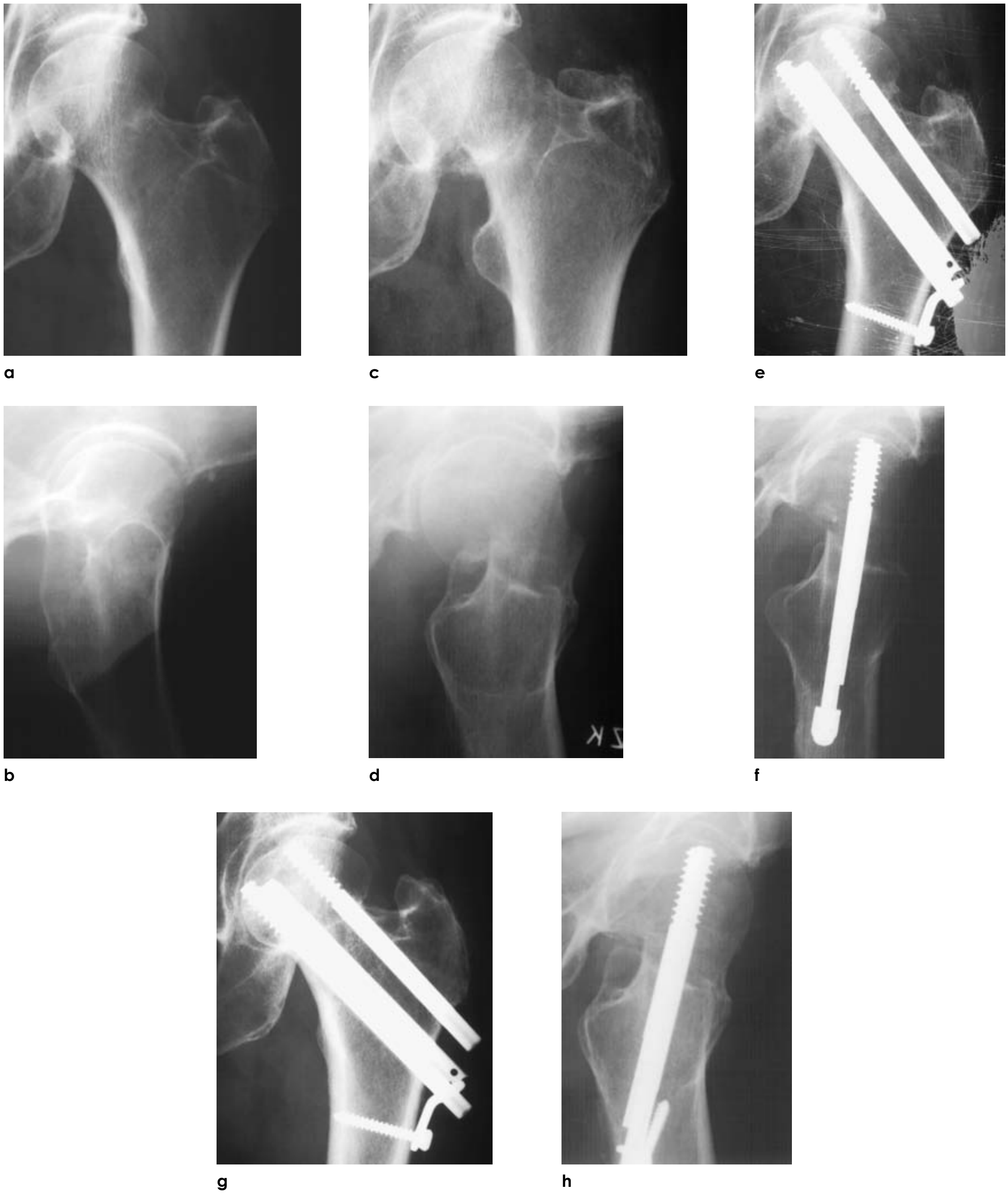


Fig. 138. Insertion of a flanged screw.
82-year-old woman. Fall at home and injury to left hip. Patient was able to walk; **a, b.** On account of hip pain radiographs were taken elsewhere and interpreted as being negative in spite of the fact that the cranial "S" (see Fig. 179) was interrupted on the a.-p. film. The lateral film is useless for assessment of the fracture (it was not taken perpendicular to the femoral neck, the greater trochanter is projected over the head). Control radiographs taken 10 days later were also thought to be negative. The patient was allowed to bear weight; **c, d.** 3 days later complaints of severe pain and inability to walk. Radiographs show a displaced fracture (varus and antecurvature). The patient consulted us; **e, f.** After a short preparation internal fixation with flanged screw; **g, h.** 1 year after the accident the patient was symptom-free, the fracture had consolidated after a minor settling

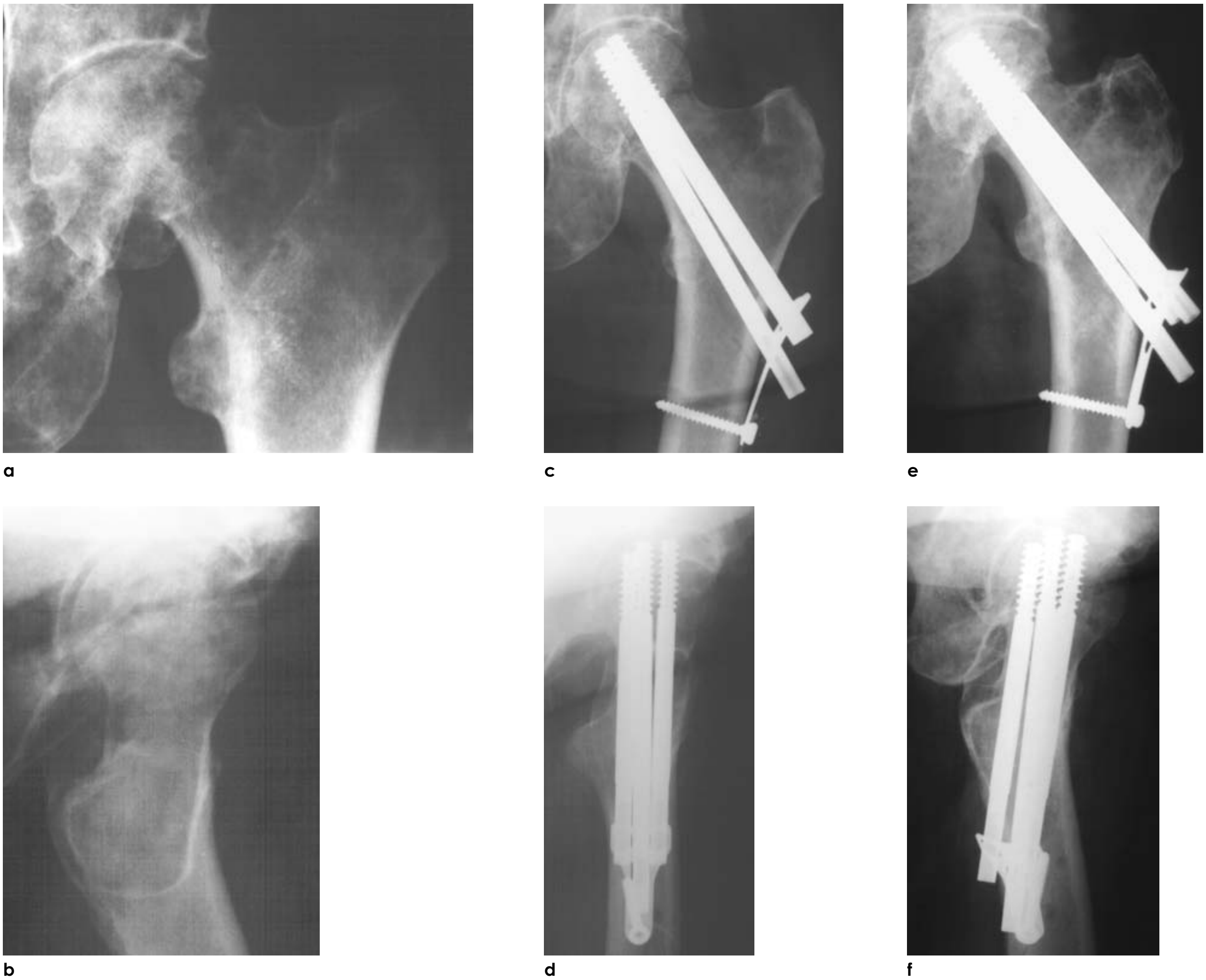


Fig. 139. Internal fixation with three cannulated screws and 2 mm four-hole plate.
46-year-old woman with breast cancer. Ten months earlier a left mastectomy had been done. Already then multiple bone metastases were present. One week before admission the patient accused pain in the left hip, on the day of admission she was unable to walk without falling; **a, b.** Pathologic Garden-III-IV fracture; **c, d.** On account of the marked instability an internal fixation with three cannulated screws and plate was performed. The postoperative films reflect the technical difficulties: failure to insert the screws in a parallel fashion into the neck, the site of metastases; **e, f.** During the follow-up examination 4.5 months later the patient could walk with two canes, the fracture was about to consolidate after marked settling

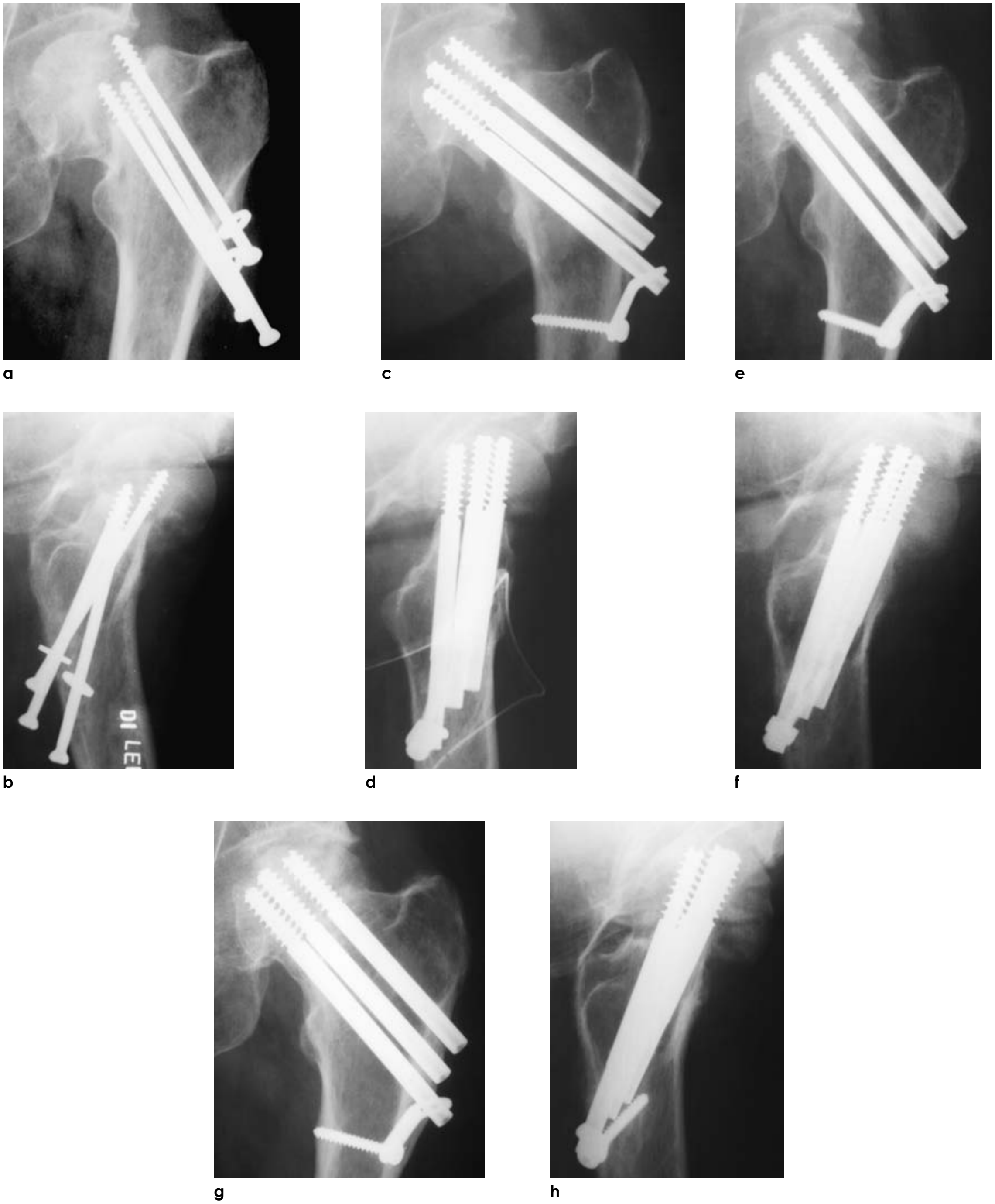


Fig. 140. Internal fixation with three cannulated screws during revision surgery.
69-year-old woman. A left femoral neck fracture had been internally fixed with cancellous screws elsewhere; **a, b.** 8 months later the patient was admitted to our institute with a pseudarthrosis and backing-out of screws. After screw removal and reduction a DS intraosseous venography was done and turned out to be positive; **c, d.** On account of her poor general health only a percutaneous insertion of three screws could be done. The position of the screws forms a triangle, the basis being anteriorly and the apex posteriorly (see Fig. 136b). The 2 mm two-hole plate is only attached to the caudal screw; **e, f.** 9 months later the pseudarthrosis has healed; **g, h.** 3 years later a partial avascular necrosis with flattening of the pie-shaped sector is visible; the patient, however, is symptom-free

5.3 Reinforcement of the second buttressing point: Adam's arch and calcar femorale

5.3.1 Problems of stability at the second buttressing point

Following the principle of the two-arm lever the greater the part of the Adam's arch and the calcar femorale remaining attached to the caudal fragment the more stable will be the internal fixation. If the buttressing point of the caudal screw that is the pivot of the lever lies more cranial, the length of the lever arm to which force is applied increases (distance between pivot and lateral cortex). To compensate for the body weight applied to the shorter load arm a 2 mm two-hole **plate acting as a tension band** is attached at the third point of buttressing. The plate counteracts forces pushing the femoral head into varus.

For similar reasons intramedullary nails (Ender-, Gamma-) are biomechanically sounder for the stabilization of trochanteric fractures than extramedullary implants (DHS, 95° and 130° bladeplates) because they medialize the pivot (see Fig. 15c).

In vertical Pauwels-III fractures the short part of Adam's arch is further away from the femoral head. The load arm becomes longer and the lever arm to which the force is applied is shortened. This results in an increased loading at the third buttressing point (see Fig. 211c–g). In this instance a **more vertical placement of the implant** is indicated (Brittain, 1942; Garden, 1961b). This solution has, however, the disadvantage that **no place remains for the second (cranial) screw** next to the craniocentral position of the caudal screw. A vertical position of the caudal screw is also undesirable, as although the shear moments causing a varus displacement decrease, the **compression loading increases** proportionally on the already circulatory compromised femoral head and on the fracture surfaces (see Figs. 28, 33 and 34). An increased risk of avascular necrosis will result.

If Adam's arch is completely broken off from the caudal fragment or if a multifragmentary or comminuted fracture is present, **the second point of buttressing** is "absent" leading to a one-arm leverage. The forces acting on the lateral cortex increase and need to be compensated by an **angle-stable implant**.

In this case an internal fixation with a DHS could be considered as it is done in many trauma centers abroad. Irrespective of the fracture type this implant is used in patients younger than 60 to 65 years (recently younger than 75 years) in those centers where a total joint replacement in patients older than 65 resp. 75 years is always preferred (Bonnaire, 1998).

We always attempt to improve internal fixation with cannulated screws. In our opinion internal fixation of femoral neck fractures with DHS is barely suitable given their many disadvantages:

(1) Some investigations showed **that a single large implant damages the femoral head more** than multiple small ones (Brodetti, 1960; Nyiri and Rupnik, 1998). Even the strong two-hole plate, part of the DHS is oversized for neck fractures.

(2) During insertion of a large tap and screw the freely movable **femoral head** can be twisted without additional fixation and damage further the circulation. If the DHS is inserted into the center of the neck as stipulated in the original description, **it cannot prevent a rotational displacement**. It even acts as an axis around which the femoral head can turn. For this reason, internal fixation with a DHS must be complemented by a cancellous bone screw inserted cranially.

(3) During internal fixation with a DHS the screw cannot be placed **in close contact with Adam's arch** (as it can cut into it) **nor in the subchondral bone** on account of its thread diameter. Consequently, **the implant must be placed in the center of neck and head**. Particularly in older patients it does not rest on **Adam's arch** and **does not find sufficient purchase** in the femoral head. A loss of reduction may ensue.

(4) In the above mentioned centers internal fixation with a DHS (complete with the two-hole plate) is performed through a **small transmuscular approach**. The advocates believe that the invasiveness of this method does not exceed the invasiveness of the cannulated screw insertion. To accomplish the insertion technique of a DHS the

a b c d e f g

Fig. 141. Three examples of early complications after DHS internal fixation of femoral neck fractures.
These radiographs were collected during studies abroad.
(1) 89-year-old woman; **a.** Right Garden-IV comminuted fracture; **b.** initial treatment with DHS. The screw has been positioned in the cranial third of the head; **c.** After one week the screw perforated the femoral head followed by a loss of reduction necessitating a hemiarthroplasty.
(2) 68-year-old woman; **d.** Left femoral neck fracture treated initially with DHS. The screw has been placed in the center of the head, not subchondral; **e.** After 6 weeks loss of reduction. A total hip replacement was done.
(3) 63-year-old patient; **f.** The right-sided neck fracture was initially treated with DHS and cancellous bone screw. The threads of the cancellous bone screw crossed the fracture gap causing a diastasis interfering with consolidation; **g.** Three months after accident a loss of reduction occurred with breakage of the cancellous bone screw

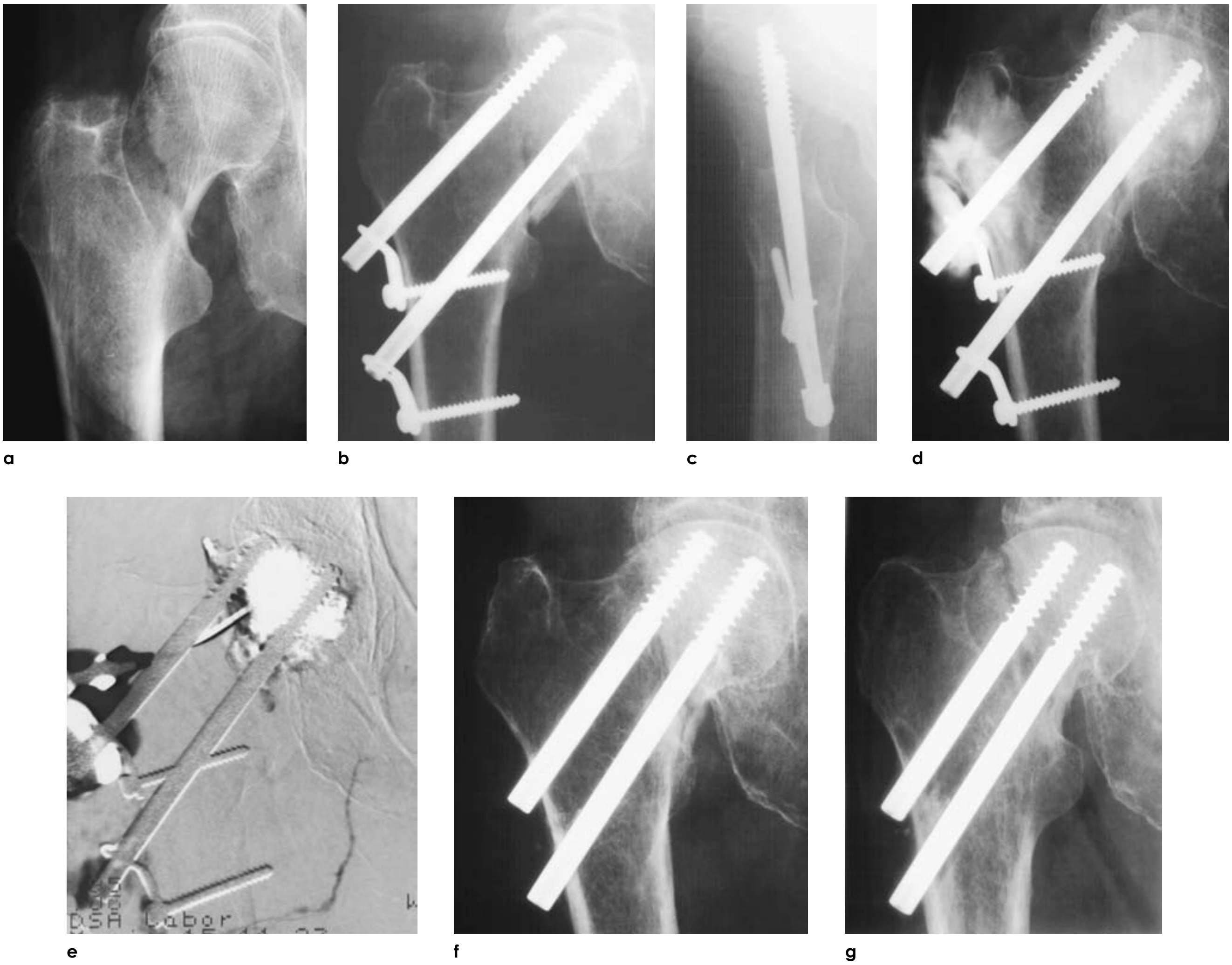


Fig. 142. Anchorage of both screws with one 2 mm two-hole plate each.
80-year-old woman; **a.** Six days earlier the patient suffered a right Garden-III-Pauwels-III neck fracture in the Ukraine. She was treated conservatively without thrombosis prevention. Her relatives requested an admission to our institute. On account of her poor general health we opted in favor of a cannulated screw fixation in spite of the fact that the fracture was not fresh; **b, c.** Both screw ends were attached to a 2 mm two-hole plate each to obtain percutaneously a stability as great as possible. The fracture gap remained slightly distracted, the cranial screw reached under the contour of the femoral head as otherwise no place was available for the two plates. Four days postoperatively a pulmonary embolism occurred necessitating the transfer to a cardiac intensive care unit because of her poor general health. Her conditions improved and she could be mobilized later on; **d.** Three months postoperatively she was able to attend a follow-up. Increasing hip pain was attributed not only to a marked backing-out of screws but also to a perforation of the cranial screw into the joint; **e.** The DS intraosseous venography was not optimal (marked congestion, metaphyseal drainage, the contrast agent had flowed through the screws into the soft tissues); **f.** Considering the recent severe illness only a removal of both plates and change of screws was possible. After 3 months of satisfactory evolution and mobilization the patient felt a sudden cracking of her operated hip and was unable to walk; **g.** The radiograph showed a diastasis of the initial fracture line without loss of reduction (nonunion). It is likely that the patient was weight bearing on her necrotic femoral head (in retrospect a difference in density between femoral head and metaphysis can be recognized in **f.** At this moment her general health permitted a total hip replacement. Thanks to the minimally invasive internal fixation and revision surgery the elderly and seriously ill patient could be kept alive and improve her condition to allow a total hip replacement. This procedure would have been indicated initially but was precluded by her poor general health

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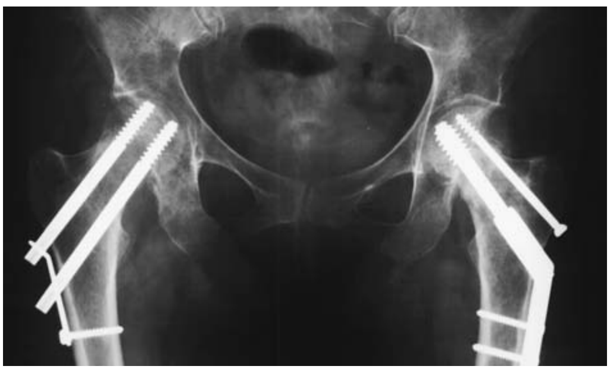

c

Fig. 143. Anchorage of two screws in a 2 mm three-hole plate. 46-year-old woman. Eight months before her first admission to hospital for a right mastectomy for breast cancer followed by radiotherapy for metastases in the first lumbar vertebra and other bones. At the day of admission she felt a cracking in her left hip; **a.** A pathologic basal neck fracture was diagnosed and treated with a DHS. During the next three months the patient walked with two canes, but then experienced a similar event; **b.** She suffered a pathologic right Garden-III neck fracture. We opted in favor of a cannulated screw fixation given her general condition and the fracture configuration. Both screw ends were attached to a 2 mm three-hole plate; **c.** Six weeks later, she was able to use a walker with full weight bearing, the hip was pain free

use of a T-shaped aiming device attached to the lateral cortex is required; it cannot be inserted through a small approach. Therefore, a free-hand technique is often employed. If the proper angle is not respected, a perfect adaptation of the massive plate on the femoral cortex is impossible. Should nevertheless an adaptation with cortical screws be attempted, a strain in the femoral head will result and may lead to a cutting out of the screw from the porotic head (Fig. 141).

(5) As proven by our series the use of cannulated screws for internal fixation is a flexible method that can be adapted during surgery to prevailing conditions, even if the original radiographs failed to reveal a multifragmentary fracture or the severity of osteoporosis.

(6) Also for **financial** considerations the use of a **single set of instruments and implants** for the stabilization of various types of femoral neck fractures is not insignificant.

5.3.2 Improvement of the stability of internal fixation with a 2 mm three-hole plate attached to both screw ends

From the beginning our goal has been to be able to individualize an adequate but stable fixation for the heterogeneous forms of neck fractures.

For Garden-I fractures impacted in good position a simple fixation with two screws is sufficient. For Garden-II fractures as well as for the more frequent but not too vertical Garden-III and -IV fractures with intact Adam's arch we routinely use a small caudal 2 mm two-hole plate. In instances where the buttressing effect of Adam's arch has "been lost" (vertical fracture line), in the presence of comminuted or basal neck fractures an additional augmentation of stability is mandatory.

To stabilize Pauwels-III fractures in high-risk patients we attach **booth screws each to a 2 mm two-hole plate** (Fig. 142).

For similar indications we used repeatedly a **three-hole plate** that **took hold of the two screws** (see Figs. 135c and 241b). The possibility to insert this plate percutaneously without enlarging the approach is a major advantage of this technique. The simultaneous attachment of both screws also allows to guarantee their parallel placement. Moreover, this set up protects against micromovements, tilting in varus and foremost against rotation. A prerequisite of this technique is however the parallel insertion of the screws (Fig. 143).

5.3.3 Improvement of stability of internal fixation of Pauwels-III fractures in combining screws of different thread lengths

For the fixation of Pauwels-III fractures in which cranially a small and caudally a large neck fragment remains in continuity with the femoral head, the use of **screws differing from the standard screws with either shorter or longer thread lengths can be necessary.** The 24 mm thread length of a standard screw inserted cranially exactly into the subchondral bone will cross the fracture gap and reach into the caudal fragment, thus enlarging the gap possibly interfering with consolidation. On the other hand, it is advantageous to use caudally a screw with **longer threads.** Therefore screws are available with thread lengths of 24 mm (standard screw), 18, 34 and 44 mm (Figs. 144 and 145).

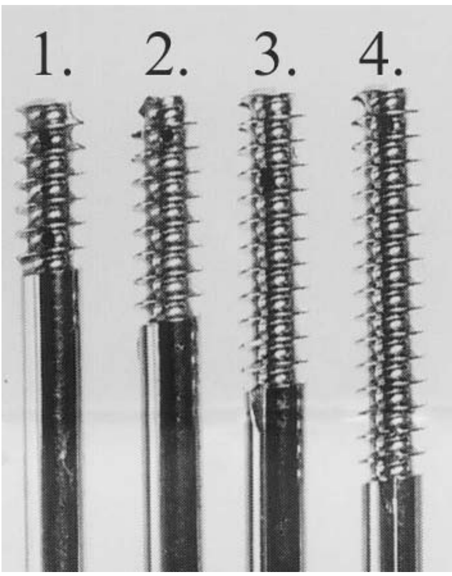

Fig. 144. Screws with different thread lengths.
1. 18 mm, 2. 24 mm (standard), 3. 34 mm, 4. 44 mm

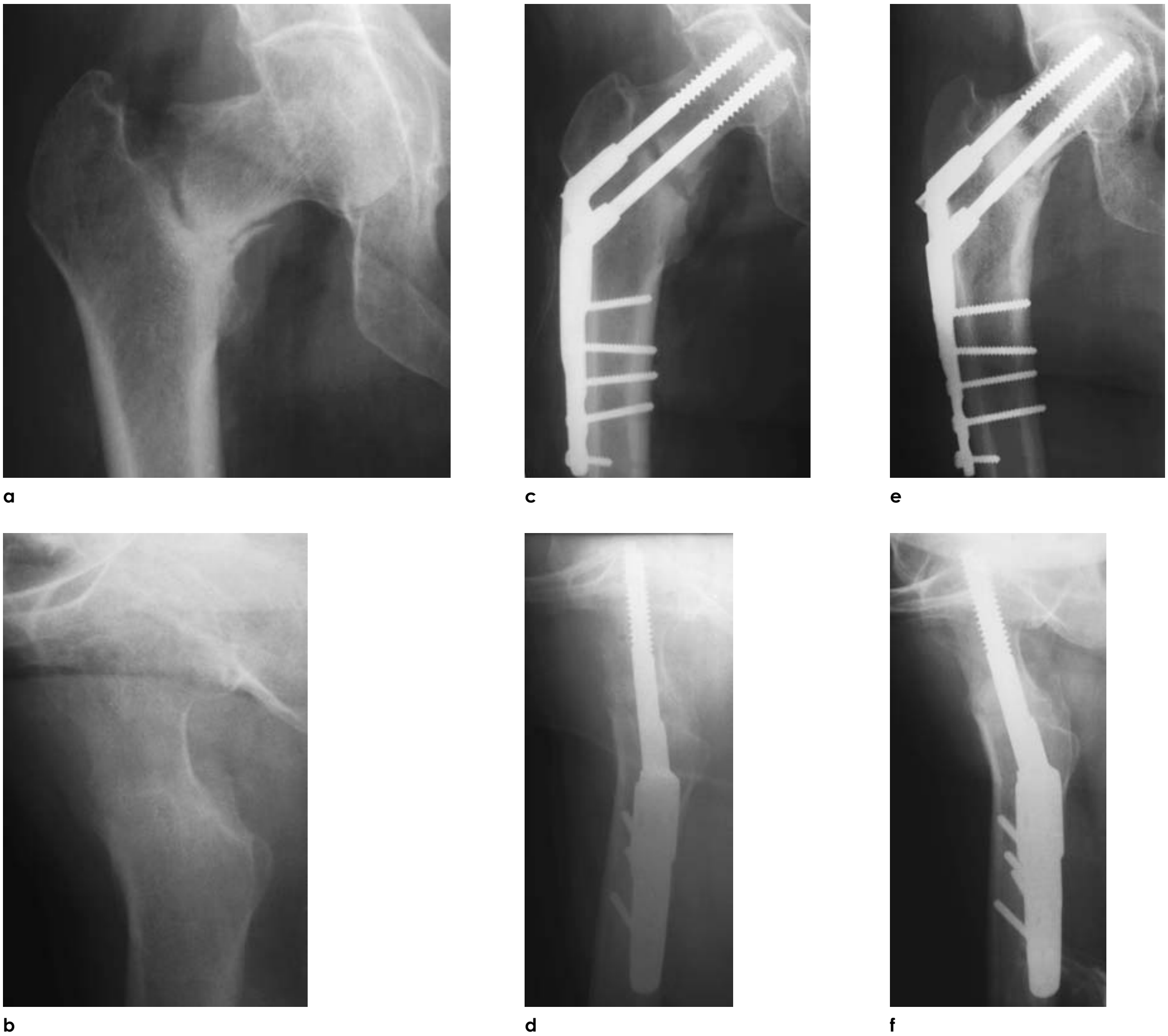

Fig. 145. Clinical example of the use of screws with longer threads.
67-year-old woman complaining about right hip pain for several months. Conservative treatment was unsuccessful. Family physician requested radiographs; **a, b.** A pseudarthrosis after basal neck stress fracture was diagnosed. It was most probably "stabilized" over an extended period by a spur of Adam's arch and calcar femorale; **c, d.** During internal fixation the fracture gap was perforated several times by drilling. Insertion of two cannulated screws with a 34 mm thread and a double Dynamic Collo-Diaphyseal (DCD) plate (see Fig. 192e, 5.). Nevertheless, a fracture gap remained due to the scar tissue; **e, f.** Six months later the gap has disappeared. Due to satisfactory settling the fracture consolidated, the patient can weight bear and is symptom free

5.3.4 Angle-stable Dynamic Collo-Diaphyseal (DCD) plates for "absent" Adam's arch

If Adam's arch, being the second buttressing point, cannot support the implant, the two-arm lever becomes a one-arm lever and the third buttressing point, being the lateral cortex, will be overloaded. This happens in:

- The presence of multifragmentary or comminuted fractures;
- Pauwels-III and base of neck fractures;
- Some pathologic fractures (neck metastasis);
- Fractures in the presence of coxa vara often due to stress;
- Trochanteric fractures.

In these instances the missing buttress must be **replaced.** Only a **strong reinforcement of the third buttressing point** can neutralize the strong displacement force that is due to the action of the body weight on the one-arm lever. For this reason we designed **a set of implants** consisting of thin plates in three sizes that can be combined with the cannulated screws. The following are the advantages of these plates:

- They allow a sliding of the screws necessary to compensate for the neck shortening secondary to settling;
- They maintain the screw position in the proper **collo-diaphyseal angle** in spite of the missing Adam's arch;
- They can be **flexibly adapted** to the degree of fracture instability thanks to additions;
- If necessary, a **compression** of the fracture can be obtained with a small screw (see Fig. 192d);
- Their insertion is technically easy.

The need to expose the lateral aspect of the femur for proper plate placement is a definite disadvantage.

The **DCD plates** are placed over the caudal screw after proper aiming and drilling. Depending on the required stability three- and five-hole plates are available having a plate barrel angle of 120°, 130° and 140° (see Figs. 192 and 241h). Thanks to the selection of a proper size femoral neck fractures with coxa vara (not infrequently stress fractures) can also be treated.

The barrel of the DCD plates allows a sliding of screws during settling of the consolidating fracture. Contrary to the DHS the 5 mm long square section preventing rotation does not lie in the cranial but in the caudal part of the barrel (see Fig. 192f); it corresponds to the lateral flattening of the cannulated screw. With the help of a **screw** (compression screw) that fits into the caudal end of the cannulated screw a careful compression of the fracture can be achieved (Fig. 146).

To further increase the stability a **satellite plate** can be attached to the DCD plate that holds the **cranial screw.** The satellite plate fixes the cranial screw and protects foremost against rotation and tilting in varus (Fig. 147, see Figs. 192b, e and 241i).

In instances of severe instability such as in comminuted neck fractures, double fractures and revision surgery, a **double angle-stable DCD plate is available,** it allows insertion of both cannulated screws and thus a secure fixation. The cranial angle stable part of the DCD plate serving to hold the cranial screw has an oval hole. It is pushed over the barrel of the caudal part of the double DCD plate. The cranial part is available in 120°, 130° and 140° (Fig. 148, see Figs. 192c, e and 241j).


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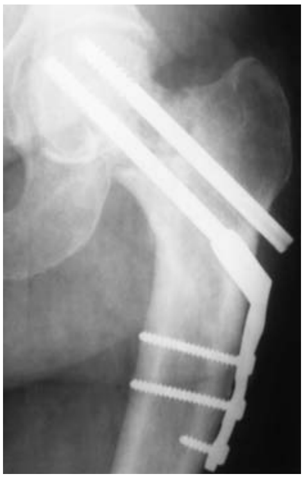

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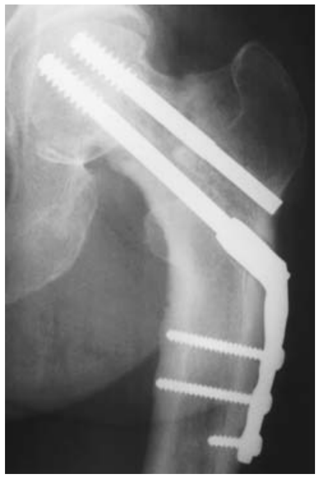

g

Fig. 146. Simple DCD plate. Impaction of a distraction-stress fractures and coxa vara.
56-year-old woman. She performed strenuous work in her garden three weeks before admission and felt slowly increasing pain in her left hip. Two weeks later she was unable to walk. The family physician requested radiographs; **a, b.** A diagnosis of a distraction-stress fracture of the neck with coxa vara was diagnosed; **c, d.** After a short preparation we treated the fracture with two cannulated screws after exposure of the lateral femoral cortex. The distal screw was attached to a DCD plate. As at that time we did not have attachment plates with an angle smaller than 135°, we had to bend the plate to fit it to the coxa vara. With a small screw inserted over the plate we also achieved a compression. The patient bore weight for 9 months, initially with a walker, then with a cane. Instead of decreasing her hip symptoms became more pronounced; **e.** Radiographs showed a delayed union and a slow bending of the caudal screw. Revision surgery was done and the fracture site was perforated several times with a 3.2 mm spiral drill bit; **f.** The standard screw was changed for a 9.5 mm screw and the plate for one with 120° that was specially made for this purpose. The fracture was put again under compression. The removed caudal cannulated screw was bent at the junction with the plate and partially broken (this was one of the three patients with screw breaks in 3185 screw fixations); **g.** Six months later the patient was symptom-free and the fracture had consolidated

Fig. 147. DCD plate and satellite plate.
57-year-old woman. She fell at her place of work (office) and injured her left hip; **a, b.** Garden-IV neck fracture considered by us as very unstable, Adam's arch was detached and posterior fragments avulsed (arrows); **c, d.** For this reason we complemented the cannulated screw fixation with a DCD and satellite plates (10 hours after the accident). The patient returned to her office work two months later; **e.** Radiographs taken after six months show a consolidated fracture in good position – after settling of the fracture

Fig. 148. Double DCD plate for a subtrochanteric fracture used in revision of a previous neck fracture.
82-year-old woman. Several previous fractures: left femoral neck fracture, left subtrochanteric fracture, left olecranon fracture, fracture of the right, lateral tibial plateau are witness to her severe osteoporosis; **a, b.** Patient fell on the day of admission and suffered from a right Garden-II neck fracture with slight varus displacement. Treatment with cannulated screws; **c, d.** On account of the severe osteoporosis we also applied a standard 2 mm plate. The reduction was not perfect, the Garden-II fracture became displaced and the traction was inadequate. Five weeks later the patient fell out of the bed at home and injured again her right hip. As she complained about pain of both hips, (the left one still painful after an earlier subtrochanteric fracture) and as the patient could not be mobilized, no physician was consulted for six weeks; **e.** The scheduled follow-up radiograph showed a remote right subtrochanteric fracture; **f, g.** During the revision surgery we replaced the standard screws with 9.5 mm screws and attached them to a double DCD plate; **h.** Follow-up after six months revealed a consolidation of the subtrochanteric fracture, the patient ambulates with a walker with some discomfort


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5.4 Reinforcement of the third buttressing point – lateral cortex

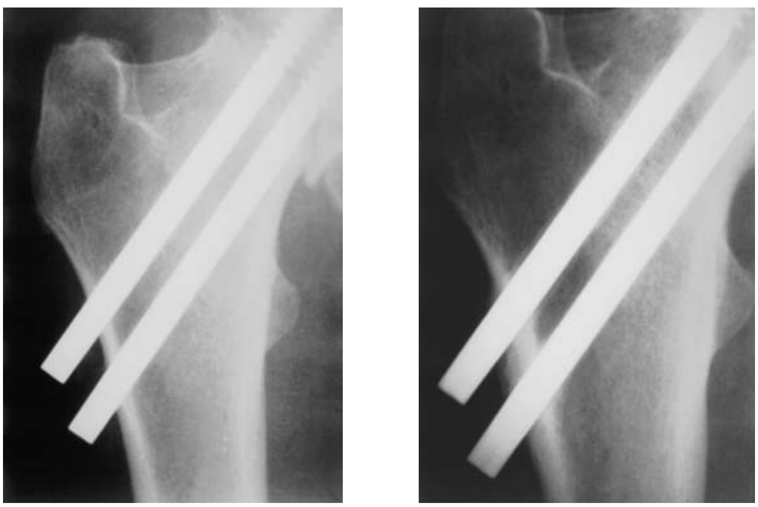
5.4.1 Stability problems at the third buttressing point – varus and rotational movements as well as loss of reduction

In Sect. 4.2.1, we mentioned that we had designed a prominent 2 mm two-hole plate for the fixation of the caudal Smith-Petersen nail. During the preparation of nailing the lateral cortex often bursts during chiseling and the stabilizing action of the third buttressing point is lost. The plate could not prevent movements and backing-out of the nail from the femoral head. A loss of reduction with tilting in varus ensued. The "distant" buttressing of the sliding screw had only a tension band effect. Protection against rotation was assured by the flanges of the nail.

Our Swedish colleagues did not use a lateral anchorage of the cannulated screws whereas our goal had been from the beginning to obtain such an anchorage (see Sect. 4.2.4). In some of the early cases we used a modified 1/3 tubular plate but abandoned this method soon due to technical difficulties (tension at the screw ends, need for larger exposure). Therefore we designed a **2 mm two-hole plate having a tension band effect** and the relevant instruments for percutaneous insertion. To reduce further the risk of displacement in rotation and to ascertain the desired sliding of screws we **flattened** the end of the screw and the corresponding hole in the plate. While analyzing in the meantime the results of fractures fixed with two screws without a tension plate we noticed these details that confirmed our ideas (Fekete et al, 1992).

To assess the stability of internal fixation we compared the postoperative radiographs with those done at follow-up. We had to realize that in 29 out of 134 patients in whom the fractures were treated without a lateral plate, a slight change in the position of the screws against each other had occurred. **The initial parallel position had been lost.** We concluded that a slight displacement in **varus and rotation** of the fracture had taken place. After introduction of the 2 mm two-hole plate the incidence of rotational movements decreased markedly: among the 29 first patients treated with this plate, a rotational displacement was observed only twice.

An additional indication of overloading of the third buttressing point in instances where no plate was used was reflected by the fact, that in some patients the lateral cortex surrounding the caudal screw thickened some months after internal fixation.



a b

Fig. 149. Thickening of the lateral cortex around the screw end (see Fig. 93).
A magnification of part of the a.-p. radiograph illustrates the difference in thickness of the lateral cortex; **a.** Postoperative radiograph; **b.** Radiograph taken after nine months: the increase in thickness is well seen. It seems that not only the closeness of the screws but also the absence of a plate led to an irritation of the overloaded lateral cortex

5.4.2 Thickening of the lateral cortex after screw fixation without a 2 mm two-hole plate

Several of the 134 above mentioned patients complained about pain after three to six months lasting a few weeks. Under **weight bearing this pain** increased in the beginning and then decreased. Initially we failed to find an explanation. Reexamination of late follow-up radiographs revealed **a marked thickening (doubling) of the lateral cortex involving an area of 2 to 3 cm around the end of the caudal screw** in 12 patients (Fig. 149).

We interpreted this phenomenon as being caused by load-induced small screw movements that induce an **osteogenesis followed by the formation of an irritation callus and then a supporting periosteal callus.** Pain is felt until this **"biologic plate"** solidly supports the screw (Fig. 150).

These examples show that **the lateral cortex cannot always respond to the demands** put on the third buttressing point. Even in perfectly

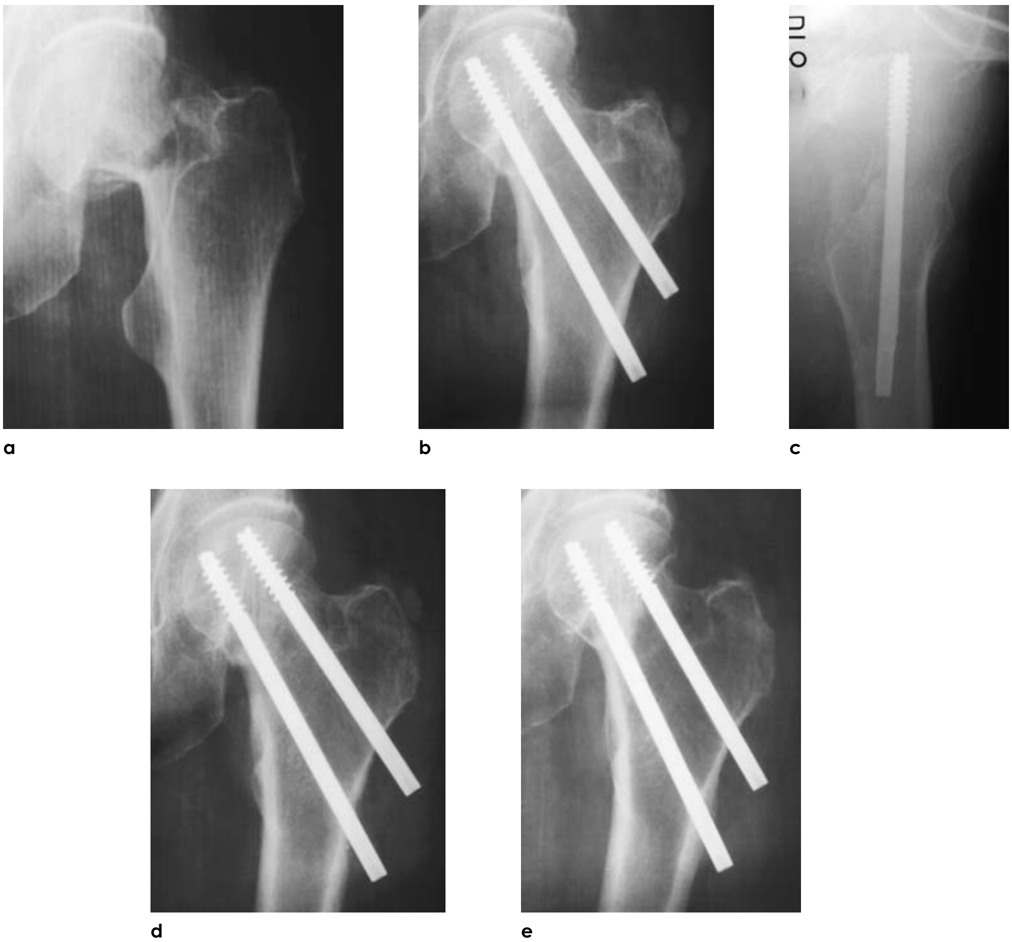


Fig. 150. Thickening of the lateral cortex in another patient.
66-year-old patient; **a.** She fell at home and suffered a left Garden-III multifragmentary fracture; **b, c.** Internal fixation with two cannulated screws was done inside six hours. During the subsequent weeks the patient complained at times about hip pain that increased with weight bearing. Six weeks later bone resorption around the caudal screw was noted; **d.** This osteolysis became more marked after 10 weeks. After six months the pain subsided, the thickening of the lateral cortex is evident; **e.** During a follow-up after one year no progression was seen

stabilized fractures micromovements occur, these may increase in the presence of less stable fixation without a plate (errors in internal fixation, multi-fragmentary and comminuted fractures). Other factors such as osteoporosis, age, weight bearing and body weight will determine, whether the fracture will consolidate (possibly with a "biologic plate") or whether a loss of reduction will take place. To avoid the latter complication it is mandatory to **reinforce the lateral cortex,** particularly in the presence of osteoporosis in older patients. If the caudal screw finds support on Adam's arch and thus a two-arm leverage is operative, **a 2 mm two-hole plate exerting a tension band effect is sufficient** in the majority of patients. The use of a heavier and bigger plate is not warranted.

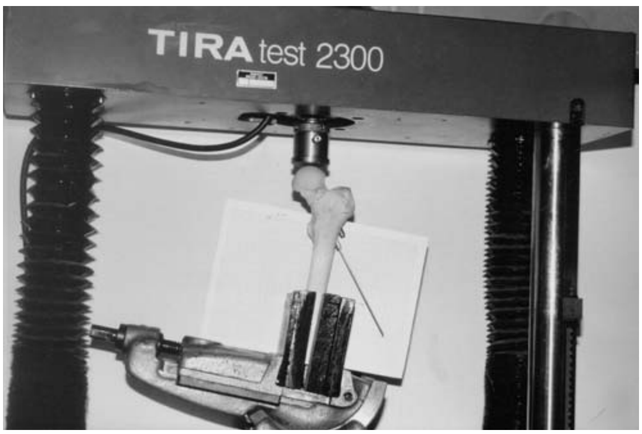


Fig. 151. Photograph of the experimental set-up.

5.4.3 Investigations testing the effectiveness of a 2 mm two-hole plate

We believed that an experimental investigation of the action of the 2 mm two-hole plate was warranted. These tests were executed at the Department of Material Science and Mechanical Technology of the Budapest University of Technology and Economics (BUTE) in 1992.

A Pauwels-II fracture was produced in paired proximal femoral specimens of human cadavers by osteotomizing the neck at 45º. The osteotomy was then properly stabilized with two cannulated screws. To compare the effectiveness of a 2 mm two-hole plate, it was used on one side and omitted on the other. The diaphyseal stump was secured in an appropriate holding device of a TIRA test 2300 apparatus and a linearly increasing force applied to the weight bearing surface of the femoral head in a direction parallel to the longitudinal axis of the femur (Fig. 151).

Comparative measurements were executed on four pairs of specimens. The force applied was continuously graphically registered until a displacement of the femoral head occurred. The load to cause a displacement of fractures secured with a 2 mm two-hole plate was one and a half times greater (Fig. 152).

These tests proved that the **2 mm two-hole plate increased the stability of the lateral cortex by approximately 50%.** In other words, this plate is sufficient to increase the stability when the Adam's arch is intact.

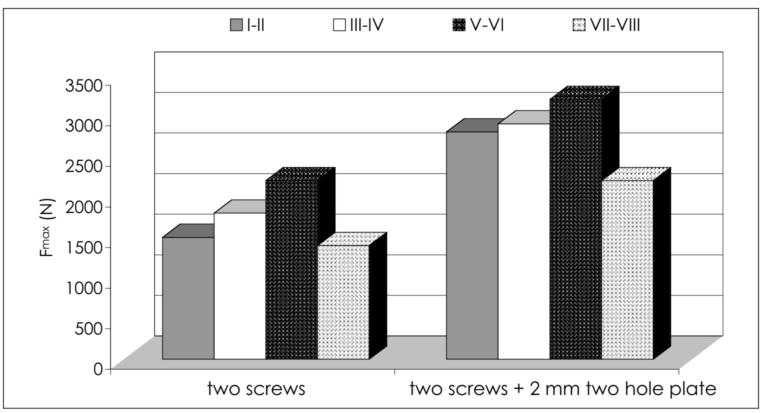


Fig. 152. Experimental comparison of the stability of fixation of femoral neck fractures with only two screws and supplementation with a 2 mm plate.
The pairs of proximal femora are identified by Roman numbers and different shades. It is evident that the force (Fmax in N) to obtain a displacement of the femoral head is 50% greater when a 2 mm two-hole plate was used

5.4.4 Proper attachment of the 2 mm two-hole plate

As already stated the goal of internal fixation with sliding screws combined with a plate exerting a tension band effect has been the protection against rotation. The use of a conventional cerclage did not fulfill this requirement. Also the percutaneous placement over the screw ends would have been technically most difficult. For this reason the need arose for further development of the 2 mm plate.

The end of the screw was flattened over a distance of 30 mm and the corresponding hole in the plate squared on two sides only. A flattening extending over the entire screw length was purposely omitted given the risk of screw bending at the level at the second buttressing point, the Adam's arch. An even better protection against rotation would have been a squaring of the screw's end and to make square holes in the plate. The disadvantage, however, would have been the absence of a cranial and caudal contact of the screw shank in the round drill hole in the lateral cortex (Fig. 153).

To compensate for any weakening caused by the bilateral flattening the diameter of the screw's shank was increased by 1 mm. The identical design of screw end and plate hole geometry allowed a sliding of the screw.

The angle of the plate is 140°. Its thin design, however, allows adaptation to a certain degree of the screw to the neck-shaft angle. If in the presence of an extreme coxa valga a steeper angle of screw insertion is necessary, the **angle of the plate can be changed** with a pair of flat-nosed pliers. A deeper insertion of the screw end may become necessary in very slim patients.

It is important to attach **the 2 mm plate to the screw end without any tension.** A freehand percutaneous insertion of the 2 mm plate can be problematic in moderately heavy patients. Manipulations in a small wound may cause a major soft tissue trauma. In addition, it may be difficult to hold the plate with the hand during drilling, tapping and insertion of the 4.5 mm cortical screw while avoiding any tension. Therefore, the use of a **seating instrument** for proper placement of the plate is recommended. It permits to hold the plate in proper position during radiographic control in both planes and to protect the soft tissue as well.

When using several modifications such as three-hole plate stabilization of two screws or double DCD plate, care has to be taken to orient the flattened screw end parallel to each other and to the femoral diaphysis. In the absence of such a precaution the plate cannot be placed properly or only with the use

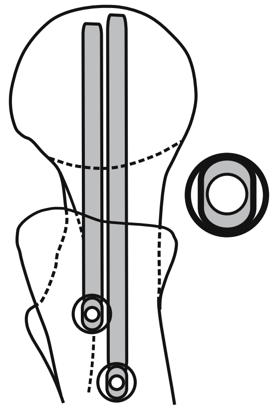


Fig. 153. Ideal position of the distal screw ends in the lateral cortex (schema).
During screw insertion care has to be taken to place the squared surfaces parallel to the femoral diaphysis. In this way the rounded screw shank surfaces will be in perfect contact with the cranial and caudal borders of the drill hole in the cortex

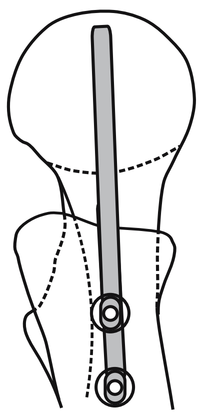


Fig. 154. Ideal position of the distal screw ends in the lateral cortex when using a 2 mm three-hole plate holding two screws or a DCD plate (schema).
The line connecting the end of both screws runs parallel to axis of the femoral diaphysis

of great force causing unwarranted tension and possibly leading to deformation and resulting in complications (Fig. 154, see also Sect. 5.7, point 8 and Fig. 167).

5.4.5 Clinical examples of stabilization with a 2 mm two-hole plate

The patient shown in Fig. 94 attracted our attention to the fact that in an initially undisplaced **Garden-II** fracture after internal fixation with **only two screws** a displacement can occur after a new fall. In this instance a **severe rotational displacement** also occurred. For this reason we recommend the use of a 2 mm two-hole plate not only in Garden-III and -IV fractures but also in every Garden-II fracture and in Garden-I fractures when:

- Initially a marked antecurvature or tilting in varus was present and reduced;
- The patient is older than 80 years (osteoporosis);
- A repeated fall can be anticipated (confused patient, alcohol abuse, neurologic diseases such as epilepsy and Parkinson disease) (Fig. 155).

The next example reinforces the importance of a proper placement of the screw ends. The faulty surgical technique contributed also to a deep joint infection (Fig. 156).

Fig. 155. The preventive action of a 2 mm two-hole plate during repeated falls of an epileptic patient.
The 69-year-old woman fell in a nursing home during an epileptic seizure; **a, b.** She suffered a right medial Garden-IV fracture; **c, d.** 36 hours later we internally fixed the fracture with two cannulated screws and a 2 mm two-hole plate; **e, f.** Three months later the patient fell again during a grand mal seizure and suffered a left Garden-I neck fracture; **g, h.** This fracture was initially treated with two cannulated screws and a plate; **i, j.** Radiographs of the right hip performed after the second fall show that the right neck fracture that had been internally fixed with screws and a plate did not displace during this fall in spite of the fact that after three months a bony consolidation could not have been expected. The more stable internal fixation prevented a displacement during the epileptic seizure

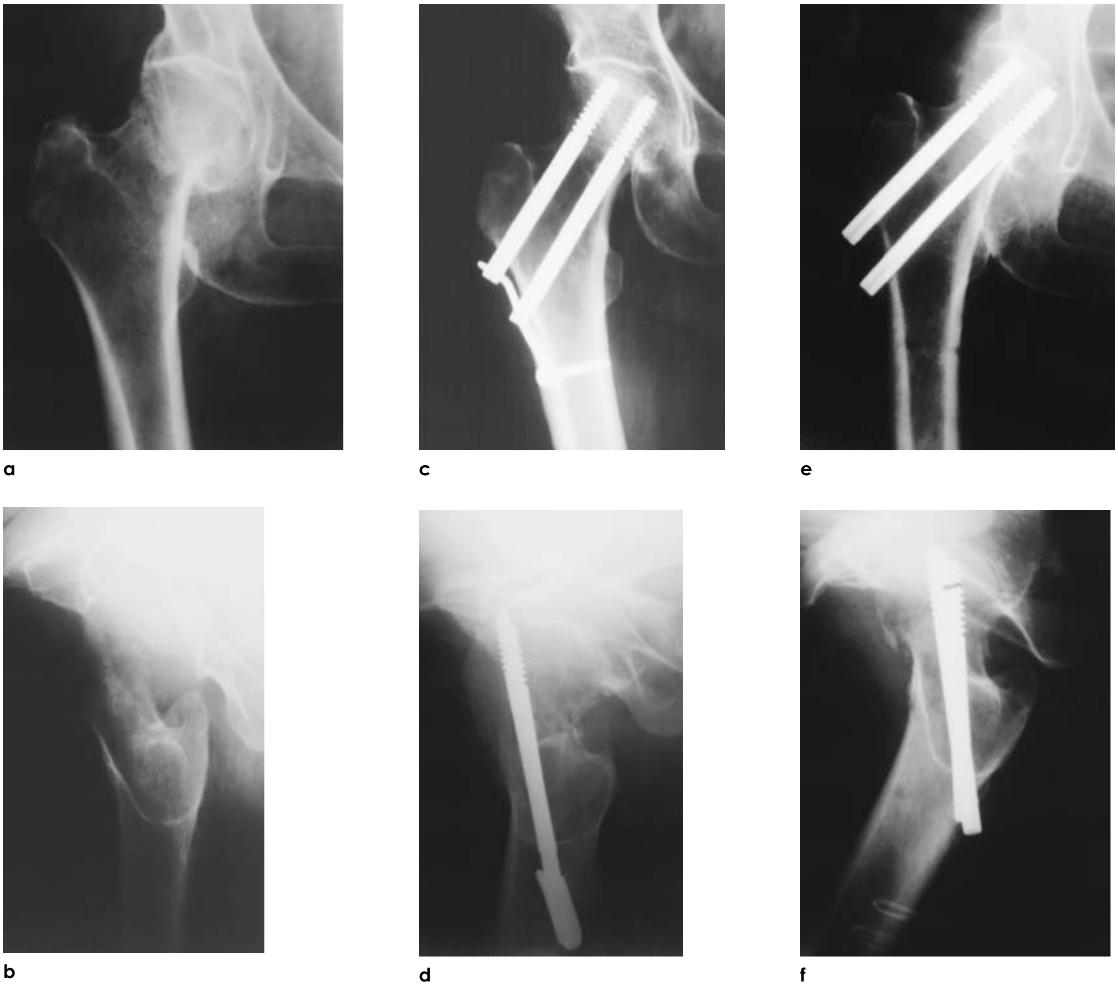


Fig. 156. Consequences of an incorrect placement of a 2 mm three-hole plate anchoring two screws.
64-year-old woman who underwent an aorto-bifemoral bypass surgery three months earlier. This intervention was followed by a revision surgery for an abscess in the Douglas cul-de-sac. She fell on the day of admission; **a, b.** We diagnosed a Garden-III-IV fracture with slight varus tilting and marked displacement in antecurvature; **c, d.** The fracture was treated with two cannulated screws. During surgery the surgeon diagnosed a severe osteoporosis and decided after screw implantation in favor of a plate attached to both screws. A plate bending was necessary and was achieved with great difficulties resulting in a prolonged operating time. Fever developed postoperatively. A wound revision was done on the 11th postoperative day on account of a superficial infection. During debridement it was noted that the plate was under tension and therefore it was removed. Six weeks later subfebrile temperature and parameters of inflammation persisted in spite of antibiotic therapy; **e, f.** A deep infection with disappearance of the joint space had developed necessitating later a Girdlestone resection. We believe that the cause of this complication has been twofold: due to a persisting remote abdominal septic process and due to the prolonged operating time on account of technical difficulties

5.5 Importance of the loss of reduction in rotation and possibilities to avoid it

The **primary displacement in rotation** of the femoral head, the rotation around its axis, occurs in general when the **interdigitation of the fracture surfaces** fails to materialize (multifragmentary or comminuted fracture). It is difficult to diagnose as tilting in varus and antecurvature dominate the picture.

The **secondary displacement in rotation** happens when the stability of a neck fracture has been misinterpreted, when an insufficient number of implants has been used or when the implants were not strong enough to neutralize the deforming forces during walking. In such an instance radiographs show a change in position of the femoral head or a loss of reduction not only in varus and antecurvature but also a changed position of the screws in relation to each other. This loss of reduction appears to cause on a.-p. films a **convergence of screws that were initially parallel** and on lateral films a **divergence.** Even a **crossing of screws** may be present (see Figs. 94, 185 and 186).

The understanding of fracture healing has recently undergone a marked change. **Methods of internal fixation** that lead to the formation of a periosteal callus induced by micromovements (such as intramedullary nailing) have proven to be biologically and biomechanically more favorable than rigid internal fixation (such as DC plates) that causes a consolidation by a primary angiogenic callus formation. The **intracapsular neck,** however, represents an **exception** as it is not covered by a **periosteum.** For this reason no periosteal callus can form after fracture except in vertical fracture where the fracture line reaches beyond the capsule. In the absence of periosteal callus already **small rotational movements may have unfavorable consequences.**

The **diagnosis** of a primary loss of reduction in rotation is **difficult.** Contact between fragments in multifragmentary fractures is usually not complete. Consequently, it is difficult on standard radiographs to determine up to which point the deviation between the main fragments from the **oval neck shape** is the consequence of secondary displacement of small fragments or of a secondary displacement in rotation. During the assessment of **lateral radiographs** it is useful to look carefully at the usually less damaged **anterior cortex. Kyle** et al (1994) have shown that a primary displacement in rotation can be recognized by a deviation of **the course of trabeculae.** This requires **a.-p. radiographs of excellent quality** that are often difficult to obtain on account of senile osteoporosis (Fig. 157).

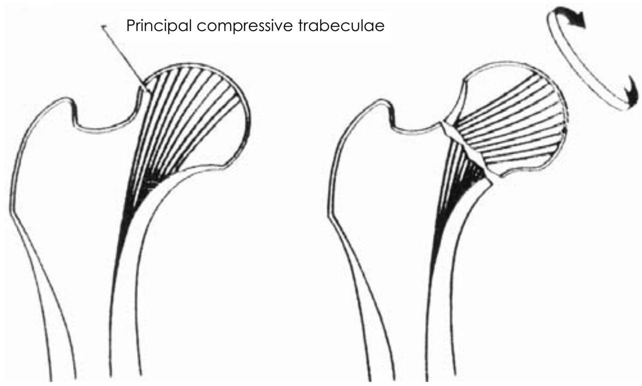


Fig. 157. Diagnosis of a rotational displacement of the femoral neck based on a changed trabecular orientation (Kyle et al, 1994)

The **postoperative secondary loss of reduction in rotation** can be prevented in the majority of cases with a standard double screw fixation complemented by a 2 mm two-hole plate attached to the caudal screw. In the presence of marked instability (severe osteoporosis, multifragmentary or comminuted fractures) the **following modifications (possibly in combination) protect also against rotation** when using the methods described earlier:
- Use of three screws,
- Attachment of both screws to one two-hole plate each;
- Fixation of both screws with a 2 mm three-hole plate anchoring both screws;
- Fixation of both screws with a 2 mm three-hole plate anchoring both screws and additional fixation of the caudal screw with a two-hole plate (see Fig. 165);
- Use of screws with a greater thread diameter (9.5 mm);

- DCD plates (particularly satellite plates and double angle-stable DCD plates);
- Use of flanged screws.

The true rotation of the femoral head should not be confused with the torsion of the head occurring during the reduction of a displaced neck fracture. The latter displacement is usually corrected **by internal rotation of the lower limb around the longitudinal axis of the femur** (the antecurvature seen in lateral radiographs). In this instance the caudal fragment is adapted to the cranial one, this does not produce a rotation around the neck axis: the neck stump does not turn but rather tilts medially and posteriorly. The **insufficient internal rotation** is recognized in the lateral film by a remaining antecurvature and a posterior translation. The caudal fragment, the stump of the neck, lies further anterior. The more frequently occurring increased **internal rotation** indicates a recurvatum and an anterior translation. The neck stump is seen posteriorly. Here we are dealing with gross errors of reduction. Due to the missing adaptation between the fragments a loss of reduction is imminent. The tension of the posterior capsular vessels seen in instances of recurvatum increases the risk of circulatory disturbances (see Sect. 7.2).

5.6 Settling of the fracture leading to shortening of the femoral neck

Already **Linton** (1944) drew the attention to the fact that backing-out of the nail is a frequent complication of internal fixation. Early on, traumatologists attributed this backing-out to the oblique orientation of the nail's channel and to the forces acting on the femoral head. They attempted to prevent the backing-out by inserting a screw into the lateral cortex perpendicular to the nail, by attaching a plate to the nail (or nail plate) or even by using a one-piece implant such as the Jewett nail or the 130° AO blade-plate. The nail did not anymore back-out but increasingly the nail perforated the femoral head or a diastasis of the fracture gap happened. The latter often resulted in a non-union.

The merit of being the first to have drawn the attention to a shortening of the neck by 3–10 mm during bony consolidation goes to **Böhler** (1996) who published his observation in the edition of his textbook in the thirties. He designed his own nail that allowed a backing-out of the nail to a point where it got stuck in the lateral cortex. Other authors – **Pohl** (1951), **Pugh** (1955), Schumpelick and Jantzen (1955) – published already in the fifties **telescoping system** that allowed a certain sliding. Encouraged by these advances our team designed a plate that supported the nail. The nail and plate were later joined by a sliding screw (Manninger et al, 1961b).

Analyzing our first results we also found among our patients that fractures had consolidated in a great number with femoral neck shortening of 3 to 8 mm. The caudal nail end backed out without changing the nail's position in the cranial portion of the head. In 1960, we analyzed 1000 patients and reported that an **advantageous primary sliding** occurred during the first two weeks; it improved **the contact between the fragments and assisted the consolidation** (Manninger et al, 1961b).

This desired sliding is different from the secondary backing-out of the nail that is always the sequence of an unstable fixation: the **nail slides out of the femoral head** followed by a loss of reduction. Micromotions between bone and nail cause a tissue reaction characterized by resorption and regeneration. If the fracture has been properly stabilized, regeneration predominates. During the healing a well visible bone formation surrounding the implant occurs. If, however, the anchorage of the implant in bone is insufficient as seen after comminuted fractures or after a bursting of the lateral cortex during nail insertion, regeneration fails to materialize. **Nail loosening happens in an enlarged implant bed and the nail slides out of the femoral head down to the fracture gap.** A loss of reduction follows. An actual cutting-out of the nail was seen by us very rarely, for example, after a subsequent fall or a faulty nail position in the cranial, anterior third of the head.

During examination of **autopsy specimens of fresh neck fractures of senile patients** we observed repeatedly **avulsion of neck fragments.** Even under direct vision we could not adapt the fracture surfaces properly (see Fig. 47). Already in the fifties, we noticed the presence of an avulsed fragment in two thirds of the patients on intraoperative serial radiographs done with two mobile units. The thin guide wires did not hide the fragments as much as a nail or screws do. Of course, the failure to achieve a proper reduction is also due to the fragmentation and **impaction** of the soft osteoporotic **cancellous bone.** Some smaller fragments can be **resorbed** during the initial regeneration of cancellous bone. When the internal fixation is unstable, resorption is particularly pronounced.

Sliding of screws can be recognized to a certain degree on radiographs done after mobilization and before discharge. It is due to an approximation and impaction of the fragments resulting in **an adaptation of the fracture** obliterating the diastasis that remained after reduction. The resorption of the fragments, the shortening of the neck and thus the resulting sliding of the screws can **(de-**

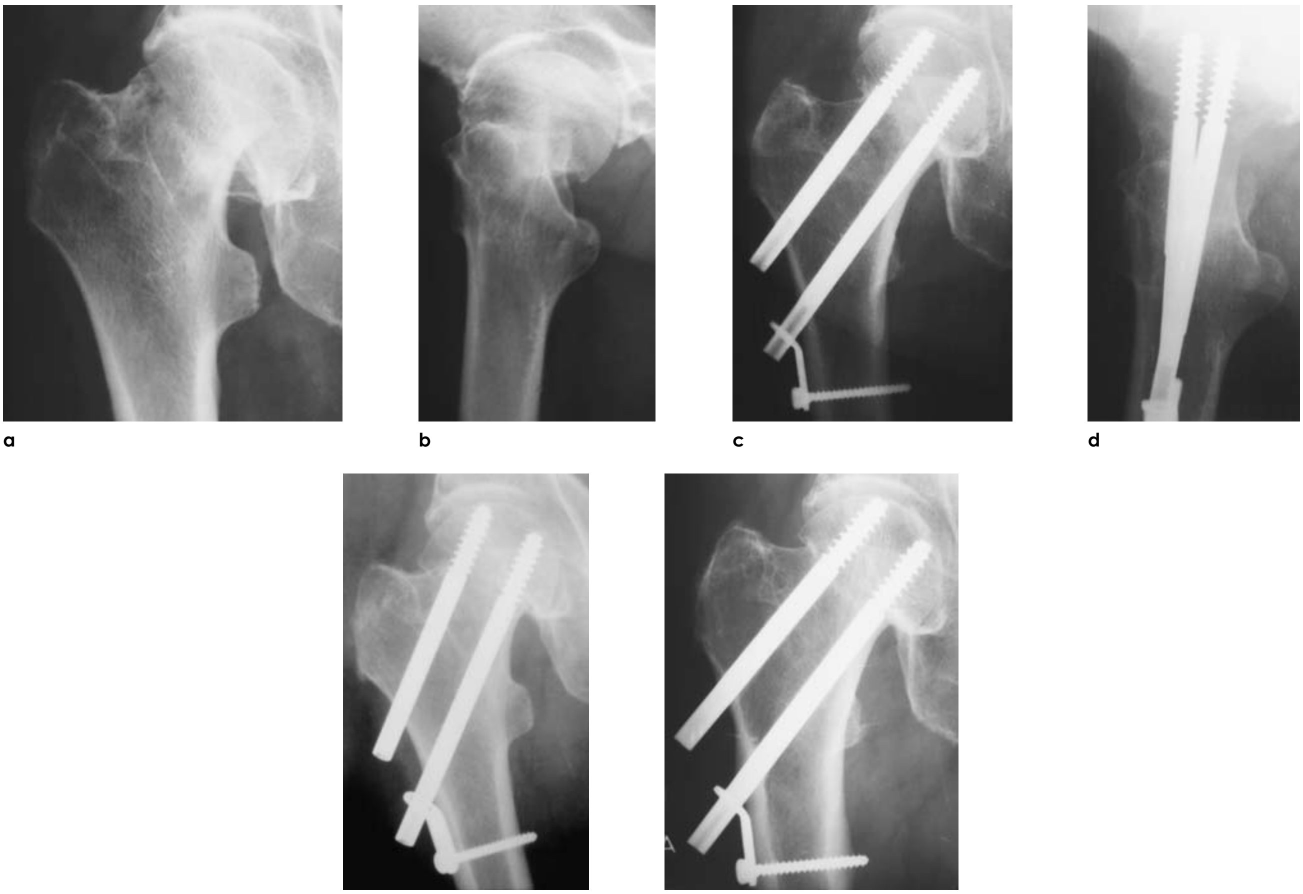


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Fig. 158. Healing of a femoral neck fracture after marked settling.
73-year-old woman. She fell ten days before admission and injured her right hip. A fracture was not diagnosed. Patient was able to continue to walk but the pain increased and the leg shortened; **a, b.** Repeated radiographs showed a severely displaced, impacted subcapital Garden-IV fracture. Patient was transferred to our institute; **c, d.** Eight hours after admission an internal fixation with cannulated screws was done. Proper reduction and internal fixation were achieved, a certain shortcoming is the divergence of screws in the lateral plane; **e.** Already five days postoperatively, radiographs taken after mobilization show a marked shortening of the neck corresponding to an impacted fracture. Backing-out of the screws by 5 mm without any change of their position in the head (settling); **f.** Three years later the fracture has healed after marked screw sliding (more than 10 mm). There is no clinical or radiologic evidence of head necrosis

layed settling) continue up to the end of the third month as part of the normal consolidation. It should be emphasized that **the unchanged screw position in the head** is characteristic for the sliding (Fig. 158).

Not seldom is a retaining of a slight valgus position an error of reduction. In most instances the fracture gap is **caudally (medially)** wider. Our experiences let us conclude that immediately after surgery the diastasis closes rapidly due to the muscle tone, but this happens especially after start of weight bearing.

Intimate contact between the fragments guarantees an early restoration of intraosseous drainage. Therefore we designed a special instrument, the so-called **adapter.** After release of traction but before insertion of the 2 mm two-hole plate we insert this adapter over the protruding screw end until contact with the cortex has been reached. Then we impact the fracture gap with **slight hammer blows** thus obliterating the diastasis (Fig. 159).

This procedure has two advantages: an early and good contact between the fragments and the possibility to check on **the unobstructed sliding of the screws.** We have to emphasize that the **adaptation of the fragments is not synonymous with a forceful impaction of the fracture surfaces.** Since years we took care not to follow the recommendation of L. Böhler in the thirties to reduce the fracture gap with 20 forceful hammer blows, as we did not want to imperil the circulation in the head. Later Böhler retracted this advice.

The shortening of the neck (up to 10 mm) is in general **not detrimental,** it happens regularly during the first weeks and is a **natural and favorable sign of fracture healing.** The direction of distal sliding of screws is properly directed by the plate and can be measured in mm precision. Sliding of the screws **does usually not take place in fractures in valgus and without displacement (Garden-I and -II)** as no settling occurs and no bony fragments are present. In instances of **comminuted fractures** the sliding of screws can exceptionally **exceed 1 cm.** If no additional displacements (varus, antecurvature, rotation) are present, we are not dealing with a loss of reduction and thus no revision surgery is indicated (Fig. 160).

Absence of sliding after surgery for displaced neck fractures should be given particular attention as it can be an omen for the development of a **diastasis of the fracture gap, non-union or head perforation** (see Fig. 237).

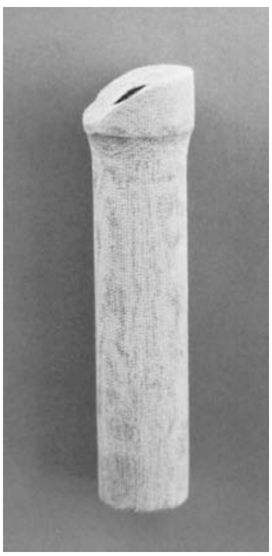
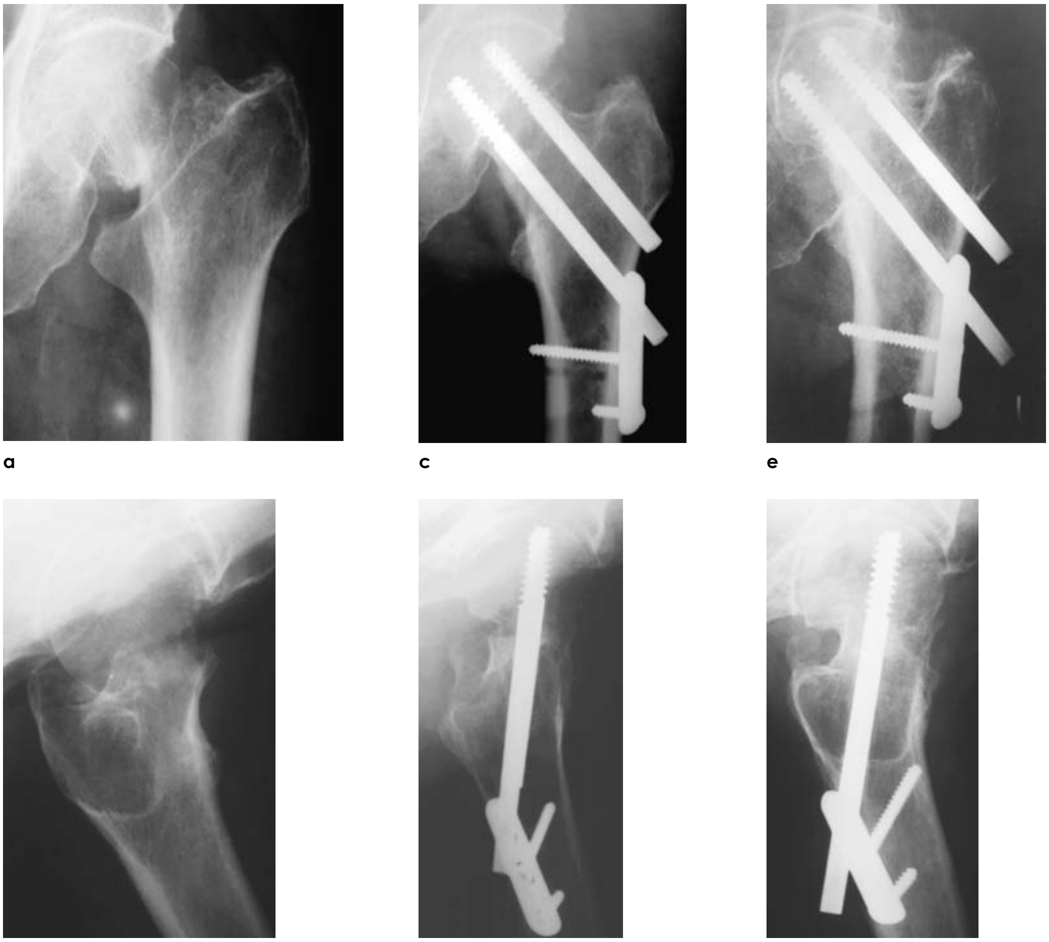


Fig. 159. The adapter used for the intraoperative elimination of diastasis.



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b d f

Fig. 160. Severe screw sliding in multifragmentary neck fracture.
79-year-old woman who injured her left hip during a fall at home; **a, b.** Garden-IV fracture was diagnosed with multiple fragments at Adam's arch and posterior cortex. (This is less evident on the initial radiographs taken in internal rotation but on the subsequent films. The poor initial radiograph obscures also a Pauwels-III fracture); **c, d.** Due to the delayed admission internal fixation with cannulated screws could only be done 24 hours after the accident. The caudal screw was supplemented with a small DC plate given the fracture's instability. Traction in slight valgus and antecurvature during internal fixation was slightly exaggerated (this is not a faulty but rather a favorable position). Follow-up after six weeks showed a marked (8 mm) backing-out of the screw secondary to the shortening of the neck; **e, f.** One year after the accident the fracture had settled further (15 mm). The leg length discrepancy was corrected with a shoe insert, the patient had no appreciable symptoms, she was using a cane

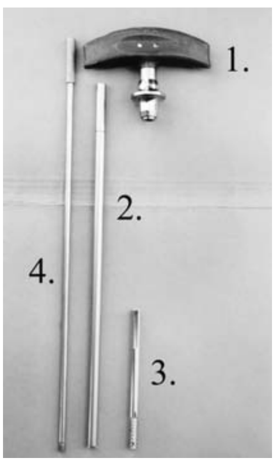
5.7 Recent improvements and concepts for the future

Our plans regarding further developments, particularly in respect to the **increase in stability**, are dictated by problems that were due to treatment, methods used and instruments and implants chosen. Some designs (1–5.) have already been mentioned in this chapter but have since further been developed. Prototypes of other implants and instruments (6–10.) have been manufactured and are being tested clinically.

(1) **Slotted screws with a modified extension rod.**
Parallel placement of screws is mandatory during the use of some stabilization procedures (use of three screws, 2 mm three-hole plate anchoring two screws, double DCD plate and DCD plate with satellite plate). Otherwise the screws can get stuck in the plate precluding sliding when minor deviations have occurred. To improve the precision of parallel placement we developed an extension rod with a diameter of 8 mm and length of 290 mm. A tongue at the end of the extension rod fits into a slot at the end of the cannulated screw ensuring the proper fitting of the extension rod. Thus the surgery can be terminated without changing the guides. This addition **facilitated and shortened the intervention** (the 6th step is no longer necessary (see 8.3.2.3, and Fig. 206). It is advantageous not only during the **parallel insertion of screws but also for the protection of soft tissues** (Fig. 161).
Experimental investigations of torsional characteristics of the slotted screws were performed in the laboratory of BUTE using specimens of young humans. We found that the moment of torsion necessary to deform the slotted end of relatively thin-walled screw ends is three times greater than the moment of torsion needed to insert a screw into the compact bone of young subjects and six times greater than the force applied during screw insertion into osteoporotic cancellous bone. Being assured by these results we started the clinical trial. We used the slotted screw in approx. 40 patients and never observed a deformation of the screw. Thanks to the slot design the tightening of screws became simpler, faster and more secure (Fig. 162).

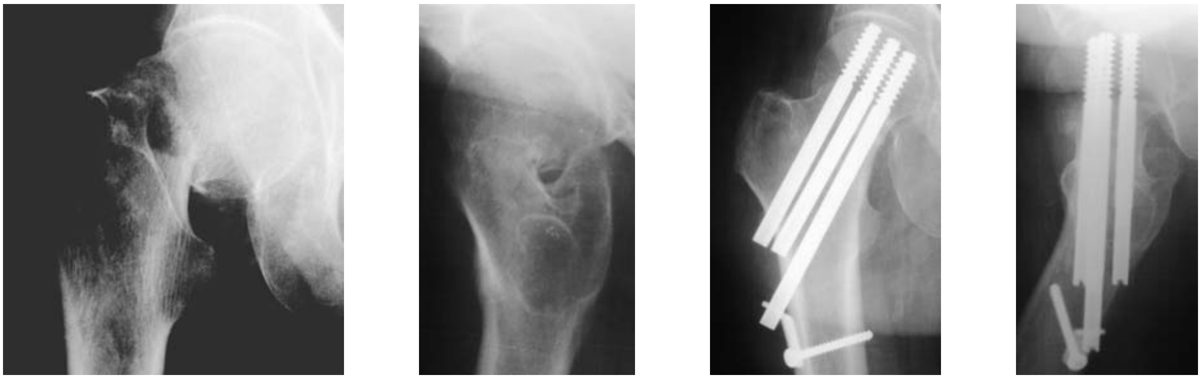
(2) **The new parallel guide can be fitted with a sleeve for the third screw.**
The bore of the sleeves of the **new parallel guide** are slightly narrower (0.1 mm) for improved parallel insertion. The distance between the sleeves is unchanged at 18 mm. For insertion of a third screw a **third drill guide can be screwed to the right or left side** of the parallel guide. The distance between the third guide and the other two is 14 mm. If during insertion of two screws only a distance of 14 mm is desirable, the third drill guide together with the first or second can be used (Fig. 163).


a



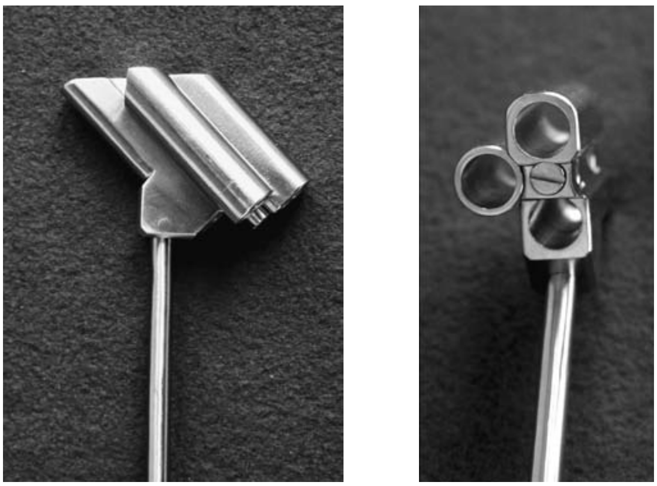
b

Fig. 161. The slotted screw and its instruments.
a. The tongue of the extension rod fits into the slot of the 7 mm shank of the cannulated screw. As the diameter of the extension rod is only 8 mm, it can be passed through the 8 mm sleeve without changing the parallel guide; **b.** Instruments: 1. handle with quick coupling; 2. fitting 290 mm long 8 mm extension rod; 3. slotted screw; 4. long screw holder (a pin, that fits into the bore of the extension rod during insertion of the cannulated screw)



a b c d

Fig. 162. Use of three slotted screws.
88-year-old woman; **a, b.** Right Garden-IV neck fracture; **c, d.** Internal fixation with three cannulated slotted screws. The surgical technique used is described in Sect. 8.6.4. We obtained a perfectly parallel position of the screws



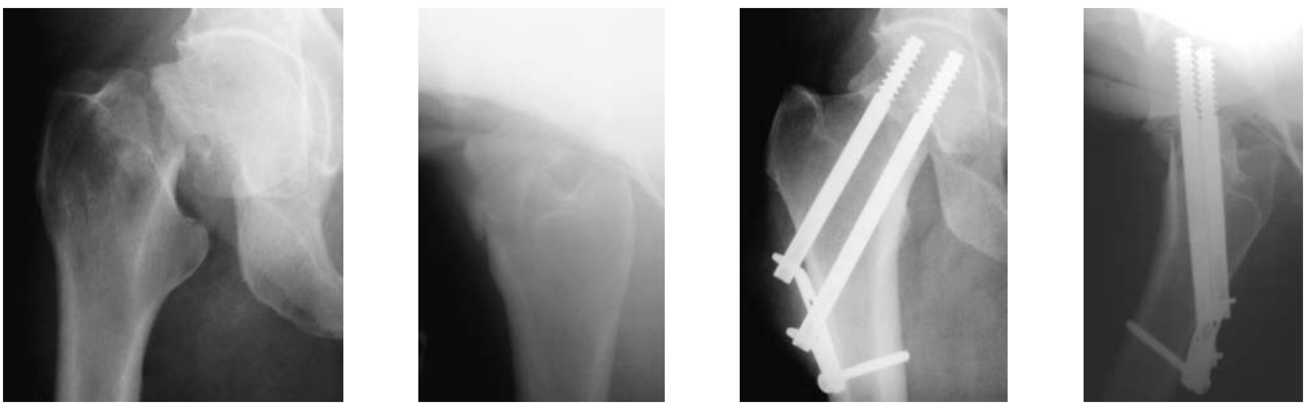
a b

Fig. 163. The new parallel guide for insertion of two or three screws.
The bores of this new guide are more precise. It can also be used for an improved triangular placement of screws, left or right.
a. View from the side; **b.** Frontal view

(3) **Guide to ensure anterior positioning of the caudal screw, can also be used for insertion of three screws.**
The use of the new parallel guide and the placing of only one plate for both screws permitted to increase the stability. We are currently experimenting with a plate for all three screws, in left and right configuration. Figure 136 shows the **new triangular position.** That position was confirmed with the help of femoral neck specimens and serial CT images. CT images as shown in Figs. 10 and 136b demonstrate well that the **gutter between calcar femorale and Adam's arch lies slightly anterior to the longitudinal neck axis.** Measurements done on **sagittal CT images** showed that the midline of the gutter lies approximately 3 mm anterior to the midline of the neck. Our attempts during surgery to place the drill hole slightly anterior **often failed.** The drill bit slides easily off the hard and convex bone surface in an anterior direction. Therefore, we developed a drill guide with two sleeves and one handle for drilling in a predetermined anterior translation. This instrument (Fig. 164) was used together with the soft tissue sleeve with handle. A 2 mm bore is situated in the center of the drill guide. A short, pointed 2 mm Kirschner wire is driven into the cortex

to a depth of a few mm. The drill guide is oriented in the lateral projection to the middle of the bone shadow. **The K-wire protects the sleeve against sliding.** The other bore of the guide has a diameter of 3.2 mm for the insertion of 3.2 mm spiral drill bit. It lies 3 mm away from the midline of the neck on the side opposite to the handle. If the handle of the drill guide points vertically down, the predrilling with the spiral drill bit is made exactly 3 mm anterior to the midline. **This ensures a secure drilling in anterior translation without the risk of sliding; it is placed anteriorly by exactly 3 mm.** It goes without saying that drilling at

Fig. 164. Two-hole drill guide with handle for anterior translation of the caudal screw.
A hole is situated in the center for the temporary fixation of the drill guide with a pointed 2 mm Kirschner wire. The larger hole is for the long 3.2 mm spiral drill bit



a b c d

Fig. 165. Simultaneous use of a 2 mm three-hole and a two-hole plate.
62-year-old woman. She complained of pain in her right hip for several weeks before admission. At the day of admission she fell and was unable to walk; **a, b.** Radiographs showed a displaced stress fracture (diagnosed because of the fracture surfaces and the history) with major fragments. Even after repeated attempts the reduction was inadequate: slight tilting in varus and exaggerated rotation which were difficult to judge and to correct on account of the fragments; **c, d.** Due to the considerable instability both screws were anchored together in a three-hole plate and in addition the caudal screw secured in a two-hole plate

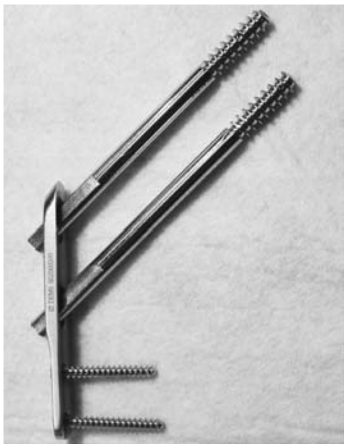
Adam's arch must be checked in the sagittal plane. The screw will then lie in the gutter between calcar femorale and Adam's arch.

(4) **Simultaneous apposition of a 2 mm three-hole plate and a 2 mm two-hole plate.**
These plates offer a further possibility to increase the stability against rotation and tilting in varus. They increase the **stability** at the third buttressing point **of the very important caudal screw** (Fig. 165).

(5) **4.5 mm plate.**
A 4.5 mm plate similar to the AO compression plate had been used regularly by us (see Figs. 160 and 183). In some instances we observed however a penetration of the femoral head by the cannulated screw as the plate blocked a sliding of the screw. Later analysis of these cases showed that the blockage was due to **a too strong tightening of the screw in the oval compression hole** of the 4.5 mm plate. In instances where this blocking action did not occur, the results with the 4.5 mm plate were excellent (see Table 18). The results were even superior to those when using thinner plates. Consequently, we changed the manufacturing process by replacing the compression holes with **round holes.** Thus we used this plate again as a simple implant increasing stability (Fig. 166a, b, see Fig. 241c, d).

(6) **Cam-plate.**
To maintain a desired angle as with the DCD plates of 120º, 130º or 140º a still thicker cam-plate has been designed. It is similar but simpler than the DCD plates and can be inserted with less trauma. These heavy plates have a prominent channel through which the screw ends


a


b


c


d

Fig. 166. Improvement of lateral fixation (third buttressing point).
4.5 mm plate without compression holes for improved fixation of one or two screw ends; **a.** Two-hole plate for the fixation of the caudal screw and of a four-hole plate for both cannulated screws; **b.** Lateral view of a four-hole plate with screws inserted.
The heavier 4.5 mm **cam-plate** is angle stable and its insertion causes less trauma particularly for older persons; **c.** Frontal view; **d.** Side view with screws inserted

slide. **The thickened portion resembles a cam.** The angular stability of the cam-plate is less than that of the DCD plate but does not necessitate a 11 mm drilling of the lateral cortex as required for the DCD barrel. The cam-plate is available in two designs, for one or two holes. Both designs have round holes for cortical screws (not compression holes!). Thus we succeeded to ameliorate the angular and rotational stability of fixation by a method that is easier to perform and less invasive than the insertion of a DCD plate. This is particularly advantageous in elderly patients (Fig. 166c, d, see Fig. 241e, f).

(7) **Further development of instruments for the DCD plates.**
The new parallel guide for the 140° DCD plates can be adapted to the femoral shaft by screwing on wedges of 10 or 20°, thus obtaining an angle of 130 or 120°. The two parallel bores were enlarged from the original 7 mm to a 10 mm diameter. This allows the application of 7/10 mm drill guides and thus an extended and exacter guidance of the drill bit (see Fig. 196a).
Instead of the 11 mm reamer for the channel of the DCD barrel used up to now, we are employing a **crown drill bit** that fits over the shaft of the already inserted screw. This makes it possible to prepare faster, exacter and more reliable the bed of the DCD barrel after insertion of the cannulated screw (see Fig. 196b and c).

(8) **Parallel positioning of the flattened screws' ends with two sleeves.**
The attachment of the screw ends to a plate or the insertion of a DCD double plate in the depth of the wound is often difficult on account of the need to align the flattened screws' ends parallel to each other. After several trials we succeeded to obtain easily and reliably a parallelism thanks to two metal sleeves. One end of the sleeves is formed in such a way that it fits over the flattening of the cannulated screw like a T-wrench with the exception that its bore is 2 cm deeper. On the other end of the sleeves a transverse slot has been made; it aligns with the flattening of the screws' ends and of the T-wrench. A 5 cm metal plate is inserted into the slot; it allows turning by 90°. The sleeve must be turned until the slot aligns parallel to the longitudinal axis of the femur. The other cannulated screw is now turned until its slot aligns with the metal plate. Once having achieved a parallelism between both screws' ends the side plate or the double DCD plate can be easily fitted over the cannulated screws, even in the depth of the wound (Fig. 167).

(9) **New instrument to chisel the bed of the flanged screw.**
At the beginning of the development of the flanged screw the site for the flange was prepared with a cannulated chisel after drilling and tapping for the cannulated screw. The chisel was advanced over a guide wire with hammer blows. We discovered that the guide driven into the femoral head was not sufficient to prevent the head from tilting. For this reason we designed a toothed chisel to prepare the bed for the flange. Its dimensions correspond to that of the flange. This was tested on cadaver specimens. The toothed chisel is inserted into the slit of the flanged screw and then carefully advanced. This allows to prepare the bed for the flange after insertion of the cannulated screw, fixing the femoral head, without endangering the result of reduction. The insertion of the plate into the slit of the cannulated screw can be easily and fast performed percutaneously (see Fig. 133a).

(10) **The use of one flange to connect two cannulated screws.**

Fig. 167. The two sleeves for the parallel alignment of the flattened ends of the cannulated screws.

Fig. 168. Two cannulated screws connected by one flange. This shared flange increases considerably the stability of the cranial screw

The stabilizing effect of the cranial screw can be enhanced in **opposing the slits of both screws and inserting a flange connecting both.** In this way the flange transmits the buttressing action of the caudal screw on Adam's arch to the cranial screw. Thus the cranial screw obtains a buttressing effect that otherwise would be absent. The flange of the implant reaches into the femoral head protecting the head fragment considerably better against rotation (Fig. 168, see Fig. 241m).

Summary

The present state of the development of our implant designs can be summarized as follows. The starting point has been the internal fixation with two screws combined with a 2 mm two-hole plate acting like a tension band. The thread diameter of the cannulated screws is either 8 or 9.5 mm. The length of the threaded portion is 18, 24, 34 or 44 mm. The diameter of the shank is always 7 mm, the last 30 mm of the shank are flattened to 6 mm. **All instruments and implants developed later on can be combined with these standard screws.**

The following new or improved versions contributing to an increase in stability and to facilitate the surgical technique are available:

(a) The slotted screw combined with the extension instrument renders screw insertion easier and permits to dispense with the sixth surgical step (see Fig. 206).
(b) Insertion of three screws with an improved parallel guide.
(c) Drill guide with two bores permits drilling and screw positioning in exact anterior translation of the caudal screw. This guarantees an optimal screw position in the gutter between Adam's arch and calcar femorale.
(d) A 2 mm three-hole plate for fixation of the end of two screws supplemented by a two-hole plate for the caudal screw.
(e) A 4.5 mm plate for an improved hold of the screw and unimpeded sliding. The plate has two flattened holes for insertion of the cannulated screws and two round holes for the cortical screws.
(f) The placement of the flanged screw was facilitated by a toothed chisel. After screw insertion the chisel is advanced in the slit of the screw. Thanks to the preceding insertion of the cannulated screw the femoral head is protected against tilting. The flanged screw ensures a reliable stability in rotation.
(g) The use of two flanged screws increases further the important stability in rotation of internal fixation.
(h) With the cam-plate the precise angle of screw position is obtained without increase of invasiveness of the procedure.
(i) Three versions of the angle-stable Dynamic-Collo-Diaphyseal (DCD) plates (DCD plate, satellite plate, double angle-stable plate) contribute to an increased angular stability of internal fixation (see Figs. 146 to 148).

The development and designs are based on our research, observations and results over many years.

We always tried to perfect time- and material-saving techniques as well as introducing refinements and secure solutions. Our ultimate goal was to ameliorate the care for injured people and to facilitate and to shorten the surgical procedures.

Chapter 6

JUSTIFICATION FOR EARLY SURGERY

6.1 Timing for internal fixation of hip fractures

Contrary to the classical orthopedic concepts **the diagnosis of emergency cases** ("acute abdomen") and the **immediate intervention** is of cardinal importance in general surgery. **These basic principles** have not lost their importance in **trauma surgery** and are the basis of immediate action. Interventions whether performed or missed during the first hour ("golden hour"), or even during the first 30 minutes determine the survival and later the quality of life of the severely injured person, victims of **polytrauma, head injury, chest trauma or abdominal trauma.** Generally accepted is also the priority of **fracture-dislocations, compound fractures and fractures with soft tissue trauma.**

The care of closed fractures of one limb only, on the other hand, is not performed in many countries by trauma surgeons but by orthopedists not burdened by emergency duties. During the last 20–30 years new aspects surfaced that supported the advantages of emergency surgery even for isolated closed traumata, in particular hip fractures.

(1) It became apparent that elderly persons could be mobilized earlier when **internal fixation allowing weight bearing is performed immediately**. Moreover, early mobilization decreases the risk of life-threatening systemic **complications associated with longer immobility**.

(2) Concomitant with the improvement of internal fixation the incidence of local complications (perforation of the femoral head, loss of reduction, non-union) decreased markedly. On the other hand, the number of **avascular necroses** did not diminish noticeably. This proves that the cause of necrosis does not primarily depend on the surgical technique but on other factors. In Sect. 2.4, we could show that circulatory disturbances after fractures are caused mainly by blockage of venous and intraosseous drainage. As shown in animal experiments, ischemic damage of bone cells (necrosis) becomes irreversible already 6 hours after complete blockage of supplying vessels.

Kinking and compression of intact intracapsular vessels can be reversed by an **emergency surgery performed inside 6 hours**. We can improve the intraosseous drainage by adapting the fracture surfaces and by choosing the appropriate implant. At the moment of emergency surgery the fracture surfaces are not covered by a layer of fibrin allowing a marked drainage of blood through the fracture and thus a decompression of the femoral head. In this way in the majority of patients a **necrosis of the head** can be prevented or at least the severity and extent of necrosis be decreased. This results in avoidance of protracted suffering by the patient as well as later of a more extensive surgery, the total hip replacement (Manninger et al, 1985; Manninger et al, 1989; Manninger et al, 1993).

We should not forget that a **fresh fracture is usually easier and more successfully reduced** than a remote fracture. Moreover, progress in anesthesia rendered emergency surgery possible even in high-risk patients.

6.2 The progress of emergency surgery in Hungary

The increased utilization of internal fixation of neck fractures gave rise to the first of many questions. Is such an intervention realizable in elderly patients often suffering from serious, preexisting systemic diseases? Experience has revealed that such an **operation** is not only advantageous in respect to the restitution of function; it **heightens also the survival chances and prevents complications** to a greater degree than conservative care. Relatively rare is the case where the general condition of the patient precludes surgery (Linton, 1944; Carlquist, 1947). A less stressful and smaller intervention further reduces the number of non-operable patients.

The next question centers on the need for a thorough **preoperative preparation of the patient** and the determination of the optimal moment for surgery. During the fifties we divided the patients of the National Institute of Traumatology (Budapest) into two groups: the first group was operated after only a few days of preparations according to the recommendation of L. Böhler; in the second group internal fixation was performed after a thorough investigation and preparation lasting 1–2 weeks. Our first retrospective study based on the analysis of 1000 femoral neck fractures treated between 1940 and 1955 clearly documented the **advantages of early surgery** (Manninger et al, 1960).

Already earlier the question whether surgery performed at the **day of injury or inside 24 hours** is better for the patient was raised in many publications (Bosworth and Fielding, 1953; Stewart, 1955; Stephens and Schenk, 1959). Stimulated by these studies we performed the first emergency surgery in our institute in 1964. Four years later our first publication appeared dealing with 23 early internal fixation including some trochanteric fractures (Fekete et al, 1968).

Early surgery became the procedure of choice in the seventies. Since that time we record the time interval between accident and surgery. An analysis of over 2600 patients operated between 1971 and 1975 allowed us to document that the incidence of major complications and of mortality **decreased significantly when femoral neck fractures were operated inside 24 hours and trochanteric fractures inside 1–2 days** (Fekete et al, 1978; Józsa et al, 1979) (Fig. 169).

The question of emergency surgery has been raised repeatedly in the literature ever since. It is generally accepted that surgery performed inside 24 hours has a favorable influence on mortality, complications and length of hospital stay (McGoey and Evans, 1960; Brown and Abrami, 1964; Berentey et al, 1972; Pankovich, 1975; Manninger et al, 1985; Kroczek et al, 1988; Fekete et al, 1989a; Manninger, 1989; Dolk, 1990; Braun et al, 1991; Raaymakers and Marti, 1991; Bredahl et al, 1992; Parker and Pryor, 1992; Plietker et al, 1992; Elmerson et al, 1994; Bonnaire et al, 1995; Zuckerman et al, 1995). A controversy persists between adherents of an **immediate intervention and those favoring surgery during the first 24 hours**. Surgeons (aussitôt brisé, aussitôt opéré) confront anesthesiologists (urgent but not emergency procedure) (Laburthe-Tolra and Courtillot, 1982; Dodds, 1988).

The decisive argument in favor of immediate surgery rests on the **peculiarities of the femoral head circulation**. Experimental and clinical investigations of **Woodhouse** (1964), of **Rösing and James** (1969) and of **Arnoldi and collaborators** (Arnoldi and Linderholm, 1969; Arnoldi et al, 1970; Arnoldi and Linderholm, 1972; Arnoldi and Linderholm, 1977) have shown that a necrosis of bone cells after an ischemia lasting several hours can be **avoided by an immediate reduction and internal fixation** restituting the circulation.

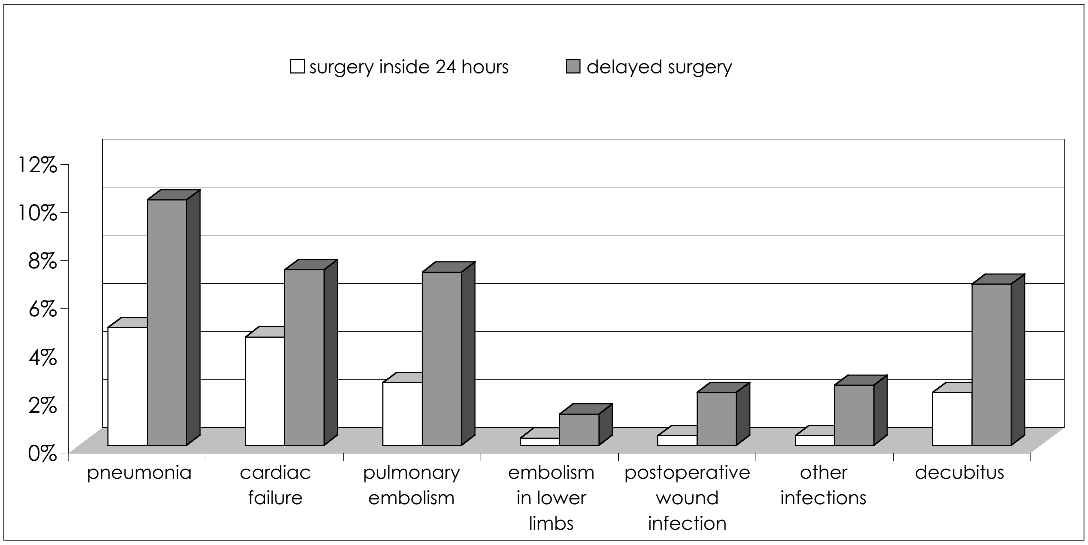
The importance of emergency surgery as a mean to avoid avascular necrosis has been voiced by us early on (Manninger et al, 1965). **Forgon** (1970) advocated strongly an early internal fixation of femoral neck fractures based on results of experimental and autopsy investigations.

We analyzed the late results in another 6-year (1972–1977) study and could document that **the incidence of various stages of avascular necrosis was significantly lower when surgery was performed during the first 24 hours than after a delayed internal fixation** (interval between accident and surgery more than 24 hours) (Manninger et al, 1985) (Fig. 170).

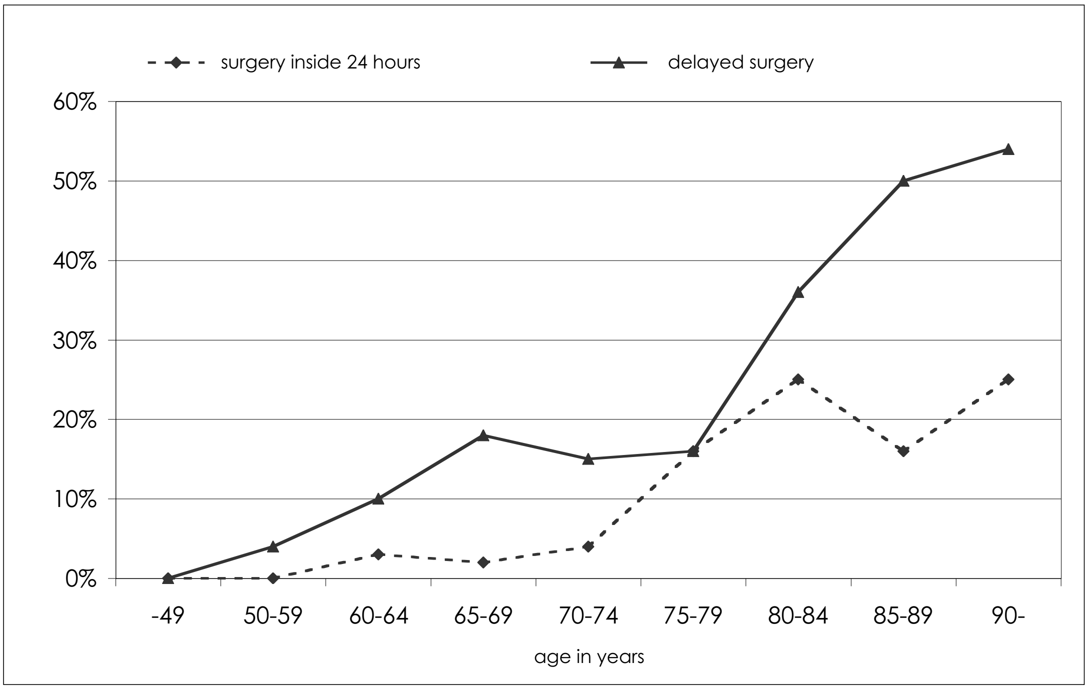
These data clearly show that **after delayed surgery complications were more frequent and more serious**. In the majority of cases they appeared already **during the first two years**. A much lower number of partial necrosis in patients operated inside 24 hours was observed in **follow-up studies done after many years**.

At the beginning of the eighties publications involving a much smaller number of patients appeared in the international literature documenting the favorable outcome of immediate reduction and internal fixation (Hertz and Poigenfürst, 1982; Pelzl, 1982).

Results of the 6-hour limit for ischemia determined in animal experiments by **Woodhouse** (1964) and by **Rösing and James** (1969) influenced us to subdivide further our patient collective. In a

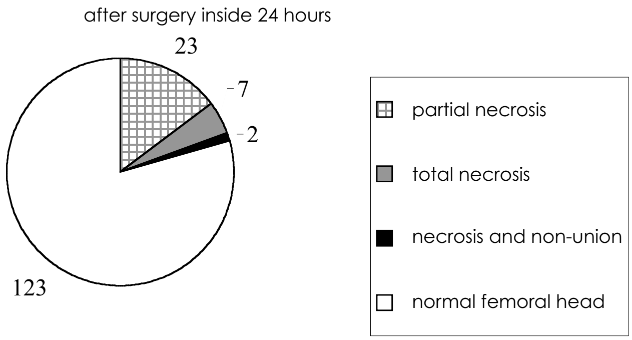


a



b

Fig. 169. Influence of surgery performed during the first 24 hours on the incidence of complications and mortality.
Between 1972 and 1975 we admitted 2612 hip fractures and operated 2055. 76/689 of patients operated during the first 24 hours and 310/1348 of patients having had delayed surgery died; **a.** Distribution of frequency of the sometimes multiple complications of the deceased patients (Fekete et al, 1978); **b.** Incidence of mortality in various age groups after emergency or delayed surgery in 792 neck fractures. Both graphics show the favorable influence of emergency surgery (Józsa et al, 1979)



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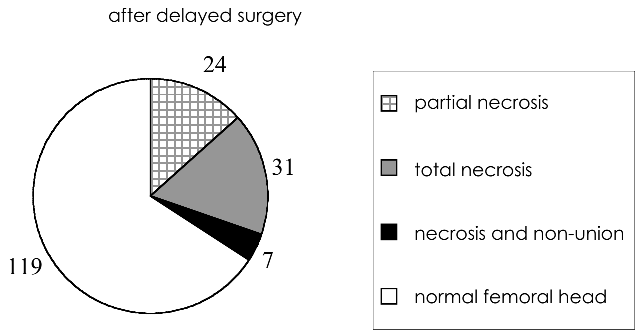

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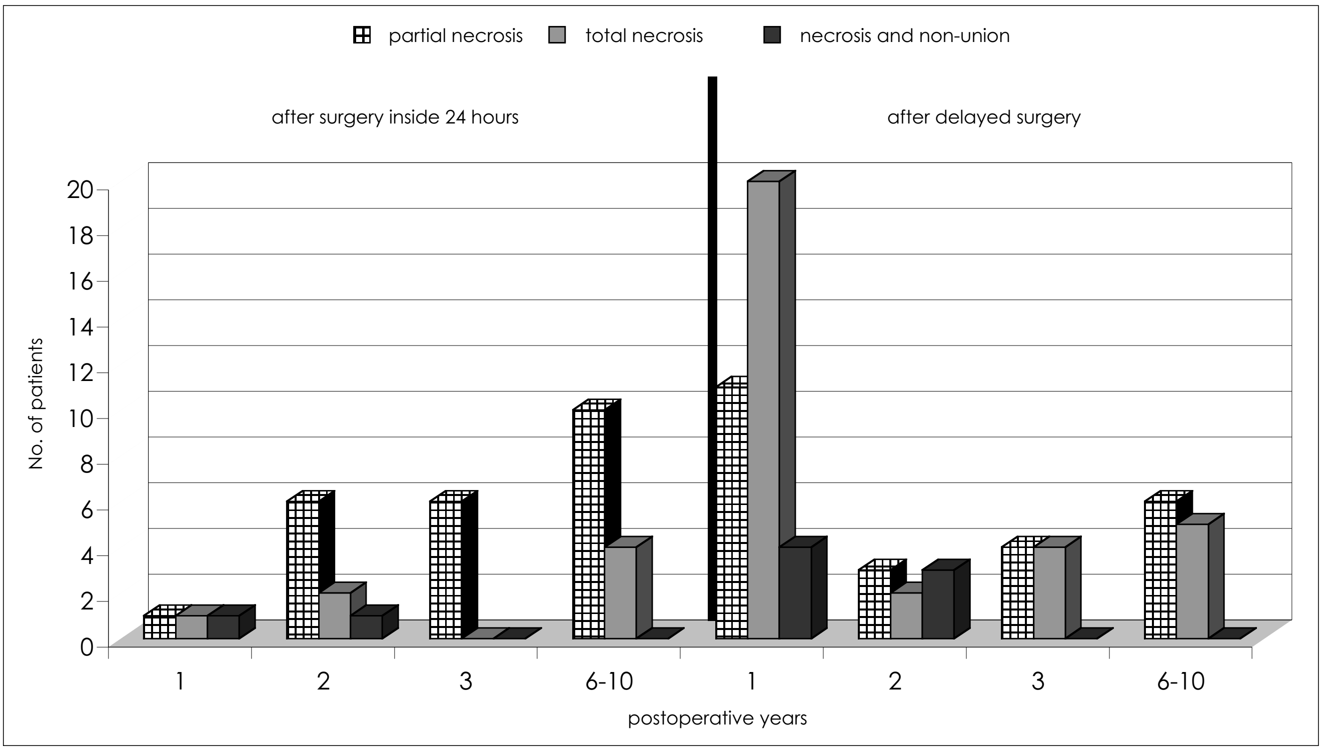


c

Fig. 170. Frequency distribution of various stages of avascular necrosis in 740 displaced neck fractures operated between 1972 and 1977 (Manninger et al, 1985).
After one year a consolidation of the fracture could only be ascertained in 336 patients. The remaining patients were either deceased or could not be found. 155 patients were operated inside 24 hours, and 181 twenty-four hours after the accident; **a, b.** Incidence of all femoral head necroses in both groups. The difference is significant (Mantel-Haenszel test $p < 0.01$); **c.** Number of known complications in both groups seen at the individual follow-up examinations (1, 2, 3, 6–10 years postoperatively)

prospective study of 494 patients we compared the incidence of severe head necrosis not only in patients operated inside 6 hours with those operated between 6 and 24 hours but also with those operated after 24 hours. Surgery was performed between 1981 and 1983 and the patients examined 3 to 6 years later (1987–1988). **The incidence of necrosis stage 3 and 4** (Arlet and Ficat, 1968) **was significantly lower in the group operated inside 6 hours** (Manninger et al, 1989) (Fig. 171).

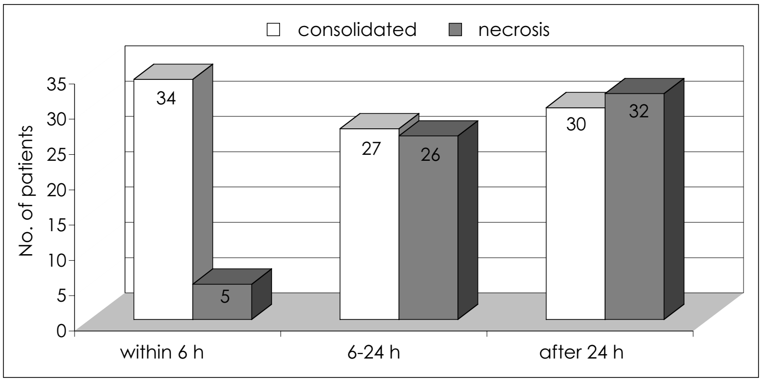


Fig. 171. Frequency distribution of femoral head necrosis in stages 3 and 4 of displaced neck fractures operated between 1981 and 1983 (Manninger et al, 1989).
Of the 494 patients 154 were evaluated after three to six years. Of these, 39 were internally fixed inside six hours, 53 between 6 and 24 hours and 62 after more than 24 hours. The incidence of severe avascular necrosis was significantly lower when surgery was performed inside six hours than in patients operated between six and 24 hours or later (Mantel-Haenszel test $p < 0.001$)

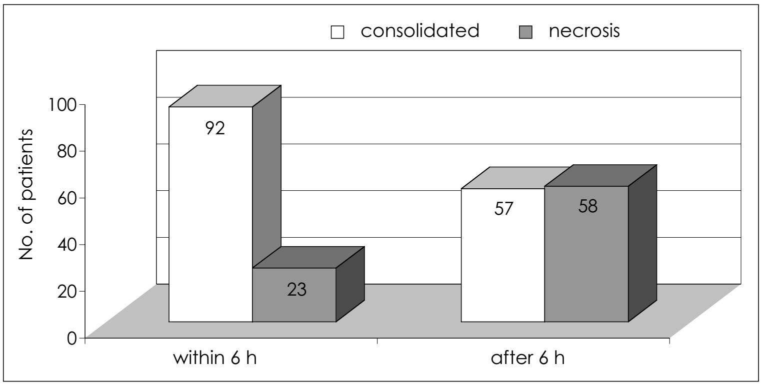


Fig. 172. Frequency distribution of femoral head necrosis in stages 3 and 4 at follow-up examination of displaced neck fractures three to six years later (Manninger et al. 1993).
115 patients were operated between 1981 and 1983 and between 1985 and 1987 inside six hours. 115 other patients were operated later than six hours between 1981 and 1983. The incidence of severe avascular necrosis after surgery performed inside six hours was significantly lower than after six hours (Mantel-Haenszel test $p < 0.001$)

For the sake of a better comparison we examined after 3–4 years also patients who **underwent internal fixation inside 6 hours in the years 1985–1987** (76 patients). We compared the late results of **115 patients operated immediately** (1981–1983 = 39 patients, 1985–1987 = 76 patients) with the later results of **115 neck fractures operated after more than 6 hours** in the years between 1981 and 1983 (see Fig. 171): 53 patients operated between 6 and 24 hours and 62 after 24 hours. **The late results of patients operated within 6 hours were again markedly better** (Manninger et al, 1993) (Fig. 172).

In 1990, we registered for the Multicenter Hip Fracture Study proposed by Acta Orthopedica Scandinavica. As required by this study we entered on special questionnaires all fresh hip fractures listing all pertinent patient information, the treatment and results of follow-up at four months, one and five years (Editorial, Acta Orthop Scand, 1988; Cserháti et al, 1992; Laczkó et al, 1992; Laczkó et al, 1993; Cserháti et al, 1997; Kazár et al, 1997; Cserháti et al, 2002a). We entered 754 hip fractures, of these were 312 femoral neck fractures.

The majority of fresh, displaced femoral neck fractures (165 patients) were internally stabilized with two Smith-Petersen nails. A little more than one third of them (61 patients = 36.7%) were operated within 6 hours after the injury (Table 3).

The evaluation brought to light the fact that the designers of the questionnaire had more in mind the **functional outcome** than the anatomical result (femoral head necrosis). We would like to add that the patient operated within 6 hours showed superior results not only in respect to survival and incidence of revision surgery but also in respect to use of walking aids and use of public transportation; they also had fewer complaints (Cserháti et al, 1997). Admittedly, this may also depend on the **patient's better condition at the time of admission**: in this group there were less patients with polymorbidity; they were more active, injured on the road and promptly admitted to hospital.

In 1997 and 1998, we analyzed **the outcome of**

Table 3. Late results analyzed in light of the interval between accident and surgery of 165 fresh femoral neck fractures that were internally stabilized with two Smith-Petersen nails in 1990 (Cserháti et al, 1997)

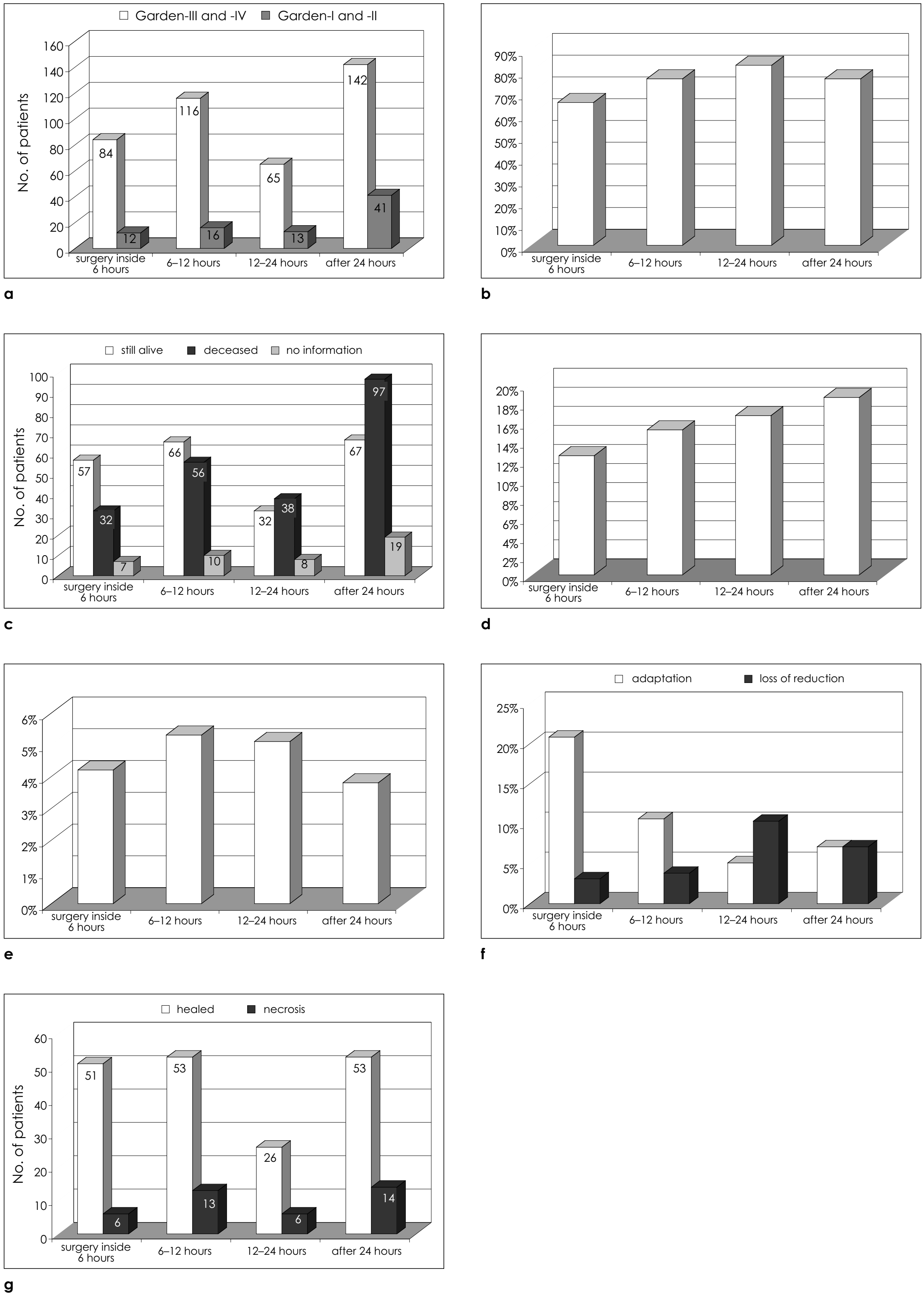
	Within 6 hours	Beyond 6 hours	Significance χ^2 test
n	61	104	
Survivors after 5 years	34 (55.7%)	34 (32.7%)	$p < 0.01$
Live at home	27	21	$p = 0.110$
Revision, arthroplasty	1	5	$p = 0.098$

489 patients who were treated in 1993 and 1994 by a percutaneous fixation with two cannulated screws. For the analysis of the questionnaires of the Multicenter Hip Fracture Study we used the software VisualdBase® developed by us. One-fifth of the patients were operated within 6 hours (96 patients = 19.6%). At follow-up after 3–4 years these patients showed **markedly better results in respect to femoral head necrosis and survival**. They were in better health at the time of admission, a fact reflected by a lower frequency of concomitant diseases. On the other hand we often delayed surgery in patients with Garden-I and -II fractures, known for their better prognosis in respect to necrosis and mortality. Their number among patients operated within 6 hours was lower (Fekete et al, 2000b; Fekete et al, 2000c) (Fig. 173).

The opponents of immediate surgery field in general two arguments: they believe that particularly in elderly patients a **thorough examination and preparation** is necessary. In their second argument, they refer to the unfavorable circumstances of surgery at night (over-fatigue at night, less qualified surgeon) influencing the **quality of internal fixation and the frequency of local complications**.

Our study showed that immediate surgery did neither lead to an increase in local nor in systemic complications. To the contrary, we found in the group operated within six hours a lesser incidence of **loss of reduction**. A bony consolidation ensued even in spite of a slight tilting in varus (5–10º), a rotation and a marked settling after mobilization ("adaptation"). This seems to indicate that even **under unfavorable mechanical conditions** (slight loss of reduction on account of a screw not resting on Adam's arch) **a consolidation can be expected on the condition we are preserving the circulation in the femoral head**. We had reached similar conclusions in preceding studies (Fekete et al, 1989a; Manninger et al, 1989).

Fig. 173. Frequency distribution in relation to the interval between accident and surgery of 489 patients undergoing a percutaneous internal fixation with two cannulated screws between 1993 and 1994.
a. Percentage of Garden-I and -II fractures. Considering the entire patient collective the difference is not significant (χ^2 test, $p = 0.0586$). If one compares, however, the groups operated inside 6 hours and between 6 and 12 hours with the patients operated after 24 hours the difference is significant for both groups (χ^2 test, both groups $p < 0.05$).
b. The frequency of concomitant diseases diagnosed at the time of admission was significantly lower in the group operated within 6 hours (χ^2 test, $p < 0.05$).
c. Patients living, patients deceased and those unable to be contacted 3 to 4 years after the accident. The survival rate of patients operated within 6 hours is significantly higher (χ^2 test, $p < 0.01$).
d. Postoperative systemic complications due to confinement to bed (Decubitus, urinary infection, thromboembolism, pneumonia). The difference is not significant (χ^2 test, $p = 0.603$).
e. Early local complications (hematoma, wound infection). The difference is not significant (χ^2 test, $p = 0.914$).
f. Loss of reduction or of adaptation (tilting in varus, marked resorption of neck, settling) seen in consolidated fractures. The difference between patients operated inside 6 hours and those operated later on is significant (loss of reduction: χ^2 test, $p = 0.0562$; Fisher's exact test $p < 0.05$; adaptation: χ^2 test $p < 0.001$).
g. Incidence of avascular necrosis diagnosed in survivors after 3 to 4 years. The difference between patients operated within 6 hours and those operated later on is not significant (χ^2 test, $p = 0.788$, when excluding Garden-I and -II fractures $p = 0.06$)


Garden-III and -IV
Garden-I and -II
No. of patients
0 20 40 60 80 100 120 140 160
84 12 116 16 65 13 142 41
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
a
0% 10% 20% 30% 40% 50% 60% 70% 80% 90%
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
b
still alive
deceased
no information
No. of patients
0 10 20 30 40 50 60 70 80 90 100
57 32 7 66 56 10 32 38 8 67 97 19
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
c
0% 2% 4% 6% 8% 10% 12% 14% 16% 18% 20%
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
d
0% 1% 2% 3% 4% 5% 6%
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
e
adaptation
loss of reduction
0% 5% 10% 15% 20% 25%
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
f
healed
necrosis
No. of patients
0 10 20 30 40 50 60
51 6 53 13 26 6 53 14
surgery inside 6 hours
6–12 hours
12–24 hours
after 24 hours
g

As Fig. 173 clearly displays, the incidence of mortality and early complications is increased by immobility. Moreover, the frequency of **loss of reduction increases the more surgery is delayed. For this reason surgery should be performed, even when the 6-hour limit has been exceeded as soon as possible (within 12 hours).**

In children and during puberty metaphyseal vessels do not cross the physis, a fact that endangers even more the circulation in the femoral head. In these instances the necessity for immediate surgery has been accepted world-wide (Ratliff, 1962; Böhler, 1981; Fornaro et al, 1982; Niethardt, 1982; Rüter and Krenczer, 1982; Barabás and Manninger, 1989; Schlickewei and Paul, 1993; Canale and Tolo, 1995).

In summary our opinion based on the current literature and our own experience is that surgery performed within 6 hours following a femoral neck fracture is mandatory as it leads to **a lowering of the incidence of mortality and general complications and to the prevention of avascular necrosis**. Our statistically supported principles influenced the thinking in Hungary. This influence spread to our Austrian colleagues after the combined scientific meeting in Sopron; even in other countries our standpoint has found acceptance (Marti and Jacobs, 1993; Parker and Pryor, 1993; Kyle at al, 1994).

6.3 Determination of the optimal moment of surgery – summary of investigations performed in Budapest

Already during our first investigations we found out that a protracted preparation for surgery of patients with hip fractures had an unfavorable effect on mortality and systemic medical complications (Manninger et al, 1960).

Later we could prove our point. The incidence of mortality and systemic complications (thromboembolism, decubitus, pneumonia) was markedly lower in patients with femoral neck fractures as well as trochanteric fractures operated within 24 hours than in subjects undergoing delayed surgery (Fekete et al, 1978; Fekete et al, 1989a). Admittedly, the incidence of concomitant diseases was slightly lower in the group operated within 24 hours. Comparison, however, of patient collectives having a similar state of health still showed a marked difference in respect to mortality (Molnár et al, 1979; Fekete et al, 1989a). We would like to add that in general we did not consider surgery for Garden-I and -II fractures urgent. The proportion of Garden-I and -II fractures has been higher particularly in patients undergoing delayed surgery (Manninger et al, 1989; Fekete et al, 2000b; Fekete et al, 2000c).

We do not employ the term **primary surgery anymore since it gave rise to misunderstandings**. In orthopedic surgery this term is used to denote surgery performed within 24 hours. If the patient is not admitted during normal working hours, surgery is postponed until the next day. Since the eighties we undertake surgery within 12 hours in four-fifth of our patients (Manninger et al, 1985).

Our analyses show that our fear of an increase in local complications has been unfounded. We could not find any difference in respect to quality of reduction or incidence of hematomas and infection between patients operated after various time intervals (Fekete et al, 1989a; Fekete et al, 2000b; Fekete et al, 2000c). The results, however, regarding mortality, early complications due to immobility, loss of reduction and delayed consolidation were superior in patients operated within six hours. The outcome of these parameters deteriorated proportional to the length of the interval between accident and surgery (Fekete et al, 1989a; Fekete et al, 2000b; Fekete et al, 2000c). The analysis of late results confirmed this trend: immediate surgery decreased the incidence of mortality (Cserháti et al, 1997).

Our clinical experience repeatedly and unambiguously confirmed the findings made in animal experiments: the effect of ischemia on the femoral head is still reversible after six hours. If the patency of still intact vessels can be restored by the reduction inside six hours, the incidence of avascular necrosis is significantly lower (Manninger et al, 1989; Manninger et al, 1993). Isotope studies and intraosseous venographies have shown that the interruption of femoral head circulation is not complete in fresh displaced fractures. We had assumed that the incidence of necrosis can also be reduced by the restoration of circulation after 12 resp. 24 hours. Pertinent studies failed to show any significant differences (Manninger et al, 1985; Manninger, 1989). Follow-up examinations also revealed a better functional outcome (ability to walk, use of walking aids) and less pain in the hip when surgery was performed within six hours (Cserháti et al, 1997).

The advantages of immediate surgery in respect to the **general condition of the patient** are:
- The muscles are still flaccid during this phase and the displacement is less pronounced. **The reduction can be achieved easier and with less trauma. At the time of admission Garden-III fractures predominate.** After prolonged bed rest, movements in bed and improper traction the displacement can worsen with the result that Garden-IV fractures are more frequently seen (Weller, 1964; Manninger et al, 1992).
- Surgery performed soon after the trauma is **psychologically less stressful to the patient**. Episodes of confusion reverse rather fast after stabilization.
- The patient can already be **mobilized on the day after surgery**. Complications due to confinement to bed can be avoided (Berentey et al, 1972).
- Hospital stay is shortened. Rehabilitation can be started earlier.

Advantages of immediate surgery during the phase of reversibility in respect to the **avoidance of femoral head necrosis**:
- Compression, incarceration, kinking and torsion of vessels are removed.
- In the presence of an intact capsule the intra-articular pressure decreases after proper reduction. Compression of vessels is diminished. (Emergency surgery obviates the need for an aspiration of the hemarthrosis).
- Adaptation of cancellous bone surfaces allows the drainage of blood congestion, as usually seen in impacted fractures (Kazár and Manninger, 1993).

  An appropriately designed implant can further improve the early drainage after emergency surgery.

Immediate surgery has marked advantages for the **elderly patient**:
- Earlier relief from severe pain.
- The long period of preparation with the limb in traction is avoided.
- Thanks to an early mobilization an hospitalism can be avoided.
- The incidence of major early and late complications is lower as is the mortality rate.

Nowadays nobody denies the absolute (life-saving) indication for immediate surgery for acute purulent appendicitis. For the same reasons we can call the immediate internal fixation a **life-saving measure**. Finally, immediate internal fixation has also **financial advantages**:
- Reduced need for initial total joint implants;
- Shorter duration of hospital stay;
- Shorter period of preparation;
- The number of additional, often expensive therapies and surgeries caused by local and systemic complications decreases;
- Patients can be discharged home or to a rehabilitation clinic in a much better general condition. They constitute a lesser burden to their active, gainfully employed family members (care).

6.4 Guaranteeing the prerequisites for an immediate surgery

Personnel and material prerequisites available 24 hours must be met for immediate surgery. Otherwise neither the hospital nor a given department can fulfill their expected task. Given the limited resources an adequate **organization** must be established that makes full use of the available means for the betterment of patient care.

Our goal in Hungary has been to guarantee each patient an optimal treatment **independent of the hour of the day and the place of accident**. It is evident that we cannot offer an around-the-clock emergency service in smaller towns. Therefore centers must be established and means of transportation realized. The risk to the patient is not only caused by a delay in surgery but also by a lack of necessary equipment and experience: “bad results of nailing are results of bad nailing” (Lloyd, 1938).

It is unacceptable to operate patients at hospitals where emergency surgery can only be performed during the day. Patients admitted through the emergency will have to wait one day before surgery and on weekends 2–3 days. Even in major centers where surgery can be performed around the clock, a delay exceeding 6 hours may occur when the patient load is heavy. It often takes **more than six hours for an elderly patient living alone to reach the family physician. Delay in establishing the diagnosis is another factor.** The fracture is not recognized and the patient treated for a contusion during several days. If many **polytrauma patients are admitted at the same time**, surgery for a hip fracture is often postponed. Another reason for delay of surgery is the **patient's poor** condition. Our clinical experience has taught us, however, that **immediate stabilization relieves pain** contributing to a surprisingly fast improvement of the patient's general condition.

In Hungary a great resistance to a 24-hour on call duty among the underpaid and overworked personnel is noticeable. These organizational problems have not been overcome at our institute as seen by our inability to increase the number of patients operated within 6 hours during the last 30 years (Table 4).

The analysis of clinical results showed that the percentage of patients operated within six hours increased steadily between 1972 and 1990. At the end of this period one fourth of all femoral neck fractures were operated inside six hours. After 1990 the portion of immediate surgery decreased but the number operated within 24 hours still increased. **In 1998 the percentage of patients operated inside six hours fell under the level 1972 amounting to one seventh.**

The reason for this unfavorable tendency is multifactorial:

– In 1992 in Budapest the organization of patients' admission was altered. This resulted in a delayed transfer from the outlying institutions to the tertiary hospital.
– These numbers reflect the ever increasing problems in health care during the last years. Due to lack of specialized personnel the care of severely injured persons becomes gradually more difficult. At the same time, the access to the operating room for emergency operations is more restricted.
– The fact that the number of patients treated primarily with an arthroplasty is steadily decreas-

Table 4. Frequency distribution of internal fixation done within six hours and within 24 hours or joint replacement after the injury at different time periods

Period	n	% of patients operated within 6 hours	% of patients operated within 6 hours without Garden-I and -II fractures	% of patients operated within 24 hours	N and % of primary arthroplasty
1972–77	740	14.9%	No data	37.7%	0
1981–83	592	16.2%	18%	54.8%	17 (2.9%)
1985–87	862	19.1%	21.9%	No data	No data
1990	312	22,8%	25.9%	No data	75 (24%)
1993–94*	596	15.7%	17.1%	62.6%	64 (10.7%)
1997–98**	261	13%	13.5%	68.6%	13 (5%)

* Patient collective of 2 years
** Patient collective of 1 year being part of the SAHFE project from Oct. 1, 1997 to Sept. 30, 1998
In the 2nd column the percentage of neck fractures for a given period is listed. In the third column Garden-I and -II fractures were excluded. Part of these fractures was treated conservatively up to the 80s, but even thereafter, they were not operated on an emergency basis (except hypervalgus fractures), but only when the access to the operating room was available.

ing (see Table 4) occurs the elevated number of delayed internal fixations in our institute.

– No doubt, this tendency has also personal reasons: at the end of the eighties leading members of the research team studying the hip fractures retired. Thus the emphasis on immediate surgery declined.

In the years 1981 to 1983 we investigated **how many patients were admitted to hospital within six hours and how many of these were also operated inside six hours. More than half** of 491 fractures treated with internal fixation were **admitted within six hours after the accident** (256 patients = 52.1%), one-fourth were admitted between six and 24 hours (126 patients = 25.7%), one-fifth after more than 24 hours (109 patients = 22.2%). Of the 256 patients admitted within six hours approximately **two-fifth** (96 patients = 37.5%) were operated within six hours, almost half (116 patients = 45.3%) between six and 24 hours and one-sixth (44 patients = 17.2%) only after more than 24 hours (sometimes several days) (Manninger et al, 1989) (Fig. 174).

Of the patients admitted within six hours but only operated between six and 24 hours (one-fourth of all patients, 116 of 491 = 23.7%) the immediate internal fixation could not be done due to lack of access to the operating room. As these patients were still operated on the day of accident, it is highly improbable that internal fixation was delayed due to their poor general conditions. This may have been the case in only 44 patients, one-tenth of all, (44/491 = 9%) who were operated after more than 24 hours.

In summary we can state that **the reason for delay of surgery was due to delayed admission to the hospital in half of the patients, in one-fourth due to lack of access to the operating room and only in one-tenth due to the patients' poor general health.**

Once having realized the advantages of immediate surgery both from the patient's and from the insurer's perspectives the necessary prerequisites have to be established for all elderly patients. We are confronted by the following tasks:

– Primary care physicians (in general family physicians) have to be **informed**. We must succeed that all elderly patients who are unable to walk after a fall should be transferred as fast as possible to a hospital, preferably to a trauma unit, where the diagnosis of a hip fracture must be clarified by radiographs.
– The **time to bring the patient to the hospital** must be kept to a minimum (more ambulances, better organization).
– Once having proven the advantages of immediate surgery we must **convince the insurer and the personnel** involved in patient's care of these advantages. We have to elicit a positive attitude and obtain reasonable renumeration for overtime and guarantee a deserved period of rest for the personnel.
– A **24-hour preparedness** in the department has to be provided which includes availability of specialists and trained personnel, image intensifier and traction table of good quality and complete set of sterile instruments and implants.
– A careful, fast and **minimally invasive procedure** should be used and taught. As the patient is exposed to little stress, no major preparations are necessary.
– Even high-risk patients should not be deprived of the advantages of immediate surgery in spite of the limited access to the operating room. To achieve this, dissemination and use of regional anesthetic procedures are mandatory.

The **percutaneous internal fixation with two cannulated screws** fulfills completely the last two prerequisites. We hope that the advantages of

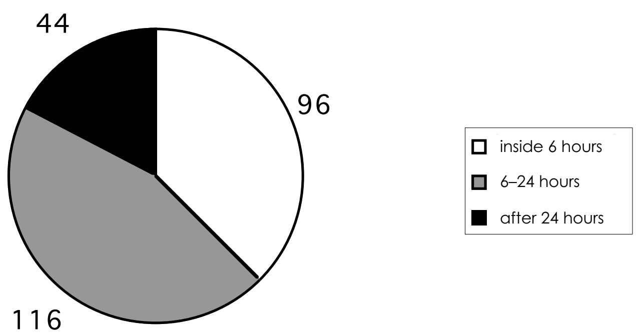


Fig. 174. Frequency distribution of 256 neck fractures admitted within six hours and operated after various intervals between accident and surgery (Manninger et al, 1989).

this method will not only lead to a decrease of early complications but also thanks to an increase in numbers of internal fixation performed on an emergency basis a decrease in late complications including avascular necrosis can be expected.

6.5 Present treatment methods at the National Institute of Traumatology (Budapest)

The **internal fixation of femoral neck fractures is an emergency operation** as long as no contraindication exists. If at all possible it should be done **inside six hours** after the accident. This however does not include fractures impacted in slight valgus the Garden-I and -II fractures that are not displaced. The risk of ischemia is low in these fractures. If no displacement is present, surgery can be delayed by one or two days. Obviously, **surgery becomes urgent,** when a displacement has occurred. Garden-I fractures impacted in **hypervalgus** (a.-p. alignment angle > 190º) have to be treated as emergencies to remedy incarceration of the supplying vessels.

If surgery is not possible within six hours due to poor health of the patient, a delayed establishment of diagnosis, a slow transportation to the hospital or lack of access to the operating room due to other emergency operations, an internal fixation should be done **if at all possible within twelve hours** (or at least between 24 and 48 hours) to reduce the incidence of mortality and early complications and to allow early mobilization.

If internal fixation cannot be performed inside 48 hours, an **arthroplasty** is indicated in patients older than 65 years with severe osteoporosis or markedly displaced fractures. In incidences where emergency operation was not possible due to the poor general health of the patient and where the patient's condition has not improved considerably in spite of medical treatment **(high-risk patient), the insertion of a total joint component will also certainly be contraindicated**. In such cases we recommend a **minimally invasive stabilization** with two percutaneously inserted screws, if necessary under local anesthesia to facilitate care. Should the patient's condition improve later on, a loss of reduction or avascular necrosis occur, a secondary arthroplasty is usually possible (Cserháti et al, 2000).

In **remote fractures** (admission after **several days** after the accident) an **arthroplasty** is usually the procedure of choice when the patient's general condition allows the procedure. It is often difficult to determine during the anamnesis the exact date of the fracture. Such a determination is more reliable on **radiographs**. Marked resorption of the femoral neck, the formation of a false joint or the smoothing of the fracture surfaces confirm our suspicion of a remote fracture. If in doubt, the choice of the procedure has to be weighted prudently. Considerations must be given to age of the patient, his general condition, the type of fracture, the amount of displacement and other affections of the hip joint. If necessary, in younger patients (certainly under 50 years of age) the vitality of the femoral head can be determined by **intraosseous venography** or **MRI** (see Fig. 187). We should stress that **Garden-I and -II fractures that displace during several days of preparation or under conservative treatment should not be considered remote fractures!**

6.6 General condition and co-morbidity of the elderly accident victim

During elective surgery for a chronic condition a detailed examination and meticulous preparation are the basic prerequisites for anesthesia. In emergency conditions, on the other hand, considerations for the patient's life and avoidance of serious complications predominate. An **absolute contraindication** for surgery must be expediently determined. It is increasingly accepted that the internal fixation of neck fracture is an emergency procedure.

From the beginning we realized that delay in surgery due to a prolonged preparation only led to a decreased number of operable patients. It definitely led to an increase in the incidence of mortality and complications, in particular of thromboembolism, septic complications and decubitus (Manninger et al, 1960; Molnár et al, 1979).

Based on our early and recent investigations only one-tenth of elderly patients are healthy (Molnár et al, 1979; Fekete et al, 2000b; Fekete et al, 2000c). Half of these patients suffer from several serious, age related diseases. Therefore, surgery performed within a few hours after the trauma entails a markedly diminished stress, particularly in light of modern, prudent and faster techniques.

Consequently, surgeon and anesthetist must consult each other and decide on the urgency, the methods of anesthesia and surgery, on the delay of surgery in the presence of contraindications as well as on the preoperative preparations.

The necessary measures in the presence of a femoral neck fracture are:

(1) **Speedy assessment of the patient's condition:** history taking (this is sometimes difficult when dealing with a senile, elderly patient, even when consulting relatives), meticulous clinical examination, immediate routine laboratory tests, ECG, chest radiograph (together with radiographs of the hip in two planes).

(2) **Exclusion of absolute contraindications to an emergency internal fixation such as:**
   - Acute myocardial infarction;
   - Lung edema.

   In the pertinent literature the following absolute contraindications are also listed:
   - Severe cardiac failure,
   - Severe diabetes (uncontrolled);
   - Chronic obstructive pulmonary disease;
   - Serious coagulopathias.

We believe that a minimally invasive, percutaneous internal fixation with screws is possible in the majority of patients after a short preparation.

If no absolute contraindication exists, surgeon and anesthetist decide together on the appropriate method of anesthesia and the necessary surgical technique, that is the least stressful to the patient. It is advisable that the surgeon decides immediately after having seen the radiographs on the method of internal fixation based on the fracture type, in particular determine whether a percutaneous technique or an exposure of the lateral femur (for DCD plates) is necessary. For open techniques blood must be reserved.

Really difficult is the decision in certain diseases that constitute risk of general anesthesia **even in the absence of an absolute contraindication** (decompensated liver cirrhosis with ascites, a severe chest wall or spine deformities). A properly performed local anesthesia would be under these circumstances the least stressful procedure (see Sect. 8.1.2). Here a carefully executed psychological preparation of the patient is mandatory.

The less stressful, fast operation will lead sometimes to a surprising improvement of the patient's physical and mental state by relieving the symptoms, often faster than a prolonged preoperative preparation can do.

Chapter 7

REDUCTION OF THE FRACTURE

7.1 Introduction

A meticulous clinical and radiologic examination (analysis of the fracture type), an anatomic reduction, a properly executed internal fixation and a correct rehabilitation (mobilization as early as possible with weight-bearing) are the most important parts for any head-preserving treatment of neck fractures. We are in full agreement with authors who insist on the cardinal role of reduction (Parker and Pryor, 1993). According to **Pannike (1996) the exactness of reduction is decisive for the success or failure of internal fixation.** Any error in reduction cannot be **compensated by the implant** (see Figs. 211 and 212). He also made it equally understood that a **joint replacement** will always only be a substitution. The current trend points toward a head-preserving intervention as achieved by an internal fixation. Problems nowadays encountered are due to the fact that major parts of the **reduction maneuvers have already been forgotten.** The younger generation of surgeons has not anymore been exposed to a proper execution of a closed reduction.

In the majority of cases the **immediate and early** reduction is easier in fresh than in remote fractures. The normal muscle tone has not recurred, the caudal fragment is not displaced as much, the soft tissues are less swollen and the patient is still in a better mental condition (Weller, 1964). The closed reduction of **remote fractures,** particularly after one to two weeks, is seldom successful. In younger persons an **open reduction** is then preferable. In older patients who are in good health a joint replacement seems preferable. A minimally invasive internal fixation should be considered in high-risk patients as it facilitates the postoperative care (Cserháti et al, 2000).

The exactness of reduction and the stability of internal fixation depend heavily on the **fracture type.** For this reason it is imperative to analyze carefully the radiographs before surgery allowing not only a proper execution of reduction but also an appropriate choice of the implant to be used.

Jagged and beak-like fracture surfaces can easily get jammed due to the displacement. **Reduction of these fractures is more difficult,** but they remain **stable** after proper reduction (Szabó et al, 1961b; Fekete et al, 1989b). In these instances it is of particular importance to execute the reduction maneuver properly starting with the abduction and **to avoid breaking** any beaks or asperities, as this will decrease the stability.

For other fracture types as **smooth fracture surfaces, one or many intermediate fragments, comminuted fractures, the reduction is** considerably **easier** but the proper assessment of reduction as well as the **maintenance of reduction** are much more **difficult.** In the presence of smooth fracture surfaces and of predominantly occurring fractures with an avulsed fragment (mostly posterocaudal), the **risk of over-rotation** (erroneous, exaggerated internal rotation) is smaller as the anterior (medial) cortex prevents slipping.

In multifragmentary fractures with a zone of comminution the instability is pronounced (also in rotation!). Care has to be taken in these fractures to avoid an over-rotation. An anatomic reduction is often impossible due to the defect. Consequently, we accept a compromise and do **not force an anatomic reduction.** We do not attempt to correct a slight displacement in valgus (up to 180º) nor an antecurvature (up to 160º). During internal fixation we recommend a **cautious impaction** for better adaptation of the fracture surfaces. The necessary stability can be obtained with a properly chosen implant. Resorption of fragments does not occur when the reduction is perfect. To the contrary, the fragments contribute to a bony consolidation **like cancellous bone grafts.**

In respect to the reduction, **Pauwels' angle** is of little importance. The danger of Pauwels-III fractures is not only the slipping but also the tilting in valgus. This can be avoided by inserting first the cranial screw during internal fixation. As the major part of Adam's arch remains attached to the cranial fragment and thus one cannot rely on the 2nd buttressing point, a reinforcement at the lateral cortex with an angle-stable plate is mandatory.

A reduction of **Garden-I and -II fractures** that are in a valgus position as seen in the a.-p. projection is not needed except in instances where the valgus angle exceeds 190º. The original Garden classification has the disadvantage of assessing the fracture only in the a.-p. projection. It happens, however, not infrequently that a fracture judged in the a.-p. film as relatively undisplaced shows in the lateral view a **marked antecurvature (< 160º),** a position that must be reduced. We believe that these fractures should not be classified as Garden-I or -II fractures on the account of their instability (Manninger et al, 1992).

In the presence of an anterior angulation **(recurvatum)** the posterior retinacular vessels are under tension (risk of circulatory disturbance!). Therefore, this displacement should be reduced.

The difference between **Garden-III and Garden-IV fractures** lies in the fact that **no contact between the fragments** remains in Garden-IV fractures. If one relies solely on a.-p. films, the superposition of the cranial over the caudal fragment is deceiving. **The position of fragments seems acceptable** as the fracture looks like a Garden-III. The lateral view, however, reveals that the caudal fragment lies completely **behind the cranial one** and that after a few days the caudal fragment will be markedly displaced cranially.

On lateral films one can also observe the rare **obliquely oriented fracture.** Here the fracture line runs from anterocaudal to posterocranial (see Figs. 63d and 177). The bony spike remaining attached to the caudal fragment cannot find support on the femoral head fragment with the result that the diaphysis slips posteriorly.

7.2 Closed reduction of displaced neck fractures

If a spinal anesthesia has been performed, the patient is only transferred to the traction table once the anesthesia has taken effect. While **grasping the leg with his hand** the surgeon proceeds carefully with the reduction under continuous image intensification. Once the reduction has been achieved the foot is attached to the foot holder. The advantage of the traction table lies in the fact that the limb is **fixed** in the reduced position and **held** there for the duration of surgery. The use of the traction table is not without dangers, when the reduction has not been carefully achieved before. If the limb is already attached, reduction with the fracture under traction can only be obtained with great force to overcome the muscle tension (Pannike, 1996). With such a maneuver the still intact retinacular vessels are at risk. Besides, the attempt at reduction may be unsuccessful. The same applies when during surgery a **correction is attempted or the reduction maneuver has to be repeated.** In this case it is advisable to grasp the limb again with the hand and start the reduction maneuver with careful abduction.

If an epidural anesthesia has been done, the limb must be very solidly fixed as the muscle tone is still preserved. Otherwise, muscle fasciculations may easily displace the fracture. On the other hand, if a general or a spinal anesthesia has been performed an overdistraction or a tilting of the fracture may occur given the complete muscle relaxation. **Once an overdistraction has happened, a revision of reduction is extremely difficult!**

Similarly, when dealing with a flaccid limb of a patient suffering from polio, hemiplegia or other neurologic diseases any strong traction is contraindicated. The result may be an overdistraction or a displacement of the fracture (Fig. 175).

Of great importance are the **sequential steps of the manipulation during the reduction.** First, the leg is carefully abducted (1) without exerting any traction, and then the leg is **internally rotated (2) depending on the degree of external rotation.** Starting with **abduction** of the externally rotated limb it is easy to fit the fragment anatomically by internal rotation. The success of reduction when **internal rotation is done before abduction** is uncertain as the fragments lying beside each other or being jammed cannot be reduced without applying force. Under these circumstances the reduction can become difficult when jagged surfaces or beaks form an obstacle or multiple fragments render the assessment of reduction difficult.

The third step of the manipulation, **the trac-**

a b

Fig. 175. Faulty reduction in a polio patient.
a. 68 year-old woman, right Garden-IV neck fracture, delicate femoral diaphysis; **b.** Already a slight traction on the paralyzed leg resulted in a hypervalgus position and a slight translational displacement

tion (3), is also achieved under image intensification. A traction is often **unnecessary** for fresh fractures as the adduction of the fracture is often already corrected by abduction (Ravasz, 1958). Should a displacement in varus or a shortening persist, increase in abduction combined with a careful traction on the limb fastened to the traction table will solve this problem. The manipulation must be followed on the monitor to avoid an **overdistraction.** If in Garden-IV fractures a marked displacement of the fragments has occurred, abduction combined with a slight traction should be done.

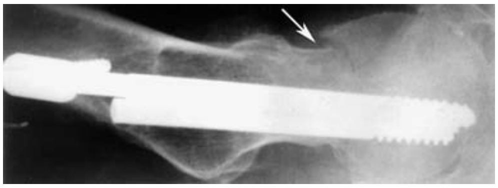
Abduction (and traction) correct the displacement in varus. The internal rotation around the longitudinal axis around the leg remedies the antecurvature. The displacement in varus will be carefully analyzed on the monitor in the a.-p. projection, whereas the antecurvature is checked in the lateral projection.

In particular, an **exaggerated internal rotation** must be avoided, otherwise the caudal neck stump will tilt posteriorly. This is seen in the lateral view as a translational (ad latus) displacement with an angle open anteriorly **(recurvatum).** A slight displacement can be tolerated whereas a major internal rotation is unfavorable as it leads to **tension or rupture of the posterior retinaculum,** thus increasing the risk of avascular necrosis. Particularly in the presence of comminuted fractures, this error is commonly made as the achieved position is difficult to assess due to the tilted posterior fragments (Fig. 176).

Absence of an external rotation of the limb is rarely seen in displaced fractures. This clinical sign should remind the physician that no displacement in external rotation (no antecurvature) of the fracture exists. **In this case an internal rotation should not be automatically done, as it will lead to an overcorrection in rotation** (see Fig. 105f, g).

If after the trauma the foot lies in neutral or slightly internally rotated position, we may deal with the rare displacement with an **anterior angle (recurvatum).** It is corrected by external rotation. However, when the limb is forcefully held in external rotation, the position of the neck as seen in the lateral view is not horizontal. Consequently, the aiming that must be done from posterior to anterior needs special attention. To circumvent these difficulties it may be helpful to place first a **separate Kirschner wire** through the fracture site into the head either anterior or posterior to the planned screw position. The wire **holds** the correct reduction in external rotation. Thereafter the limb can be **internally rotated** until the neck assumes a horizontal position **without risking an exaggerated rotation.** The typical steps of surgery can now follow. At the end of surgery the Kirschner wire is removed.

Major problems may be encountered, when the femoral head has turned around the **neck axis.** In this instance we are dealing with a real **displacement in rotation** of the femoral head (and the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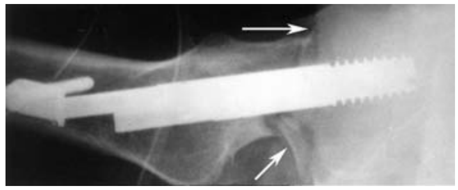
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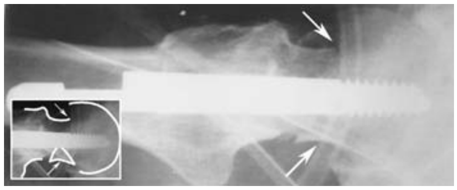
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Fig. 176. Clinical examples of various degrees of exaggerated rotation.
a. Minimal exaggerated rotation with anterior step amounting to one cortical width (anterior arrow) and slight recurvatum; **b.** Moderately exaggerated rotation with greater anterior step (anterior arrow). The assessment is rendered difficult by the large fragment avulsed from the posterior cortex (posterior arrow); **c.** Major exaggerated rotation with anterior step measuring 1cm (the position of the posteriorly avulsed fragment deceives the exactness of the reduction)

neck). Not only is the diagnosis difficult (see Sect. 5.5) but also the reduction. The severe damages that cause the rotational displacement result in an almost **free mobility of the broken femoral head in the joint.** This can be well recognized after arthrotomy with the patient on the traction table. The cranial fragment, aptly called by Pannike an extremely mobile head fragment, rotates and tilts already under slight traction like a "tumbler". It is impossible to steer the fragment with closed reduction. Reduction can only be achieved after **exposure of the fracture.** This is mandatory in younger patients. Pannike (1996) recommends the removal of the obstructing **bone spur or of the spikes** to achieve a reduction. We do not **share his opinion** as our goal is a perfect adaptation. The **prognosis** of severe rotational displacement is **poor from the onset** on account of marked osseous and vascular damages. If the diagnosis of a displacement in rotation is without any doubt, a **primary arthroplasty** should be performed in older patients.

A posterior displacement of the **caudal fragment caused by the weight of the limb** may occur on the traction table with the patient supine. It is seen in instances of **unstable fractures** (major intermediary fragments, comminution), in obese patients and in rare **oblique fractures** where the fracture line runs from anterocaudal to posterocranial as seen in the lateral projection (Fig. 177).

This displacement can be corrected before undertaking the second step of the reduction maneuver (internal rotation) by **lifting the trochanteric area by hand** and supporting it. Thereafter the limb is placed in internal rotation; this usually allows maintaining the fragments in their impacted position. If the caudal fragment **displaces again posteriorly,** the fragment is lifted again and internally rotated: a **well-padded support** (exceptionally a crutch) **attached to the traction table is placed under the trochanteric area** to maintain the caudal fragment in the reduced position. Alternatively, a firm roll of towels or a small sandbag can be used. For slim persons we recommend to place also a smaller support under the opposite side as the pelvis may easily tilt toward the uninvolved side. This maneuver is especially indicated as **currently we do not apply any traction for neck fracture in the majority of our patients.** This implies that the pelvis is not stabilized by horizontal traction. (Nevertheless, a certain degree of pelvic stability is obtained as we abduct and internally rotate the uninvolved lower limb).

Even with the above-described technique a reduction **cannot always be maintained.** The posterior translation of the caudal fragment can then

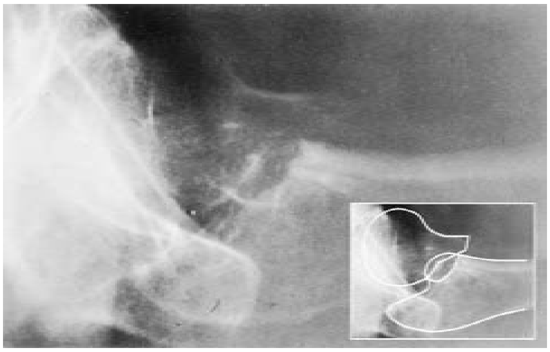


Fig. 177. Intraoperative lateral radiograph of a posteriorly sagged caudal fragment.

only be corrected by a **small exposure of the fracture** and by lifting the trochanter area with an **instrument** (bone hook). In some instances it is necessary to hold continuously the caudal fragment **during the internal fixation** until the stability of reduction is assured after **two guide wires** have been inserted.

If in younger adults – and in particular in adolescents and children – a perfect reduction with the above-described maneuver cannot be achieved, an **open reduction** through an arthrotomy is mandatory.

An internal fixation should never be undertaken when the initial displacement (exaggerated distraction or rotation, translation exceeding 0.5 cm, tilting in varus > 10º) **has not been properly corrected.** Open reduction in younger individuals does not present a problem whereas an inadequate reduction leads later to serious complications. Forced maneuvers of reduction such as that recommended by **Leadbetter** (1933), traction in 90º of hip flexion, **should be avoided** as it may damage the retinaculum and the retinacular vessels.

If the attempt at reduction has been unsuccessful, the leg should be gently externally rotated, the abduction decreased and the reduction maneuver **repeated from the start!**

The assessment of **outcome of reduction** depends greatly on the **correct positioning of the image intensifier.** Of decisive importance is the proper centering as well as the internal rotation in the sagittal plane and the **direction perpendicular to the neck axis in the lateral plane.** Only a beam hitting the neck at 90º can show the femoral neck at its entire length.

In general, the fracture is well visualized when the knee is in 10–20º of internal rotation. A small fragment avulsed from the posterior (or posterocaudal) neck is often seen. In this instance **the position at the posterior site of the fracture gap can be barely assessed, even when the direction of the beam in the lateral projection is correct.** The posterior fragment may also be **displaced or tilted** rendering the exact assessment of the translational displacement (ad latus) impossible. In such a case it is preferable to check the reduction on the **anterior surface of the neck:** the fragments should be on the same level without a formation of a step and without an anterior angulation (no recurvatum) (see Fig. 176c).

Particularly in the presence of a small posterior bone defect a small angle open posteriorly (antecurvature < 160º) **is better than** an exact reduction achieved by **forced internal rotation.** It leads to a better bony **contact** of the fracture surfaces **without diastasis** (Szabó et al, 1961b). If femoral head and neck **move en block** during internal and external rotation of the leg, the **result should be acceptable** even when the attempt to obtain a correct angle had been unsuccessful (see Fig. 239).

7.3 Open reduction of a displaced neck fracture

If two or three careful attempts at a closed reduction are unsuccessful, an open reduction is preferable as further manipulations may endanger the circulation in the femoral head. Fortunately this is rarely necessary in elderly patients who constitute the majority of our patients. Due to their osteoporosis in-

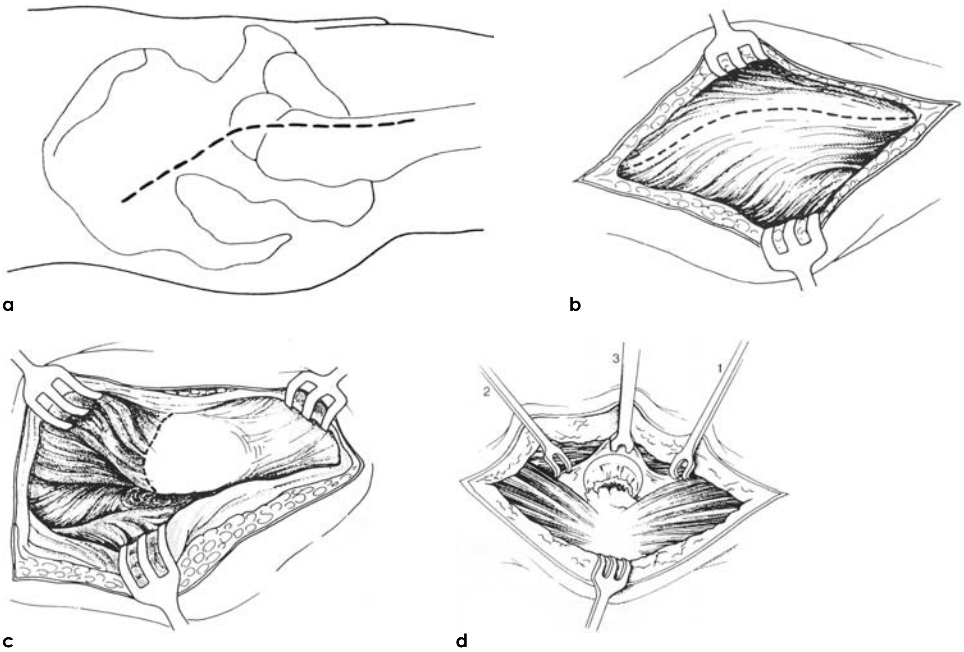


Fig. 178. Anterolateral approach to the femoral neck (Marti and Jacob, 1993).
a. Skin incision; **b.** Splitting of the fascia lata, division of the fibers of the tensor fasciae latae muscle and detachment of the gluteus medius with a cautery knife; **c.** The greater trochanter and the insertion of the gluteus minimus are shown, the latter is divided between two stay sutures to exposes the joint capsule; **d.** Insertion of the retractors: 1. caudal, 2. cranial to the neck, 3. at the anterior acetabular rim. The joint capsule is open in an inverted T-shaped fashion to expose the fracture

creasing proportionally with age, the fragments can usually be easily moved as compression and fragmentation of bony spikes occur more often. Contrarily, in younger patients the jagged fracture surfaces prevent a reduction as described above.

If a large anterior spike exists, a small lateral incision, particularly in slim patients, should be made. With the help of a periosteal elevator advanced to the anterior surface of the neck fracture exerting a pressure on the spike the desired position of the femoral head can be obtained; the fracture is stabilized by a Kirschner wire.

The posterolateral approach according to Gibson or Kocher has only been used in hospitals where in addition to an internal fixation a pedicled bone-muscle transfer has been done.

An anterior approach according to Smith-Petersen (Smith-Petersen et al, 1931; Parker, 1993; Marti and Jacobs, 1993) is traditionally used for exposure of the neck. Through a 10 cm long longitudinal incision at the anterocranial third of the thigh along the anterosuperior iliac spine the anterior surface of the joint capsule is reached lateral to the rectus femoris. The joint is open through a T-shaped incision and the capsular flaps are held by stay sutures. Retractors keep the wound open exposing the joint. The fracture can now be reduced with a periosteal elevator and gentle manipulations.

The advantage of the anterior approach lies in the fact that the important vessels in the posterior retinaculum are not damaged. The disadvantage of this approach is the impossibility to perform the internal fixation through the same approach. Therefore nowadays we use it primarily in revascularization surgery for implantation of the pedicled bone graft into the head.

More commonly used is the **modified anterolateral approach according to Watson-Jones.** This approach makes it possible to insert the implants through the same incision (Fig. 178).

In Watson-Jones' original description the center of the skin incision was placed over the tip of the greater trochanter. It extended caudally in a 7 cm long line and cranially it curved to the anterosuperior iliac spine. Today, we prefer a straight incision. We split the fascia lata in the same direction as the skin incision posterior to the muscle belly of the tensor fasciae latae. The insertion of the gluteus medius is seen in the cranial part of the wound, whereas the muscle belly of the vastus lateralis is found caudally. The muscle fibers of the gluteus medius originating close to the capsule are detached with a cautery knife. The tendon of the subjacent gluteus minimus is divided 1 cm caudal to the tip of the greater trochanter between two stay sutures. At the level of the lesser trochanter one retractor is inserted medial to the neck and one at the anterior rim of the acetabulum or posterior to the neck. Thus the capsule is visualized and incised in a T-shaped fashion exposing the fracture.

7.4 Reduction of a Garden-I fracture impacted in hypervalgus

In the majority of patients a reduction of simple Garden-I and -II fractures is not indicated. A reduc-

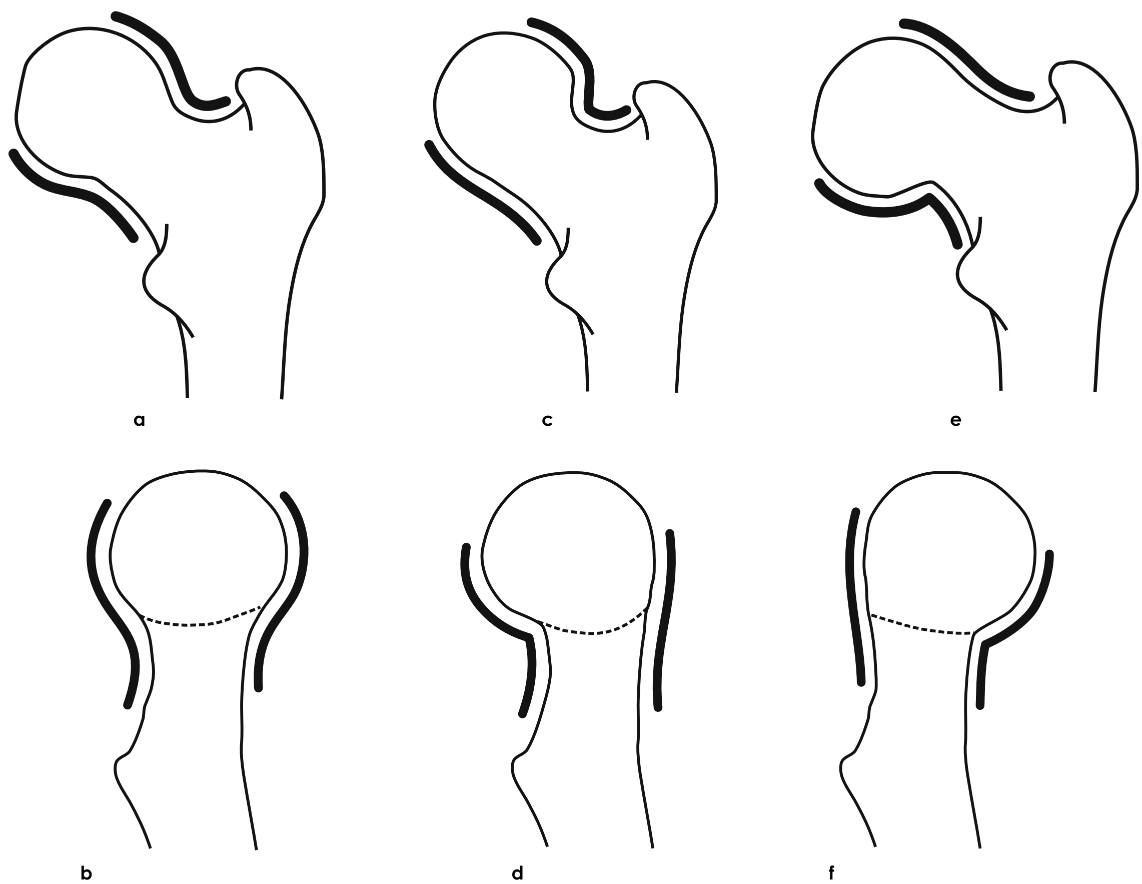


Fig. 179. Changes in the head/neck contours in various fracture types (modified and expanded schematic drawing according to Lowell 1981). **a, b.** The contours of the intact femoral neck show in the a.-p. and lateral projection an S-shape corresponding to the convexity of the head and the head/neck junction. These contours change when the femur is turned around the diaphyseal or neck axes; **c, d.** To the contrary, in the presence of a valgus tilting after a neck fracture, a caudal straightening and a cranial sickle shaped kinking of the S is seen in the a.-p. projection. In the lateral projection the S is straightened anteriorly and kinked posteriorly; **e, f.** In the presence of a varus displacement or recurvatum the shape of the S is reversed


a


c


e


b


d


f

Fig. 180. Clinical example of a femoral head necrosis after consolidation of an unreduced fracture in hypervalgus and stabilized with a delay. This 46-year-old woman fell on the day before admission and injured her right hip. She was able to walk and presented herself on account of hip pain at our institution for radiographs on the following day; **a, b.** In the a.-p. projection a hypervalgus position (alignment angle 190°) is seen, in the lateral view the fracture is undisplaced; **c, d.** Stabilization with two cannulated screws without reduction. The hypervalgus and the marked medial translation remain unchanged. Even an increase in impaction of the neck close to Claffey's point is evident; **e, f.** Eight months postoperatively the screws were changed due to increasing hip pain. The "perforation" of the cranial screw however was not the consequence of a technical error but occurred secondarily to the collapse of the cranial pie-shaped head segment, the classical site of avascular necrosis. This segment is well seen anteriorly in the lateral view. Due to the progression of symptoms (see Fig. 186c) an uncemented total hip replacement was performed two months later

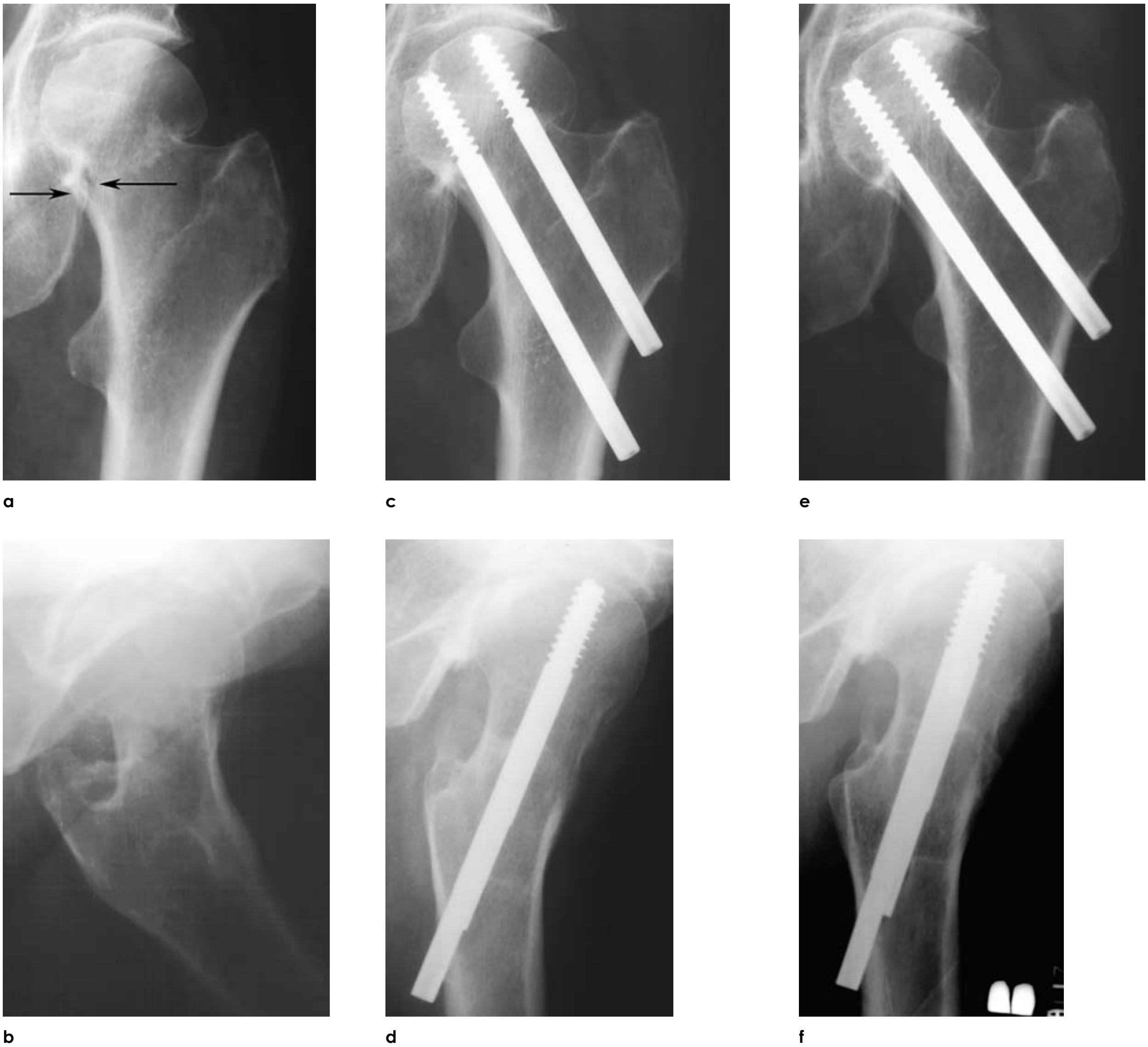
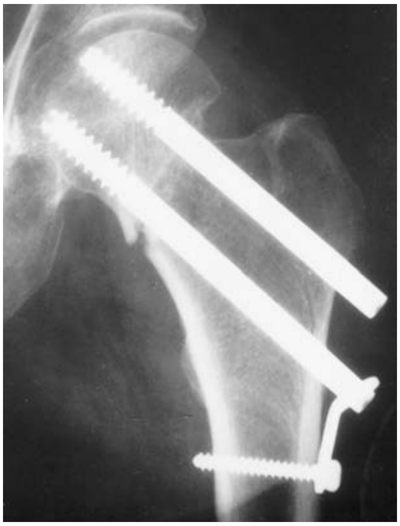
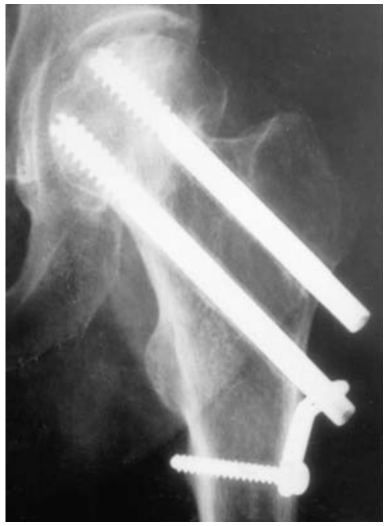


Fig. 181. Clinical example of a successful reduction of a hypervalgus fracture.
This 64-year-old woman fell while disembarking from a streetcar; **a, b.** Left Garden-I hypervalgus fracture (a.-p. alignment angle 200°) without displacement in the lateral view. The a.-p. projection clearly shows a small fragment avulsed from Adam's arch and an evident medial translation (arrows); **c, d.** Ten hours after the accident an internal fixation with two cannulated screws was done. A closed reduction reduced the valgus angle to 180° and corrected also the medial translation. The patient was discharged home on day 5. At the three months follow-up she was symptom-free; **e, f.** Also three years later she had no symptoms; the radiographs did not show any evidence of avascular necrosis



a



b

Fig. 182. Overdistraction of a Garden-I fracture.
a. After reduction of the valgus fracture a small medial (caudal) gap remained (slight overdistraction); **b.** In general, the gap closes once the muscle tone returns or during mobilization

tion, however, is necessary when the by **Lowell** (1981) published radiologic signs indicating displacement or tilting of fragments are present (Fig. 179).

If a displacement in hypervalgus is not reduced (a.-p. alignment angle > 190º), a **high risk of avascular necrosis** after consolidation of the fracture must be anticipated as the retinacular vessels entering at Claffey's point are either kinked or incarcerated (Garden, 1971; Cserháti et al, 1996) (Fig. 180). Therefore this fracture type should be treated as an emergency as recommended by **Lamare and Cohen** (1986). Similar to the other displaced fractures **reduction and stabilization should be done inside six hours after trauma to decrease the risk of avascular necrosis** (Fig. 181)!

The **reduction of Garden-I hypervalgus fracture is different** from the reduction maneuver in Sect. 7.2. It is of cardinal importance **not to put the limb in abduction.** Any increase of the already precarious valgus angle will heighten the risks associated with abduction. **Already a slight internal rotation of the extended leg is sufficient for reduction.** This maneuver not only corrects the accompanying antecurvature but also reduces the displacement in valgus. Should the displacement not being adequately corrected, the limb is **carefully adducted without traction by using a fist or a rolled up towel placed proximally between the legs as a fulcrum.**

In a.-p. projection **we do not strive for an exact anatomic reduction.** A remaining valgus of 180º does not constitute a risk for the head circulation. To the contrary, in respect to **stability it is even more advantageous** (Szabó et al, 1961b). **A medial gap** of 2 to 3 mm as seen on **a.-p. radiographs** is usually closed shortly after surgery by muscle contraction (Fig. 182). To obtain an immediate intraosseous drainage it seems however preferable to close such small gaps after release of traction by careful adaptation of the fracture surfaces already during surgery. Occasionally, a **recurvatum is associated** with a position in hypervalgus. As with displaced fractures, recurvatum is corrected by **a maneuver of external rotation.**

A defect of the femoral head may remain at the cranial site of impaction causing a risk of loss of correction during internal fixation reverting the head into the original position of hypervalgus. Exceptionally, to avoid a recurrence of displacement it is advisable to insert first the cranial screw after predrilling (see Sect. 8.3.2.3).

7.5 Frequent errors of reduction

The majority of errors of reduction are caused by an inadequate positioning either of the injured limb or of the C-arm. This incorrect positioning leads to errors in the interpretation of the images. Incorrect positioning is caused by the following factors:

– The tube was not placed perpendicular to the neck in the a.-p. projection;
– The beam in the a.-p. projection was not centered on the neck;
– The beam in the lateral projection has not been aligned perpendicular to the neck axis (the neck is not displayed adequately, the greater trochanter is projected over the femoral head);
– Wrong positioning of patient (tilted pelvis, interference by perineal post);
– Insufficient internal rotation of limb.

Other **technical problems** independent of positioning may interfere with the assessment of radiographs after reduction:

– Severe osteoporosis;
– Multifragmentary or comminuted fracture;
– Internal fixation in the presence of contracture or amputated limb;
– Morbidly obese patient (fat limb, soft tissue hanging over hip or abdomen;
– Use of a faulty image intensifier.

The surgeon must always check before surgery the positioning of the image intensifier and proceed with a correction, if necessary.

Faults and errors during reduction as seen in the a.-p. projection:

– **Persistence of a varus- or marked valgus malalignment** (alignment angle under 160° or over 180°);
– **Overdistraction** of fracture: if slight: **medial gaping and lateral translational displacement (ad latus)** of the caudal fragment;
– If severe: enlargement of the entire fracture gap resulting in a serious **diastasis;**
– An overdistraction often results in a **position of hypervalgus;**
– Very rarely **the traction is not strong enough.** It is evidenced by a **varus position, a lateral gaping** of the fracture (medial impaction) and a **medial translational (ad latus) displacement** of the caudal fragment.

Faults and errors of reduction as seen in the lateral projection:

– During the correction of the initial external rotation the reduction of the originally present angle having a posterior opening (antecurvature) is exaggerated. The exaggerated internal rotation of the limb leads to an angle between femoral head and neck axes, that is open anteriorly **(recurvatum).** It is often accompanied by a posterior step. **(This is the most frequent error!);**
– Very rarely the **internal rotation** is insufficient. If the surgeon does not reduce adequately the initial external rotation, an **antecurvature and the anterior step** remain;
– Due to the fracture type (zone of comminution or oblique fracture having the tendency to slide) or due to the weight of the limb (obese patient) the distal fragment **sags posteriorly.**

7.6 Guidelines for the assessment of reduction

Already during the first analysis of patients with femoral neck fractures seen between 1940 and 1955 our team paid special attention to the quality of reduction (Szabó et al, 1961b). We established criteria for good, satisfactory and poor reduction. In addition, we analyzed the correlation between quality of reduction and early and late complications. Our conclusions made then are still valid today.

The introduction of cannulated screws greatly influenced our practice. From the beginning we attempted to separate **problems particular to the procedure from those caused by faulty execution of the surgical technique.** Consequently, we developed a prospective documentation. The clinical parameters of all patients were registered; the initial and postoperative radiographs were assessed as to the quality of reduction and internal fixation and analyzed in light of the outcome observed at the time of follow-up.

In the course of this work executed during the first years we elaborated **criteria and borderline values** that were later also used for the review of patients treated with cannulated screws in an attempt to prognosticate possible problems (Johansson et al, 1986; Cserháti et al, 1999). The detailed analysis listed below was **foremost done for the establishment of a scientific comparison.** The resulting basic principles are also of use in daily practice.

To allow an exact assessment we established **four categories** to judge the quality of reduction: **1 = good, 2 = acceptable, 3 = faulty, 4 = poor** (Table 5). For the determination of angles we used the Garden alignment angle values (in the a.-p. projection 160°, higher values define valgus and lower values define varus; in the lateral projection 180° values below define antecurvature and higher values define recurvatum). A standard deviation of ± 5° was accepted. **The value of the analysis is increased when those patients are excluded who could not be properly evaluated on account of missing data or poorly executed or exposed radiographic techniques. These exclusions are comprised of:**

- Ill-defined contours precluding assessment;
- Underexposed radiographs with poor contrast;
- Poorly focused a.-p. radiographs (on the a.-p. films of the pelvis crucial structures are missing or not clearly shown);
- A.-p. and lateral films were taken in marked external rotation of the limb;
- Poorly centered lateral radiographs, the tip of the greater trochanter is projected over the femoral head.

For each group we submit clinical examples (for the sake of better comparison all radiographs are shown as being left-sided) (Figs. 183–186).

Table 5. Criteria for the assessment of reduction: 1 = good, 2 = acceptable, 3 = faulty, 4 = poor

a.-p. projection	lateral projection
1. good – anatomic reduction (Fig. 183a, c) – valgus up to 180°	– anatomic reduction (Fig. 183b, d) – antecurvature up to 170°
2. acceptable – valgus 180°–190° (Fig. 184a, b) – varus up to 150° – too much or too little traction, translational displacement of max. thickness of one cortex (Fig. 184c, d) – incomplete medial gap up to 3 mm	– antecurvature 170°–160° (Fig. 184e) – recurvatum up to 190° (Fig. 184f) – too much or too little rotation with translational displacement of max. 1/4 cortical thickness (Fig. 184g)
3. faulty – valgus 190°–200° (Fig. 185a–c) – varus 150°–140° (Fig. 185d, e) – too much or too little traction with translational displacement varying between one cortical thickness and 5 mm (Fig. 185f, g) – complete gap (diastasis) of max. 2 mm (Fig. 185h, i)	– antecurvature 160°–150° (Fig. 185j) – recurvatum 190°– 200° (Fig. 185k) – too much or too little rotation with translational displacement up to 1/3 cortical thickness (Fig. 185l)
4. poor – valgus > 200° (Fig. 186a–c) – varus 140° (Fig. 186d) – too much or too little traction with translational displacement > 5mm (Fig. 186 e, f) – complete diastasis > 2 mm	– antecurvature < 150° (Fig. 186g) – recurvatum > 200° (Fig. 186h) – too much or too little rotation with translational displacement > 1/3 of cortical thickness

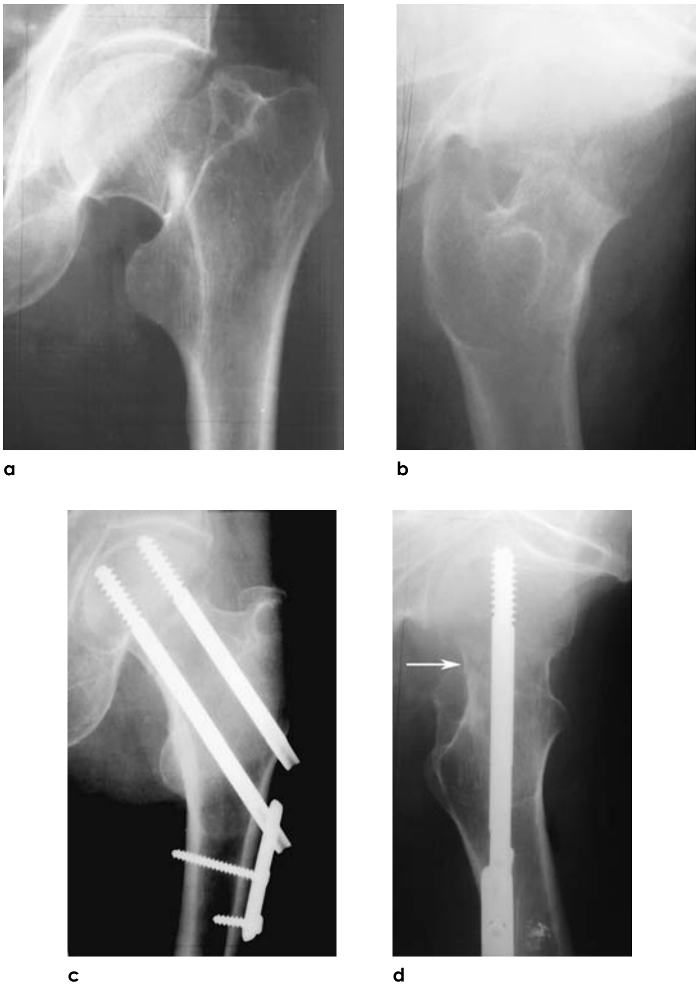
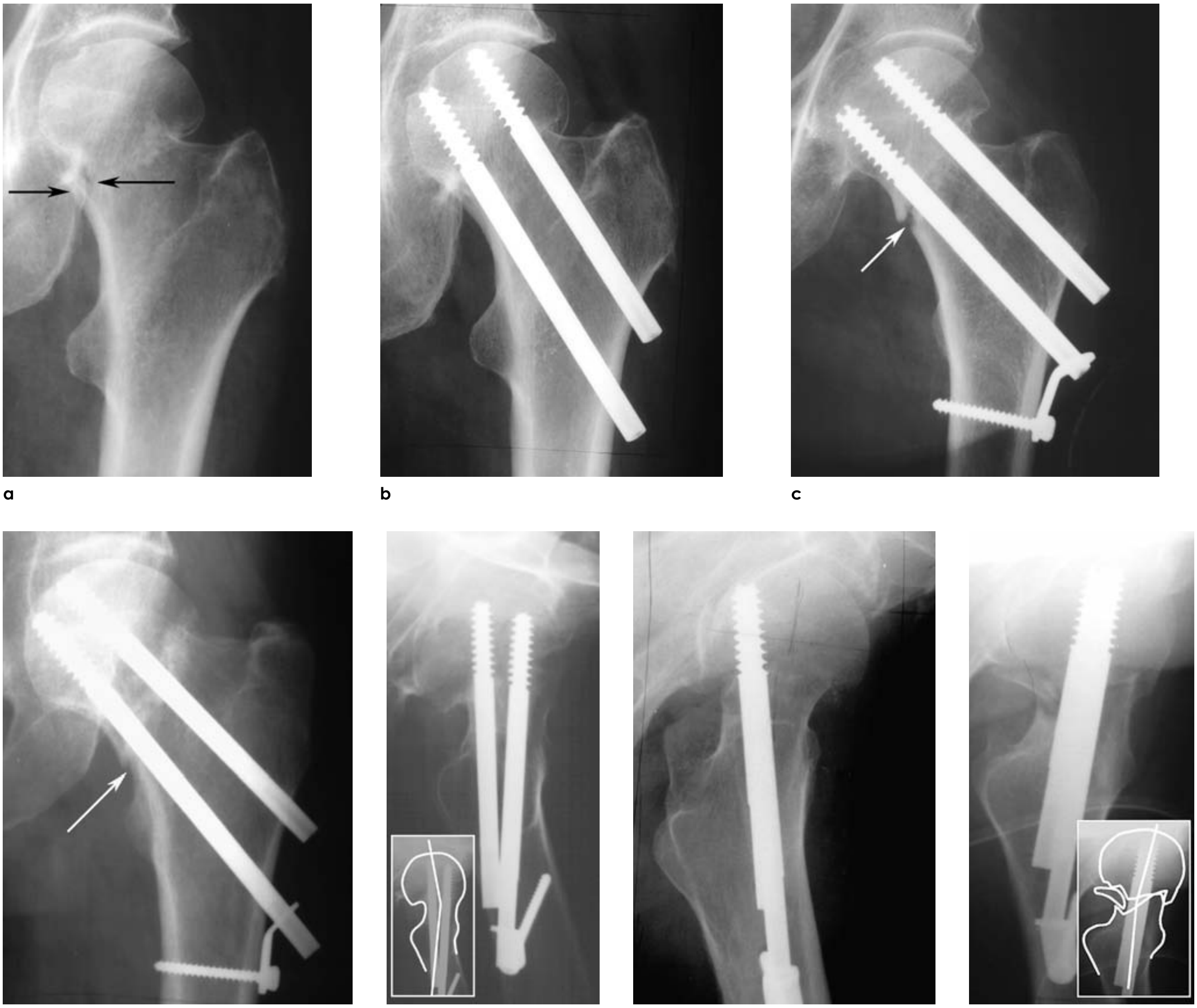


Fig. 183. Clinical example of a reduction judged as "good".
a, b. Garden-IV neck fracture; **c, d.** Anatomic reduction in both projections. A small fragment of the posterior cortex is well seen in the lateral view (arrow)



a b c d e f g

Fig. 184. Six clinical examples of reduction judged as "acceptable".

(1) **a.** Fracture in hypervalgus (a.-p. alignment angle 200°). The fragment avulsed from Adam's arch renders the assessment of the marked medial translational displacement difficult (arrows) (see also Fig. 181). Surgery was done 10 hours after the accident; **b.** Follow-up radiograph after 3 years: after a successful reduction (a.-p. alignment angle 180°) there are no indications of necrosis. The patient is symptom-free;
(2) **c.** Slight overdistraction, medial gap measuring one cortical width (arrow);
(3) **d.** Slight inadequate longitudinal traction (one cortical width), medial impaction (arrow);
(4) **e.** Slight antecurvature (lateral alignment angle 160°);
(5) **f.** Slight recurvatum (lateral alignment angle 190°);
(6) **g.** Slight overrotation, the anterior translational displacement amounts to 1/4 of cortical width. A large posterior cortical fragment interferes with the assessment

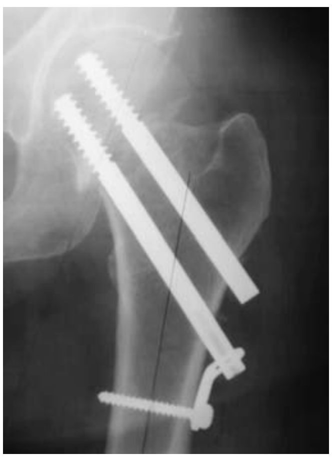
a

b

c

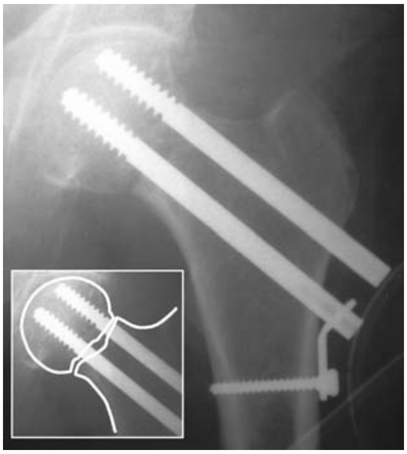
d

e

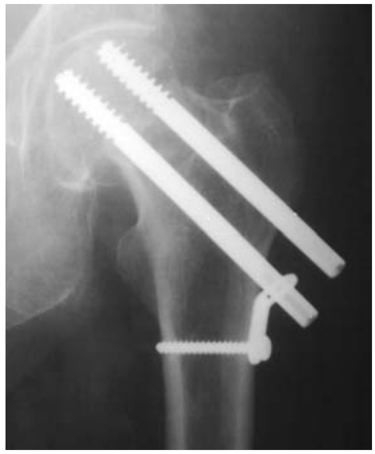


f

g



h



i

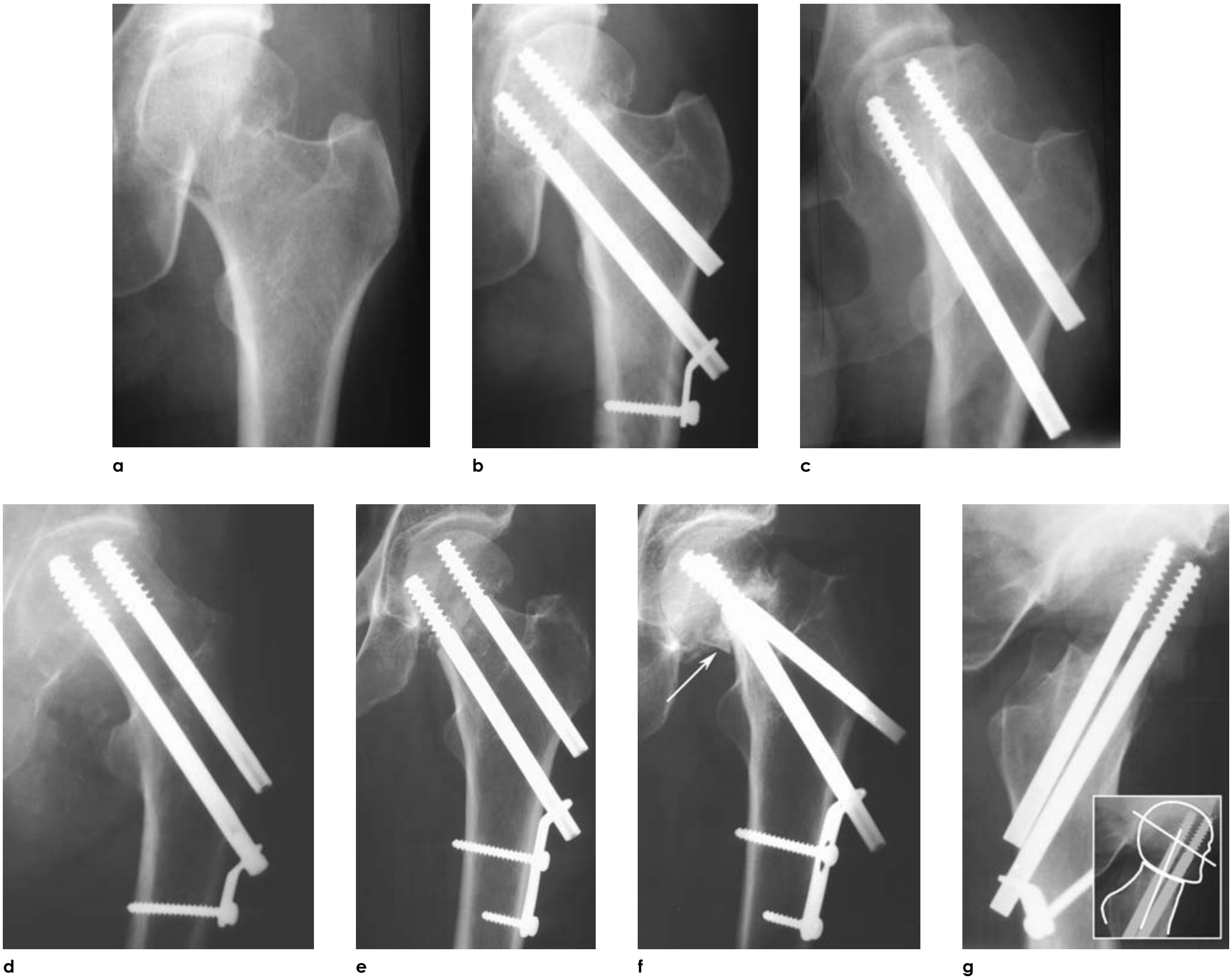
i

k

l

Fig. 185. Seven clinical examples of a reduction judged "faulty".

(1) **a.** Initially a marked displacement in valgus (a.-p. alignment angle 200°); **b.** The reduction was only partially successful (a.-p. alignment angle 195°); **c.** Control after six months: evident resorption of neck and settling (the further course is unknown);
(2) **d.** Stabilization in 140° of varus, a fragment has been avulsed from Adam's arch; **e.** Consolidation after one year with slight increase of varus, marked settling and limb shortening (patient has complaints!);
(3) **f.** Stabilization in malposition in valgus (a.-p. alignment angle 200°) and evident inadequate longitudinal traction; **g.** After six weeks displacement in varus and rotation;
(4) **h.** In addition to an error in internal fixation a marked gapping; **i.** Marked tilting in varus during the 4th postoperative week, loss of reduction (see also Fig. 211a, b);
(5) **j.** Due to an inadequate internal rotation an antecurvature of 150° persists;
(6) **k.** Patient shown in fig.105. Initially, no displacement was present. Unrecognized fracture that later displaced in varus. Faulty reduction characterized by marked recurvatum secondary to exaggerated rotation (lateral alignment angle > 200°);
(7) **l.** This multifragmentary fracture was evidently stabilized in marked overrotation



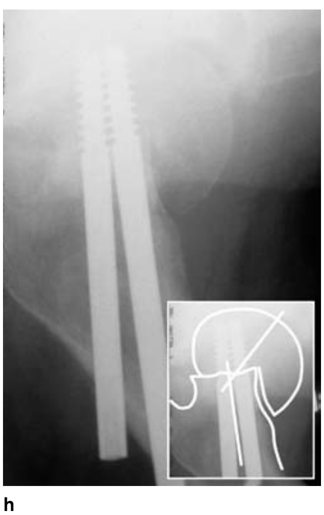


Fig. 186. Five clinical examples of a reduction judged "poor".

(1) **a.** Initial displacement in hypervalgus (a.-p. alignment angle 200°) and marked translational displacement; **b.** The displacement was not corrected during surgery. To the contrary, the impaction near Claffey's point is more pronounced; **c.** After one year the femoral head has collapsed (see Fig. 180);
(2) **d.** Stabilization in extreme varus position. Revision surgery;
(3) **e.** Exaggerated longitudinal traction. Hypervalgus, transitional displacement (probably the large fragment avulsed from Adam's arch deceived the surgeon); **f.** Loss of reduction after one week;
(4) **g.** Exaggerated antecurvature (lateral alignment angle 120°). The femoral neck has been virtually fixed to the cartilaginous surface of the head. The anterior screw perforates the femoral head (see Fig. 212c–h);
(5) **h.** Similar outcome in an instance of recurvatum.
In all five patients a hemiarthroplasty became necessary

Chapter 8

INTERNAL FIXATION

8.1 Preparation for surgery

8.1.1 Preparation for immediate internal fixation

To meet the requirements for emergency surgery the preparations should be as succinct as possible. With the exception of evidently absolute contraindications and remote fractures **all patients with femoral neck fractures should undergo an examination relevant for an emergency situation.** This includes patients in whom the interval between trauma and admission exceeds six hours. Therefore we divide the patients rather speedily into the following groups: patients that can be operated immediately, patients that need a short preparation, and patients that can only undergo delayed surgery after appropriate medical treatment for conditions such as high blood pressure and dehydration.

An **effective organization will prevent any time loss after admission.** In general the initial clinical examination allows to diagnose a hip fracture. It is helpful to take samples for **routine laboratory tests already in the emergency room.** Further tests such as cardiac or liver enzymes are only required when indicated by a relevant history.

This is usually followed by radiographs. In addition to films of **hip/pelvis** (and of other sites if indicated) an a.-p. **chest film** is taken at the same time. Surgeon and anesthetist having at their disposal all test results including an ECG can then decide whether the patient's condition permits anesthesia and surgery. If necessary, other diagnostic and therapeutic measures are ordered. A decision has also to be taken in respect to the kind of anesthesia and thrombosis prevention. The latter prophylaxis is usually started before surgery. Under rare circumstances a preventive administration of antibiotics is indicated.

Having evaluated the radiographs the surgeon has to decide whether he wants to perform percutaneous or surgery with exposure of the lateral femoral cortex (as needed for addition of a DCD plate to increase stability). **A transfusion is not necessary** for percutaneous surgery except for patients in whom an anemia has been diagnosed on admission. For internal fixation exposing the lateral femoral cortex at least two units of blood or packed cells should be reserved. The quick decision on the type of surgery and the immediate request for hematology tests avoid any delay.

The next step is an **explanation to the patient** about the diagnosis and the planned intervention. **If the patient is unable to comprehend, relatives have to be informed.** The reasons for the necessity for surgery and the **advantages of emergency surgery** (early mobilization, avoidance of complications secondary to confinement to bed, prevention of femoral neck necrosis) have to be explained in a language understandable to laypersons. This includes enumeration of common surgical risks and the possibility of complications as well as the kind of rehabilitation. In our elderly patients the main goal should be a simple description of the present situation, to calm them down and to gain their cooperation for the anticipated treatment.

If the patient appears to be unkempt, a careful and pain-free cleansing should be done. In such an instance, at the time of shaving performed outside the operating theatre, the surgical field should also be disinfected. Should the patient be incontinent or disorientated, a urinary catheter should be inserted to be removed the day after surgery.

8.1.2 Internal fixation done under local anesthesia

During the fifties and sixties the majority of patients **with neck fractures were operated under local anesthesia** at the National Institute of Traumatology (Budapest). **The patients tolerated rather well the exposure, the protracted operating time caused by the absence of an image intensifier and the increased stress caused by**

the activity of nailing (hammering). Since the introduction of spinal anesthesia younger surgeons did not gain the experience to operate under local anesthesia. This lack of experience contributed further to discredit this procedure.

Presently, we use local anesthesia rarely:
(1) In emergency operations for patients where a general anesthesia is contraindicated;
(2) For delayed surgery of high-risk patients in whom a joint replacement is impossible in spite of a lengthy preparation (Cserháti et al, 2000).

An important component before starting local anesthesia **is a pain-free positioning of the patient.** With the patient still in bed and outside the operating room after **disinfection and sterile draping** a local anesthetic is injected into the joint to freeze the fracture. (Today, steps preceding spinal anesthesia are done in the same sequence). It is more convenient to place the patient on **a movable modular operating table** already in the emergency room and transport him thus to the operating room. This allows also to perform the intraarticular injection under more favorable, aseptic conditions, if necessary under **radiologic control.**

The technique for the injection has been described in Sect. 3.3.1 with the difference that we do not aim **at the center of the femoral head but at the fracture.** Care must be taken to avoid injuring a major blood vessel with the long needle. It is therefore advisable to palpate the pulse of the common femoral artery and introduce the needle lateral to the artery while inclining the needle medially. As the artery at the inguinal region lies lateral to the vein, any injury to the vein can just be avoided. On the condition of choosing a sufficiently long needle, avoiding the acetabular rim and aiming properly, one can enter the joint or the fracture gap. At the same time, one can usually aspirate a hemarthrosis and thus place safely the local anesthetic, in general **lidocaine (Lidocaine®).** We prefer the 2% over the 1% solution that allows us to inject into a restricted area half of the volume: **50 to 100 mg (2.5 to 5 ml).** After a few minutes we check the effect of the anesthetic by carefully moving the limb. If effective, the operating table is transformed into a traction table, the fracture carefully reduced and the foot fixed in the foot holder.

After disinfection and sterile draping of the surgical field, the second step of anesthesia, the **infiltration of the area for the percutaneous approach** is performed. Patient's weight and the maximal dose of the anesthetic are to be taken into consideration. For a mean body weight of 70 kg it amounts to 200 mg lidocaine. As we have already injected 50 to 100 mg into the fracture, **not more than 100 to 150 mg should be used.** Therefore a **1% solution** (10 to 15 ml) is suitable. In obese patients a further dilution (0.5%) guarantees a better distribution. When **combined with epinephrine** a greater volume can be injected. The vasoconstrictive action of epinephrine prevents a fast elution of the anesthetic from the surgical field. At the same time it prevents any cardiovascular side effects. If the administration of a **long acting anesthetic such as Bupivacaine (Marcaine®)** is desired, calculation of the pertinent dosage must be made depending on the dilution (0.25% or 0.5%). (The maximal dosage amounts to 175 mg, therefore the maximal volume should be 70 or 35 ml). The efficacy of the **anesthesia can be heightened by injecting the agent under image intensification in the tracts planned for the screw insertion.** After anesthesia of skin and subcutis **all tissue layers will be infiltrated including the periosteum** that is richly innervated. Obviously, premedication, fluid replacement, sedation during surgery and, when necessary monitor control are the responsibility of the anesthetist!

In our experience the percutaneous insertion of cannulated screws preceded by careful drilling and tapping can be done easier under a good anesthesia than the previously used nailing (trans- or retromuscular approach, hammering). **A local anesthetic relieves the often overworked anesthetist and permits therefore more patients to benefit from emergency surgery.**

8.1.3 Preparations for delayed internal fixation, role of skeletal traction

In instances of delayed surgery the most important measure is **pain relief.** Besides administration of analgesics skeletal traction by a pin inserted through the tibial tuberosity is the mainstay of treatment. Traction also combats major displacement, it immobilizes the limb and reduces crepitation between the fracture surfaces. A satisfactory effect can be obtained by a **correctly executed technique and close surveillance.**

In the past Kirschner wires were used for skeletal traction. As they can move in bone, cause local irritations and even wound secretions, we now prefer Steinmann pins. They are fastened in traction bows, they allow rotation. After an appropriate premedication the patient is moved the least possible. While in bed the patient's leg is carefully lifted and positioned on a small pillow. Grabbing the foot the limb is carefully internally rotated to the neutral position. Once this position has been reached, the assistant maintains it till the end of the intervention. After disinfection and sterile draping the areas of pin insertion, one finger breadth distal to the tibial tuberosity, are infiltrated with 1% lidocaine down to the periosteum. A lateral stab incision is then made in a proximal to distal direction, the pin advanced to the bone and the pin driven through the tibia **perpendicular to both planes.** On the medial side a stab incision is made over the protruding pin tip.

After dressing the wound the bow is attached. Then the patient is transferred to a bed prepared for treatment in traction. **The positioning of limb is the surgeon's responsibility.** The placement of the leg in slight abduction under traction and keeping it in neutral rotation are tasks as difficult as the reduction prior to surgery.

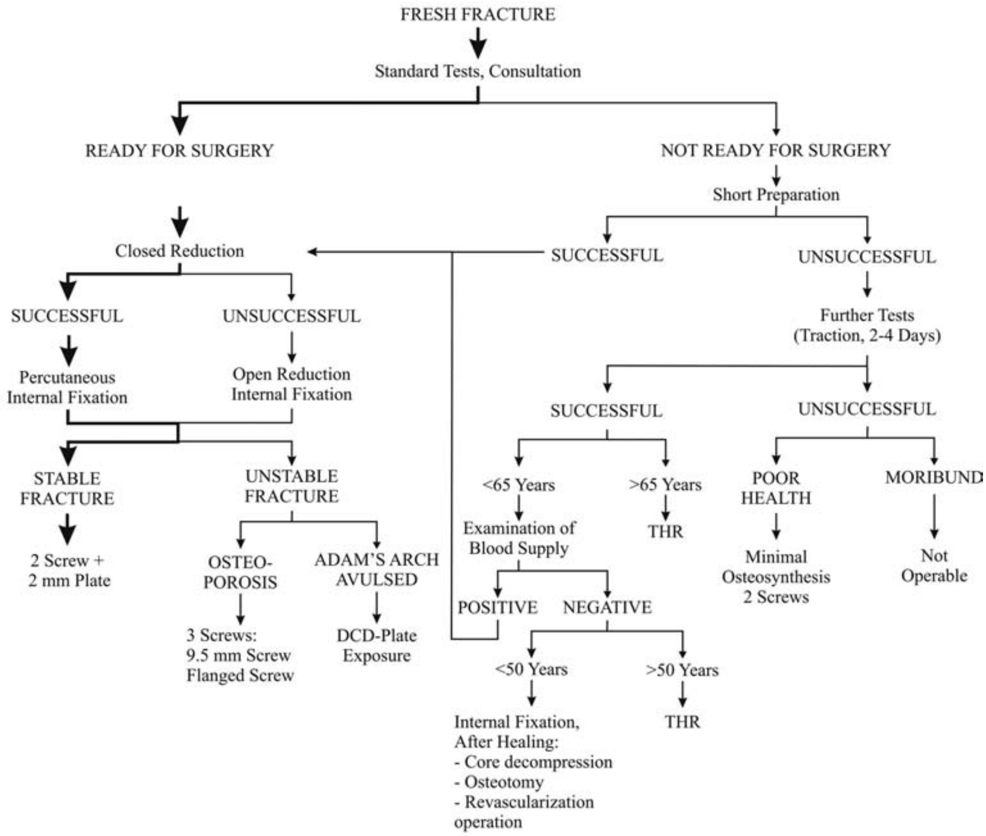
Thigh and leg are positioned on a **Braun splint** that has been prepared by loosely wrapping Ace bandages around it, thus creating a hollow for the calf muscles. It is important to choose the right size of the splint and to prevent a pressure sore at the ischial tuberosity by padding the metal prominences. The splint is fastened to the bed in slight abduction (20º). The direction of traction lies in line with the femoral longitudinal axis. Weights are slowly added up to one tenth of the body weight. The foot is fixed in neutral position in the well-padded sling and a slight longitudinal traction is applied. This forestalls any painful rotatory movements. At the foot end of the bed we install a rigid metal plate; the patient can press his unaffected foot against it with the leg extended thus preventing him from sliding down in bed. The foot end of the bed as well as the upper part of the patient's body are slightly raised (about 20º), again to prevent sliding down. At the level of the heel the Ace bandage is cut, the ends rolled up with a tape. This will prevent any pressure on the heel. The position of the fracture is checked by radiographs taken in both planes. It should not show any major displacement. Care must be taken to avoid a marked distraction.

During the daily rounds the traction must be **carefully checked and, if necessary, altered.** The pin is removed in the operating room under anesthesia before internal fixation.

The aim of **the basic preparation** lies foremost in eliminating as much as possible the contraindications diagnosed at the time of admission. This requires a collaboration as soon as possible between internist, anesthetist and surgeon. This time should also be used to take steps that guarantee a later success of surgery: local skin disinfection, treatment of wounds and any pressure sores (epithelization or at least cleansing), search of possible foci of infection (urine culture, examination of teeth, sinuses, ultrasound of abdomen).

Only very serious contraindications should initially preclude fixation with cannulated screws. In their presence even a preparation by an internist is usually unsuccessful. Therefore, **in high-risk patients percutaneous screw fixation is foremost performed to facilitate care and to ease pain.**

Only 18 (5.8%) of the 312 patients admitted in 1990 for neck fractures (in the majority displaced fractures treated in these days with Smith-Petersen nailing) could not be operated initially on account of their poor general health. **Half of these patients died while in hospital, another eight deceased within four months and only one was still living after one year** (Cserháti et al, 1992; Laczkó et al, 1992; Laczkó et al, 1993). Among 596 patients admitted in 1993 and 1994 for femoral neck fractures the general health was so poor in 34 (5.7%) that we were forced to perform an emergency fixation with cannulated screws under local anesthesia or after unsuccessful preparation by an internist a delayed screw fixation with the sole goal to facilitate care. Four of these patients died while still in hospital and another nine within one year. The fate of four patients is unknown **but half of the patients still lived one year later and three of these after three years** (Cserháti et al, 2000; Fekete et al,



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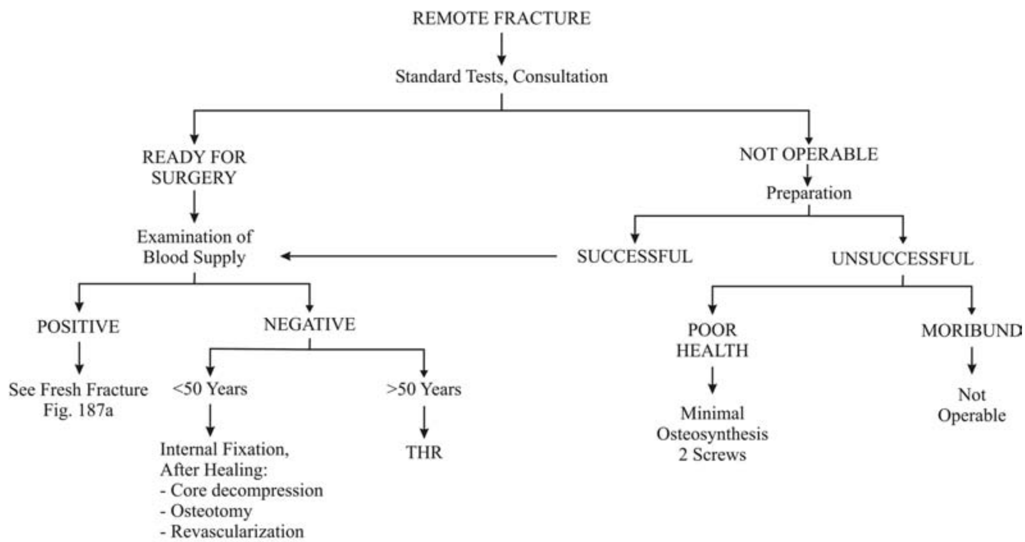

b

Fig. 187. Algorithm for the treatment of displaced neck fractures used at the National Institute of Traumatology (Budapest).
a. In fresh femoral neck fractures. The mostly used (standard) method is marked with bold lines. **b.** In remote femoral neck fractures

2000a; Fekete et al, 2002). These outcomes clearly demonstrate that **minimally invasive procedures are very advantageous** in respect to patient care. The risks taken when performing an internal screw fixation are justified in the light of the high mortality rate in high-risk patients who did not undergo internal fixation.

The justification for this approach is reflected by the fact that in two of the surviving 17 patients we could later perform **successfully an arthroplasty;** this was indicated by a loss of reduction in one and a non-union in the other patient. These two patients were still alive at a three-year follow-up (see Fig. 210e–i).

Repeatedly we made the initially surprising observation that a stabilization of the fracture and thus the elimination of pain in patients who were judged unfit for surgery by the internist on account of hypertension or diabetes led to a **rapid recovery.** This point should not be forgotten when assessing the operability of patients.

8.1.4 Algorithm for the treatment of neck fractures

The clinical management of neck fractures is clearly influenced by many factors. Procedures preserving the femoral head are selected in under 60-year-old patients. The younger the patient, the more this goal should be striven for. If a closed anatomic reduction fails, we open the fracture and use titanium screws. If reduction is delayed, we investigate first the circulation of the femoral head (DS-intraosseous venography, SPECT, MRI). If there is no evidence of drainage from the head (negative result), we consider in 50- to 60-year-old patients a total joint replacement. In the presence of a negative result in patients under 50 years of age we recommend an internal fixation with titanium screws. These patients, however, should be followed-up at shorter intervals. If symptoms are voiced or if necrosis is suspected, revascularization surgery should be done to save the femoral head.

Internal fixation of Garden-I and -II fractures is only urgent in respect to femoral head circulation when the fragments are in a hypervalgus position. In elderly persons the early mobilization is also an important consideration. The standard intervention is the fixation with two screws. We supplement this with a 2 mm plate in instances of severe osteoporosis (patients over 80 years) or if the patient's compliance is questionable (confusion, neurologic diseases, alcoholism) (see Sect. 9.1). Undisplaced fractures are rarely seen in instances of an avulsed but well fitting fragment and in vertical (Pauwels-III) fractures. Both types are unstable and therefore associated with a risk of loss of reduction. Consequently, we recommend here the use of angle-stable DCD plates.

In Fig. 187, we present the **algorithm for treatment of displaced (Garden-III and -IV) fractures** developed by the National Institute of Traumatology (Budapest). A prerequisite is the availability of relevant diagnostic and surgical facilities.

The surgical contraindications for internal fixation are not included in this algorithm. They include:

– Concomitant severe coxofemoral diseases (rheumatoid arthritis, necrosis, coxarthrosis);
– Unsuccessful attempts at reduction and apposition even when open surgery is performed (comminuted fractures, initial, severe rotational displacement).

Indications to achieve an increase in stability are extensively described in chap. 5.

8.2 Implants and instruments for cannulated screw fixation of neck fractures

8.2.1 Implants for cannulated screw fixation

(1) **Material for cannulated screw manufacturing:** stainless steel (Sandvik, ISO 5832-1:1987, Comp D.) or titanium alloy (Ti-6Al-4V, ELI ISO 5832-3:1996).
(2) **Length of screws:** between 7.5 and 14.5 cm in increments of 0.5 cm (Fig. 188).
(3) **Diameter of bore of cannulated screws:** 2.2 mm.
(4) **Diameter of screw shank,** identical for all screws: 7 mm; **thread diameter**: 8 mm (standard) or 9.5 mm.
(5) **Thread lengths:** 18 mm, 24 mm (standard), 34 mm and 44 mm; **Type:** cancellous bone

screw; **pitch:** 120°. The two last threads have **cutting edges. Diameter of shank at threads: 5 mm** (Fig. 189).

(6) **The screw end** is flattened on two opposing sides over a length of 30 mm. At this level the minimal shank diameter amounts to 6 mm.

(7) 5 mm wide and 23 mm long **metric threads** are made in the **bore of the screw end** for attachment of a T-wrench designed for screw insertion and removal. When using a DCD plate the compression screw is inserted here.

(8) **Longitudinal grooves** (depths: 0.5 mm) are made in the screw shank from the end of the threads to the flattened part. They serve for drainage of congested blood that causes a pressure increase in the femoral head.

(9) **Four lateral holes** having a diameter of 1 mm and placed in each quadrant at the level of the next thread are fashioned at the screw tip in the depth of threads to improve the drainage further (see Fig. 57). Therefore when two screws are used, 10 holes (twice four holes at the threads and twice one hole at the tip) as well as six drainage channels (two bores and four grooves) are available for drainage. The lateral openings do not weaken the screw's strength. On one hand they are staggered and on the other hand threads at the screw tip are submitted to lesser loads than threads further down. More than 6000 cannulated screws have been implanted at the National Institute of Traumatology (Budapest). Screw breakage has only been observed three times. All were due to an erroneous treatment of a remote stress fracture.

(10) **Titanium alloy screws** are implanted in younger patients with neck fractures. Their specifications correspond to those of the stainless steel screws (thread diameter 8 and 9.5 mm, thread length 24 mm). Since this material is tissue-friendly, it can remain in the body for longer periods. Their markedly reduced interference with MRI and CT, the possibility to perform imaging for suspected necrosis, is another advantage.

(11) **The surface of the nine threads** of the standard 8 mm screw that faces toward the flattened surfaces of the screw end, amounts for the 8 mm screw to 2.76 cm^2 and for the 9.5 mm screw to 3.84 cm^2 Consequently, the bigger screw has an almost **40% greater holding power in cancellous bone.**

(12) In general, **screws are not removed** in elderly patients after consolidation. However, complications may necessitate such an intervention. If screws do not have reverse-cutting threads, their removal may cause problems in younger persons as the threads cut into the lateral cortex during insertion have been filled in (Fig. 190). Today the **last two threads toward the shank are self-cutting** allowing an easy removal as they act **like a tap during unscrewing.** The cutting flute is in line with the longitudinal groove and is limited to the two threads. Therefore it does not weaken the screw (Fig. 191).

(13) **The plates used for anchorage of one, two or three cannulated screws** are depicted in Fig. 135b and c. They are fixed to the femoral shaft with **standard cortical screws.**

(14) **The flanged screw** (having one longitudinal slot into which a plate is advanced) is supplied in length varying between 70 and 120 mm in 5 mm increments (see Fig. 133).

(15) **The slotted screw** depicted in Fig. 161 comes in the same specifications as standard screws.

(16) **The DCD plates** and the cranial angle-stable

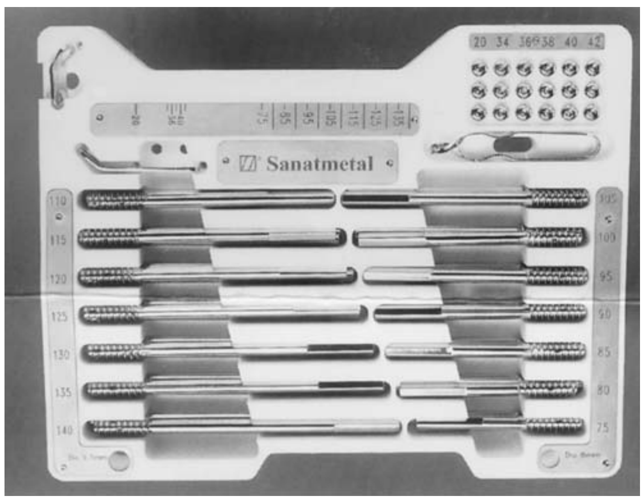

Fig. 188. Standard set of cannulated screws.

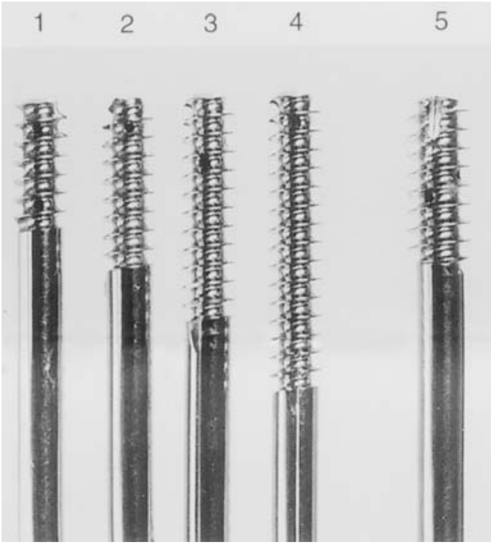

Fig. 189. Series of screws with different thread lengths and various thread diameters.
Thread length: 1: 18 mm, 2. and 5: 24 mm (standard), 3: 34 mm, 4: 44 mm, Thread diameter: 1 to 4: 8 mm, 5: 9.5 mm

Fig. 190. Deformation of a cannulated screw during removal.
In a young patient this titanium screw not having back-cutting threads was removed 18 months after surgery. The deformation of the screw shank testifies to the difficulties during screw removal

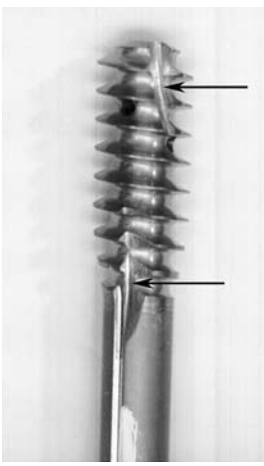

Fig. 191. Forward- and back-cutting threads.
9.5 mm titanium screw. The two threads at the tip are forward-cutting and the two threads next to the shank are back-cutting (arrows)


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b


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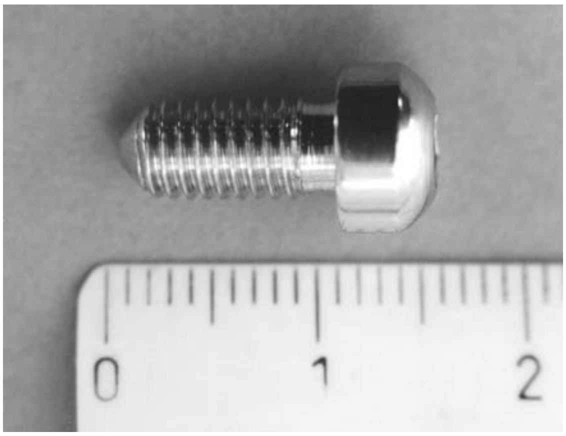
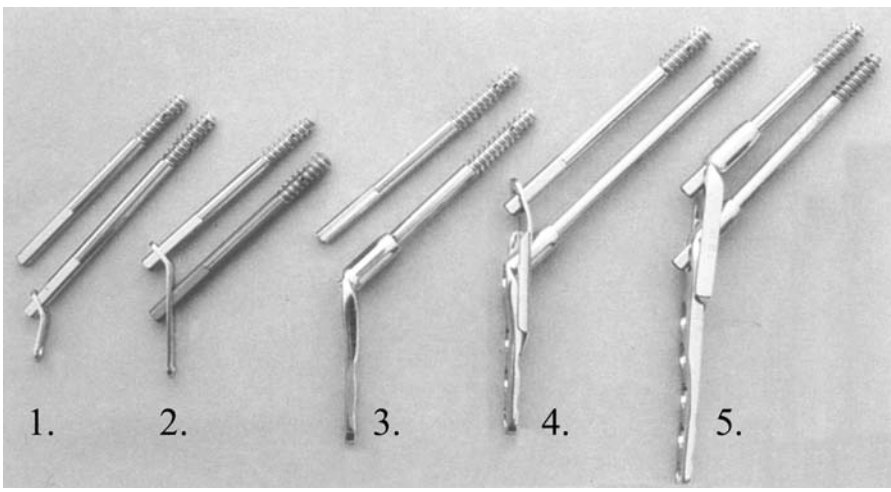


d

Fig. 192. DCD plates and compression screws.
a. 140° DCD plate for attachment with three cortical screws;
b. 140° DCD plate supplemented by a satellite plate that protects the cranial screw against tilting and rotation;
c. 140° double DCD plate;
d. 15 mm long cannulated compression screw;
e. Various designs to increase stability: 1. double screw fixation with 2 mm two-hole plate, 2. double screw fixation with a 2 mm three-hole plate, 3. DCD plate with a second cannulated screw, 4. DCD plate with satellite plate, 5. angle-stable double DCD plate;
f. Schematic section through a DCD plate. The flattened hole to prevent rotation is situated close to the angle of the plate



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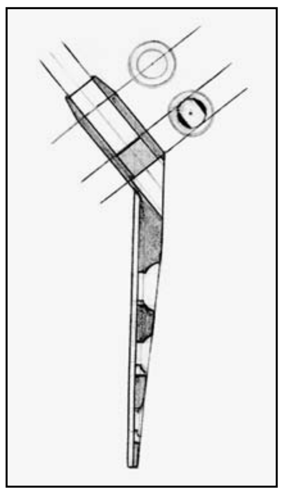
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connecting plates for attachment to the cranial screw are available in three angles **(120º, 130º and 140º)** and in two lengths, **as a 3-hole and a 5-hole version** (Fig. 192a, c and e). **The satellite plate** is only needed in one size (Fig. 192b). The undersurface of the DCD plate is designed for limited contact similar to the LC plate. The hole in the **plate barrel has two flat sides to safeguard against rotation.** It is situated close to the angle of the DCD plate – contrary to the DHS – and measures 5 mm in length (Fig. 192f). The **compression screw** is available in two lengths, 15 and 28 mm (Fig. 192d). Tightening of the screw will result in a compression of the fracture surfaces, similar to the DHS. This screw prevents the rare cranial migration of the cannulated screw.

8.2.2 Instruments for cannulated screw fixation

Besides a **standard bone set** three larger sets of **special instruments** are needed:

(1) **Long instruments** for standard percutaneous insertion;
(2) **Sleeves and guides** for protection of soft tissues;
(3) Instruments **needed for implants that increase stability.**

The long instruments as well as the sleeves and guides form part of the **standard set** (Fig. 193). On top of this set a Teflon plate can be placed that contains the **standard set** of cannulated 8 mm and 9.5 mm screws and the 4.5 mm cortical screws (see Fig. 188).

Instruments needed for use of implants designed to increase the stability are **packaged separately.**

(ad 1) Long instruments for the standard percutaneous insertion

(1) Spiral drill bit, length 300 mm, ∅ 3.2 mm;
(2) Kirschner wire, length 250 mm, ∅ 2.0 mm;
(3) Cannulated step drill bit, length 250 and 300 mm, ∅ 7/5 mm;
(4) Cannulated tap, length 300 mm, thread ∅ 8 mm and 9.5 mm;
(5) Tap for cortical screws, length 250 mm, ∅ 4.5 mm;
(6) Handle for quick release chuck for tap;
(7) Long T-wrench, ∅ 10 mm, and screw holder for cannulated screws.;
(8) Cannulated depth gauge, ∅ 7 mm, for cannulated screws;
(9) Depth gauge for cortical screws;
(10) Screw driver for cortical screws (Fig. 194).

(ad 2) Sleeves and guides

(1) Sleeve with handle, ∅ 10 mm. The end toward the femur is beveled and has two spikes for a better hold on bone;
(2) Parallel guide, ∅ 10 mm. Two holes cranially to ensure placement of screws at a distance of 14 or 18 mm;
(3) Template for plate seating with handle and threaded hole for fixation of 2 mm plate and 3.2 mm drill guide (blue marking) for centering of drill bit through the plate hole;
(4) 10/7 mm guides and 7/3.2 mm as well as 7/2 mm drill guides (red marking) for spiral and step drill bits. Also for insertion of guide wire;
(5) 10/8 guide for 8 mm tap (no marking) (Fig. 195).

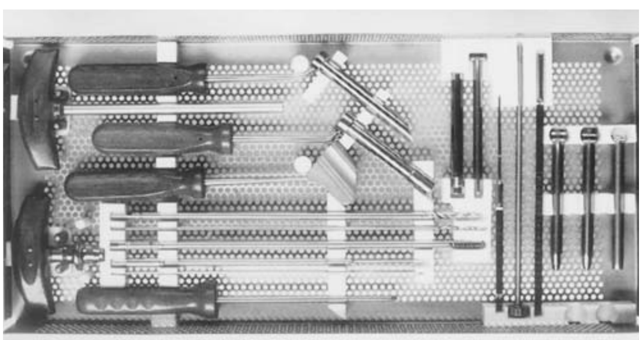


Fig. 193. Standard instrument set (Fekete et al, 2000b; Fekete et al, 2000c).

(ad 3) Instruments needed for implants that increase stability

(1) New parallel guide for insertion of **three screws** (see Sect. 5.7, point 2) (see Fig. 163);
(2) Special parallel guide for **DCD plates and attachment plates,** with small wedges having angles of 120º, 130º and 140º (Fig. 196a);
(3) **Crown drill bit** to create bed for barrel of DCD plate (Fig. 196b, c);
(4) **Cannulated adapter** to correct diastasis (see Fig. 159);
(5) Handle for quick release chuck with the **290 mm extension (∅ 8 mm)** with the corresponding **screw holder** for insertion of the slotted screw (see Sect. 5.7 point 1. and Fig. 161);
(6) **Stepped chisel and driver** for flanged screw (see Sect. 5.7 point 9. and Fig. 133).

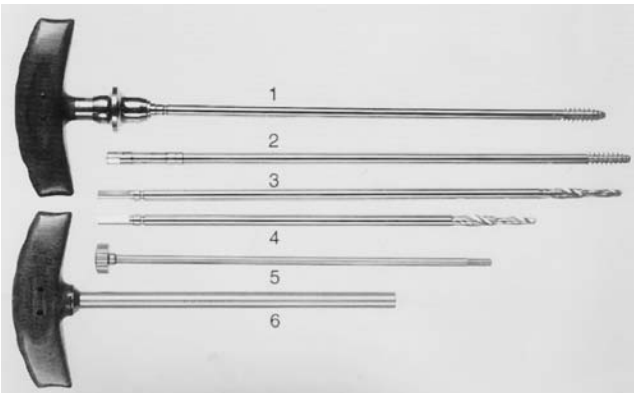


Fig. 194. The most important instruments (Fekete et al, 2002b; Fekete et al, 2002c).
(1) Handle attached to tap 9.5 mm;
(2) Tap 8 mm;
(3) Step drill bit 300 mm;
(4) Step drill bit 250 mm;
(5) Screw holder for long T-wrench;
(6) Long T-wrench

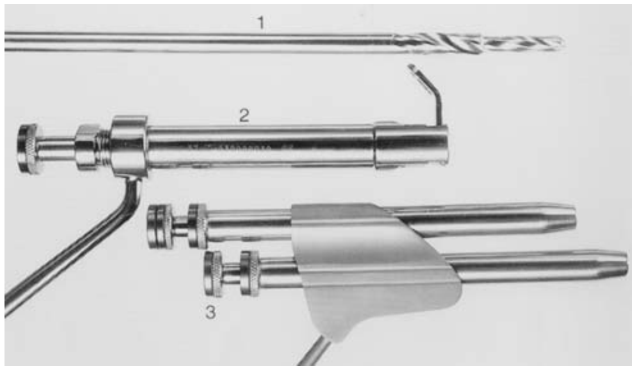
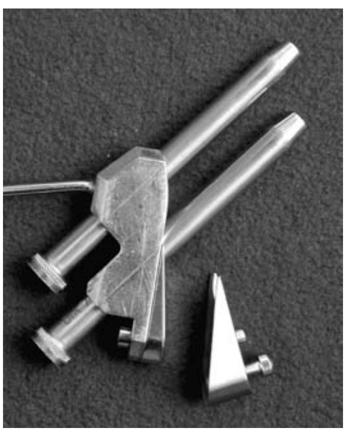


Fig. 195. Step drill bit, and instruments for soft tissue protection (Fekete et al, 2000b; Fekete et al, 2000c).
(1) Step drill bit;
(2) Plate seating instrument with 2 mm two-hole hole-plate and the 3.2 mm drill guide;
(3) Parallel guide with inserted 10/7 guides and drill guide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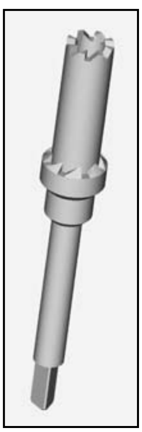
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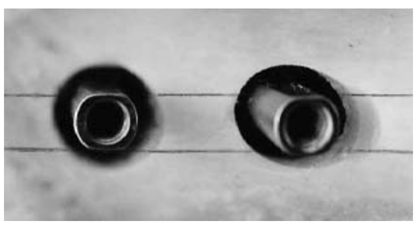
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Fig. 196. Special parallel guide and crown drill bit for DCD plates.
a. 140° special parallel guide with 10 and 20° wedges to obtain 120 and 130° angles. **b.** Crown drill bit for the preparation of the barrel of DCD plate; **c.** Preparation for the positioning of the double DCD plate with a crown drill bit. Both screw ends are orientated with the help of two parallel sleeves (Fig. 167c)

8.3 Technique of percutaneous screw fixation of neck fractures

8.3.1 Introduction

The great **advantage of this method** for the patient consists of the precise percutaneous insertion of screws through a small stab incision. Furthermore, thanks to the long instruments the surgeon is not forced to put his hands into the x-ray beam. A **disadvantage,** however, is the fact that the screws' positioning cannot be followed directly, it is only seen on the monitor and by the position of the instruments.

The percutaneous fixation of the femoral neck with cannulated screws differs markedly from techniques of other closed interventions in trauma surgery (fixation with Kirschner wires of proximal humerus and wrist fractures, external fixation of leg fractures). For hip fractures the **approach to bone must go through a much thicker soft tissue mantle with longer and stronger instruments.** Besides, some instruments are equipped with threads or have a drill bit at their tip. Without protection the tissue can wrap around the instruments and thus cause a damage that can only be appreciated with difficulties in the small wound.

Both, the need for less personnel and their lesser exposure to stress can turn out to be a **disadvantage** of the technique. The surgeon operates alone, often at night and he may be less experienced. This exposes him to errors that may lead to mistakes of a mechanical nature (perforation, loss of reduction). The prolonged operating time and the increased trauma to tissues may lead to hematomas and infection. These risks can be considerably decreased when using a correctly positioned C-arm.

Nevertheless, in a small percentage of cases an **exposure of bone will become necessary,** be it for an increase of stability, for insertion of bigger and more numerous implants or for other technical causes becoming evident during surgery. If persisting with a percutaneous approach under these circumstances, the tissue trauma will be greater with well-known consequences such as hematomas and infections. A more extensive opening with meticulous respect for soft tissues and careful hemostasis would be preferable.

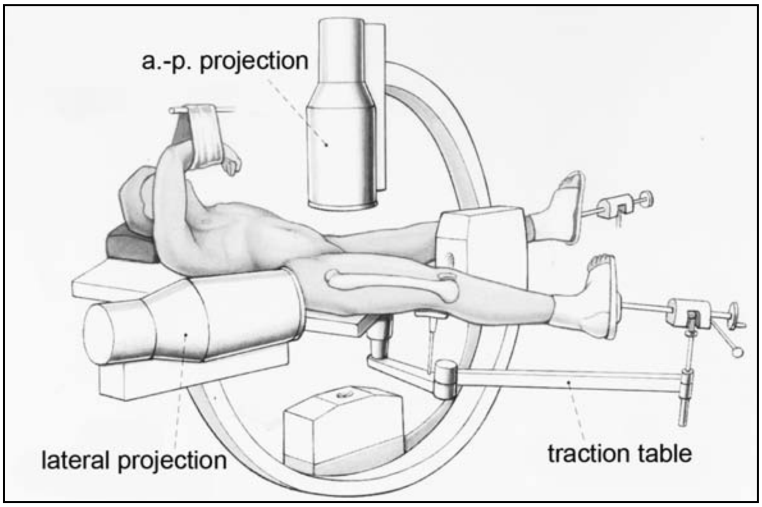
8.3.2 Technique of percutaneous screw fixation

8.3.2.1 Positioning, disinfection, sterile draping

With the patient supine the unaffected limb is fixed in the foot holder. The injured leg will only be fixed after reduction. For countertraction a radiolucent well-padded perineal post is positioned between the legs avoiding any pressure against the genitalia or the urinary catheter. The pelvis must be in a horizontal position; if necessary, it must be supported by a kidney rest on the opposite side. The arm of the unaffected side is placed on an armboard whereas the arm of the affected side in a sling suspended over the patient's head with the shoulder in 90º of forward flexion in the elbow in 90º of flexion. In this way the arm will not be in the way of the laterally placed C-arm (Fig. 197).

Both image intensifiers (a.-p. and lateral) must be exactly aligned and **not be moved thereafter any more.** In morbidly obese patients the overhanging abdomen is pulled cranially and taped in this position using broad strips of an adhesive. No object possibly interfering with the quality of imaging (textiles, catheter) should lay in the way of the X-ray beam. The manual reduction is done as already outlined. The foot is then placed in the foot holder.

After **disinfection sterile draping** is done either with textile or one-way drapes placed over a frame mounted parallel to the patient's body and overlying the surgical field also fixed to the image intensifier being used for sagittal viewing. Adhesive transparent sheets (Opsite®) are glued over the surgical site. The entire injured limb should be covered to allow the circulating nurse possible corrections during surgery under the sterile drapes without risking any contamination. For percutaneous screw fixation a surgical site measuring 15 x 10 cm on the lateral side of the thigh is sufficient. The drapes surrounding this area are sutured at the corners and edges or held together with adhesive strips. We let the drapes sag between the a.-p. image intensifier and the anterior aspect of the thigh to ensure an unimpeded aiming.



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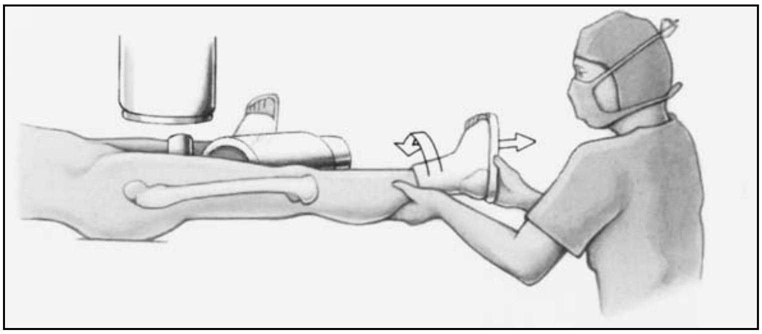

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Fig. 197. Positioning and reduction.
a. Positioning for internal fixation of neck fractures. **b.** Manual reduction (Fekete et al, 2000b; Fekete et al, 2000c)

8.3.2.2 Determination of the site of skin incision and placement of drill channels

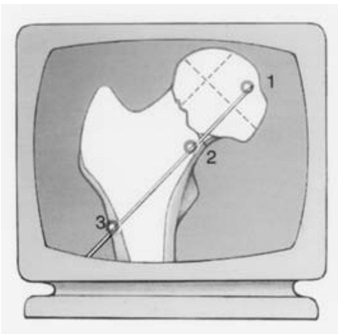
For the percutaneous technique two 2–3 cm stab incisions or one 4–5 cm **skin incision** is sufficient. The site of incision must be **carefully determined** before surgery. A later correction of a wrongly placed incision is not only cosmetically displeasing, it also traumatizes the soft tissues due to forceful manipulations. Given the different sizes of patients and the different thickness of their soft tissues as well as possible anatomic variants of the femoral neck (coxa valga or vara) the correct marking of the incision once the drapes are in place is often difficult. To facilitate the proper placement we have devised the following method that is based on imaging in both projections.

We determine in the a.-p. projection the third buttressing point and at the same time the level of the skin incision at the lateral aspect of the thigh. A **Kirschner wire** is placed in the area where the drapes are sagging over the **anterior aspect of the femoral neck.** The tip of the wire should project over the caudal third of the femoral head (1st point) and its mid-portion over the inner border of the cortex at Adam's arch (2nd point). The site where the wire crosses the outer border of the lateral femoral cortex corresponds to the third buttressing point and thus to the level of the drill hole (Fig. 198a). This approach is called retrograde. The **center of the skin incision** will lie at the level where the wire crosses the skin (Fig. 198c, d). To accommodate the rather big soft tissue sleeves and the guides the incision must be extended proximally and distally once its exact site has been determined by viewing in the lateral projection. For less experienced surgeons we propose to glue after reduction a **Kirschner wire on the monitor**

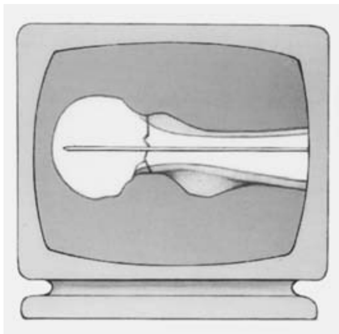
overlying the wire seen on the monitor; this latter wire lies in line with the three buttressing points. On the condition that thereafter the C-arm is not moved anymore, one can follow the outline of the wire on the monitor during drilling of the first guide wire.

For the exact wire positioning **the lateral view** is of cardinal importance. In the lateral projection a Kirschner wire is placed on the lateral aspect of the thigh. It must project over the midportion of the axes of femoral diaphysis, neck and head. The site where the wire glued on the monitor and the wire placed on the skin as seen in the lateral projection cross, determines the line of the skin incision and the entry point of the guide wire (Fig. 198b, d).

After the skin incision the fascia lata and fascia of the vastus lateralis are split in a more cranial direction. An oblique soft tissue channel is created bluntly between the fibers of vastus lateralis with a small periosteal elevator for insertion of the soft tissue sleeve.



a



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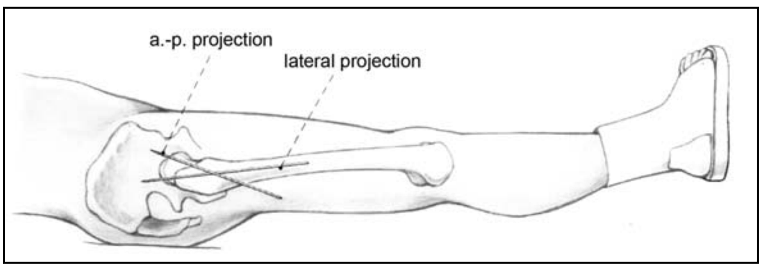
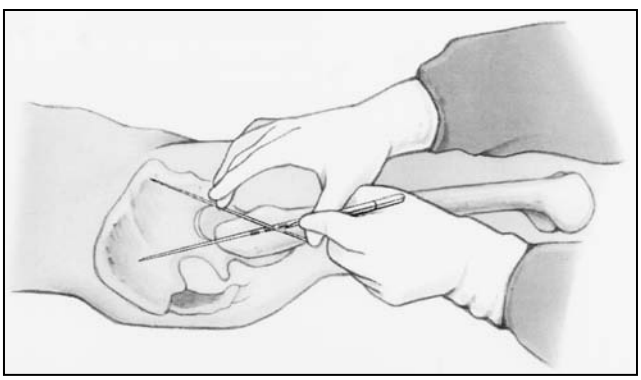


c



d

Fig. 198. Retrograde determination of level of skin incision and drill entry point at the lateral cortex based on the three buttressing points (Fekete et al, 2000b; Fekete et al, 2000c).
a. A Kirschner wire is placed on the skin in such a way that its projection in the p.-a. imaging overlies the 1st and 2nd buttressing points and thus points in a retrograde way to the site of insertion of the drill bit on the lateral cortex (third buttressing point); **b.** A Kirschner wire put on the lateral aspect of the thigh shows the level of drilling in the lateral view; **c, d.** The projection of the anterior wire shows the midpoint of the incision on the lateral aspect on the thigh; the lateral wire shows the line of incision

8.3.2.3 Steps of the surgical technique

(1) The key for a properly executed internal fixation is the **placement of the first, caudal guide wire.** A 10 mm soft tissue sleeve with handle and inserted 7 mm guide marked in red and a 3.2 mm drill guide is advanced through the soft tissue channel to the predetermined point on the lateral cortex. The beveled end of the sleeve must lie parallel to the bone's surface. Its proper positioning is checked by image intensification in both planes. The entry point into bone should generally lie **1–1.5 cm distal to the tip of the lesser trochanter** as seen in the a.-p. projection. In the lateral projection the tip of the drill guide should be seen **slightly anterior** to the midline of the femur. If neck and diaphysis are not lying in a horizontal plane but form after reduction an anterior angle, the entry point of the drill bit **must absolutely lie more anterior** to achieve placement of the drill bit in the center of the neck. The drill bit must lie in the gutter between Adam's arch and calcar femorale but avoid the calcar (see Figs. 11 and 136).

The soft tissue sleeve finds a hold on the femoral cortex thanks to two prongs. A **3.2 mm spiral drill bit 300 mm in length is advanced through the drill guide and prepares the channel for the guide wire.** Predrilling is necessary as the thin guide wire with its trocar point cannot cross the hard lateral cortex and may be deviated from its direction by the strong trabeculae of the neck. The angle of drilling must be rather steep, in fact steeper than the caput-collum-diaphyseal angle (130º). We choose a 140º angle. It is therefore advisable to exert only a slight pressure on the drill at the beginning of drilling as otherwise the drill bit may slip on the convex surface. If the cortex is very hard, we recommend to start drilling perpendicular to the bony surface and only then angle the drill. Once the cortex has been traversed, the drill bit is advanced along Adam's arch and then **stops 1 cm short of the head contour.** The guide wire finds later a good hold in that part of the head that has not been drilled. To avoid excessive temperatures the revolution of the drill should be low (Fig. 199).

Even with a 3.2 mm drill bit it is sometimes difficult to avoid deflection caused by the trabeculae. In such instance it is advisable to advance drilling in the desired direction at a lower speed and with less manual pressure. It is important to cross the lateral cortex at the right point that is defined by the intersection of a line established by the three buttressing points with the lateral cortex. The **3.2 mm drill bit may break or bend,** if an attempt is made to correct the direction at a later moment. If a change in direction becomes necessary, we recommend to withdraw the drill bit slowly and to advance carefully the drill bit at low speed without force. Then drilling should be carefully continued.

Having confirmed the desired position of the drill channel, the drill bit is removed and without changing the position of the soft tissue sleeve the 3.2 mm drill guide is removed and replaced by a 2 mm guide (red marking). The 250 mm **guide wire**

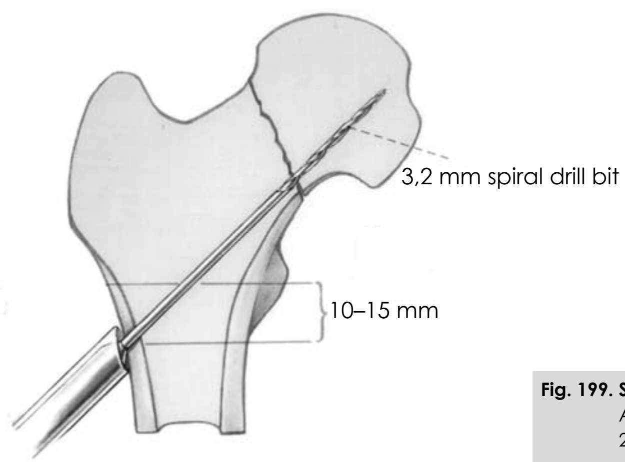


Fig. 199. Surgical technique (1).
Advancing the spiral drill bit into the femoral head (Fekete et al, 2000b; Fekete et al, 2000c)

having a trocar tip is now driven up to the bone-cartilage junction of the femoral head with light hammer blows.

After removal of the 2 mm drill guide the 10/7 mm guide for the **cannulated depth gauge** is inserted over the guide wire and advanced to the lateral cortex. The length of the cannulated screw is determined by subtracting the measured length of the wire projecting from the lateral cortex from the entire length of the wire. The indication on the depth gauge adds 5 mm to the actual distance between lateral cortex and femoral head contour. This addition is necessary to prevent a too early abutment of the screw driver on the lateral femoral cortex during screw insertion. In its absence the screw would not reach the desired subchondral position. If attachment to a standard 2 mm two-hole plate is planned, an **additional 5 mm must be added** to the standard method to select the proper screw length.

(2) A cannulated **250 mm long 7/5 step drill bit** is inserted through the 10/7 mm guide over the guide wire. Using a low revolution the lateral cortex is first perforated. Drilling is then continued along Adam's arch up the fracture (Fig. 200).

When advancing the drill bit the guide wire must be carefully observed. If the drill bit does not exactly follow the guide wire, it may bend the wire or push it into the joint. It happens not infrequently that the wire jams inside the drill bit and that upon withdrawal both come out together. **In case one observes an advancement of the wire together with the drill bit or a kinking of the wire, the step drill bit must be withdrawn immediately and redirected!** If the drill bit gets stuck in bone, one should move it back and forth carefully and avoid any increased pressure or higher revolution as this may cause a thermal damage and/or displace the reduced femoral head!

(3) **The position of the second – cranial – guide wire** is determined with the parallel guide. First the soft tissue guide with its handle is removed and the **parallel guide** with the 10/7 mm guide (red marking) inserted into the caudal hole of the parallel guide over the step drill bit and **advanced up to the skin.** In general we choose a hole distance of 18 mm. The second 10/7 mm guide with the already inserted 3.2 mm drill guide is inserted into the proximal hole of the parallel drill guide and advanced to the femoral cortex. When using the standard technique the **cranial drill hole is placed in the center of the femoral neck.** The 3.2 mm spiral drill bit preparing the channel for the guide wire is drilled up to 1 cm from the head contour (Fig. 201).

If screw placement is done through one skin incision, it has to be extended to allow advancement of the cranial drill guide to the lateral cortex. If two skin incisions are used, the tip of the drill guide must lie in the center of the cranial incision and its axis in the direction of the second soft tissue channel.

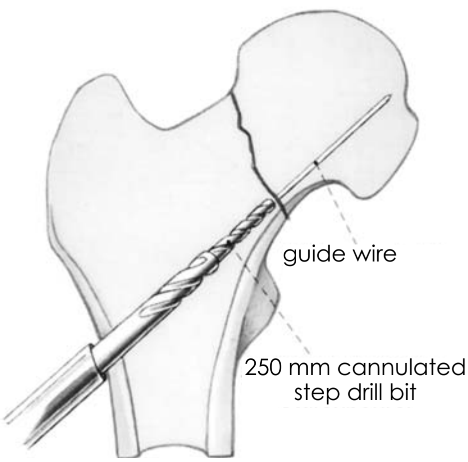


Fig. 200. Surgical technique (2).
Advancing the step drill bit caudal up to the fracture line (Fekete et al, 2000b; Fekete et al, 2000c)

A closer placement of screws, that is achieved with a parallel guide having a distance of 14 mm, becomes rarely necessary except in short persons with small bones.

(4) After exchange of the drill guides the **second, cranial 250 mm long 2 mm guide wire** is advanced with light hammer blows to the bone-cartilage junction (Fig. 202).

The 2 mm drill guide is removed and the cannulated depth gauge is inserted up to the lateral cortex. The **measured length** for the cranial screw is always equal to the length of the wire projecting from the lateral cortex. Then the second 300 mm **step drill bit** is carefully drilled **up to 5 mm from the head contour** (Fig. 203).

Cranially we use a longer step drill bit to avoid contact of the chuck with the previously caudal drill bit that has been advanced to the fracture site. When dealing with vertical fractures (Pauwels-III) and very hard bone, the pressure exerted on the drill should be carefully applied as the force transmitted by the massive instrument may displace the femoral head!

While leaving the second, cranial step drill bit in place, we now **prepare the bed for the caudal screw** without risking a displacement of the femoral head. When dealing with **fractures in hypervalgus** or with vertical fractures (Pauwels-III) a risk of loss of reduction exists. Therefore we prefer to **insert the cranial screw first!**

(5) **The chuck is now mounted on the** caudal step drill bit and the bit advanced **to 5 mm from the head contour.** Thereafter it is removed together with the 10/7 mm guide (red marking). The **cannulated 8 mm tap** inserted through the 10/8 mm guide (no marking) and coupled to the handle is **advanced manually up to 5 mm of the head contour** (Fig. 204).

(6) After removal of the tap the parallel guide is exchanged for the 10 mm soft tissue sleeve with handle. The cannulated screw held with the screw holder mounted on the long T-wrench (see Fig. 194) is advanced to the bone cartilage junction of the head (Fig. 205).

If a slotted screw will be used, the parallel guide is not replaced by the soft tissue sleeve. **In this instance the 6th step is not performed.** The screw is coupled to the handle with the **290 mm extension rod** (∅ 8 mm) and the longer screw holder. The screw can be advanced to the head contour through the parallel guide (see Figs.

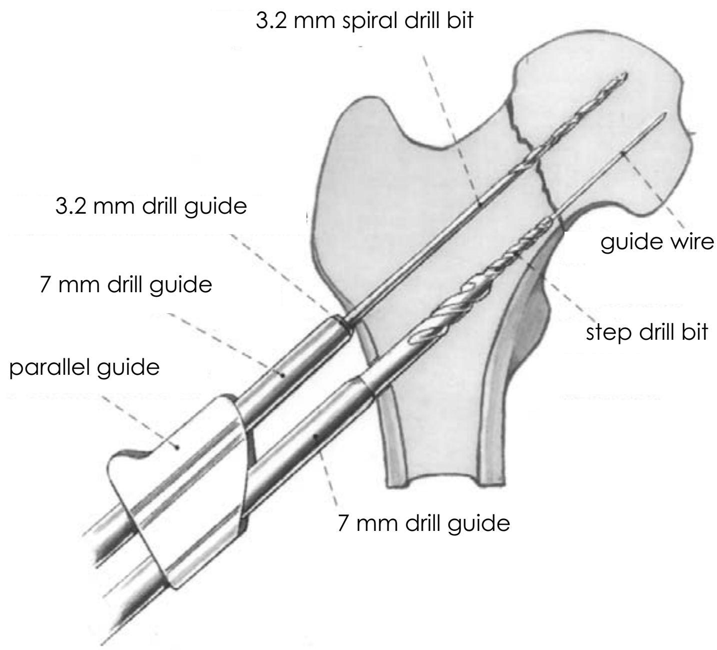


Fig. 201. Surgical technique (3).
Predrilling for the cranial screw through the parallel guide (Fekete et al, 2000b; Fekete et al, 2000c)

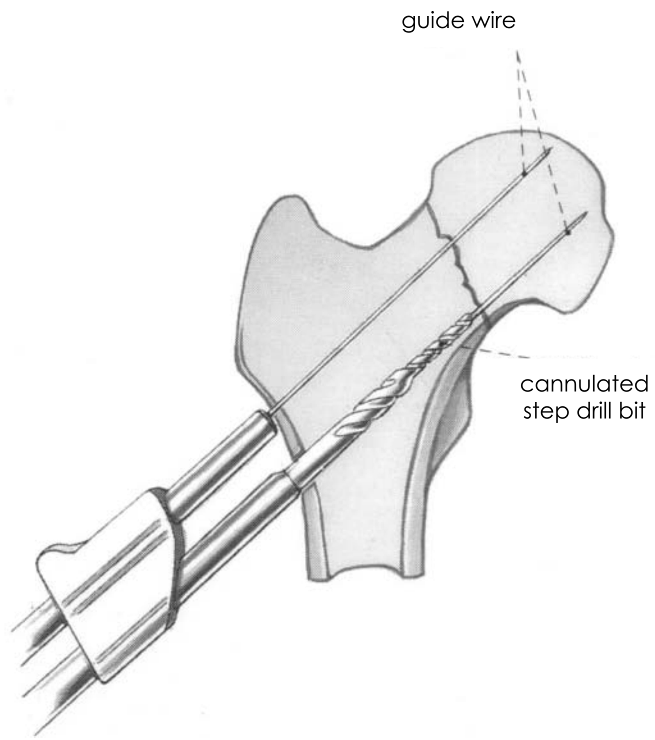


Fig. 202. Surgical technique (4a).
Advancing the second guide wire (Fekete et al, 2000b; Fekete et al, 2000c)

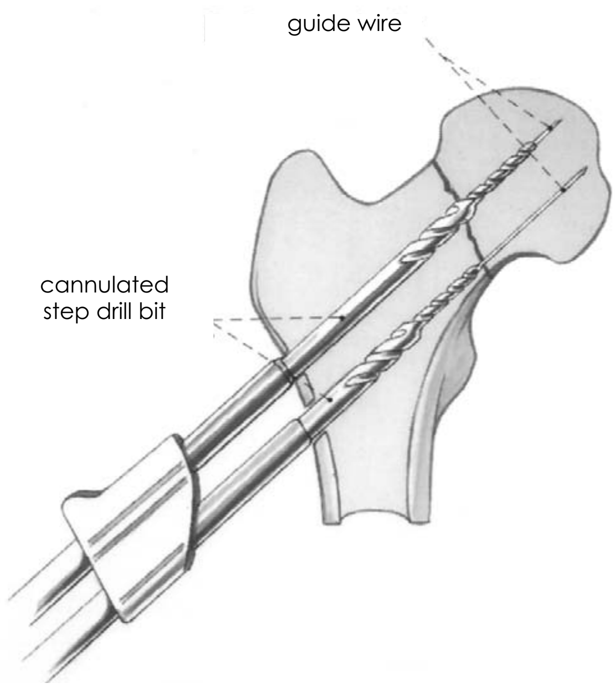


Fig. 203. Surgical technique (4b).
Advancing the cranial step drill bit into the femoral head (Fekete et al, 2000b; Fekete et al, 2000c)

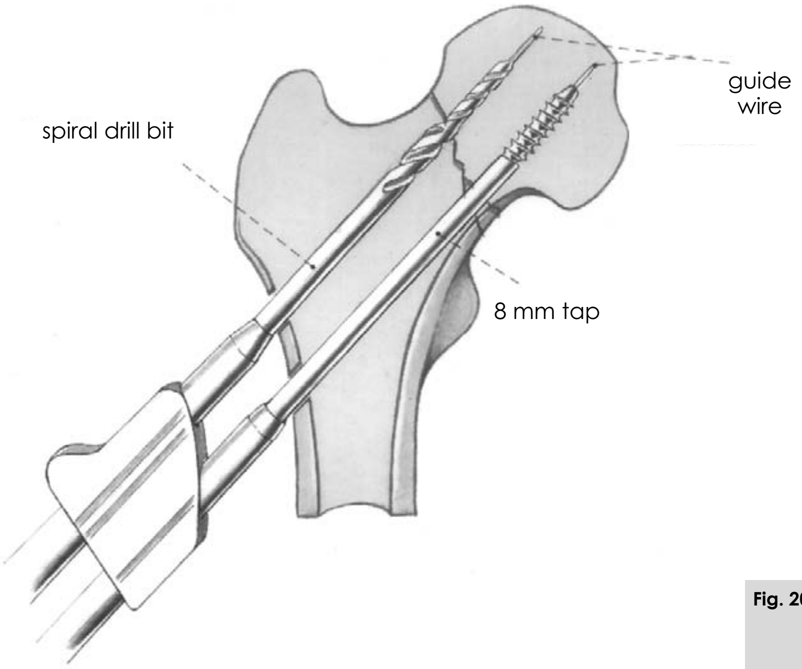


Fig. 204. Surgical technique (5).
Caudal tapping (Fekete et al, 2000b; Fekete et al, 2000c)

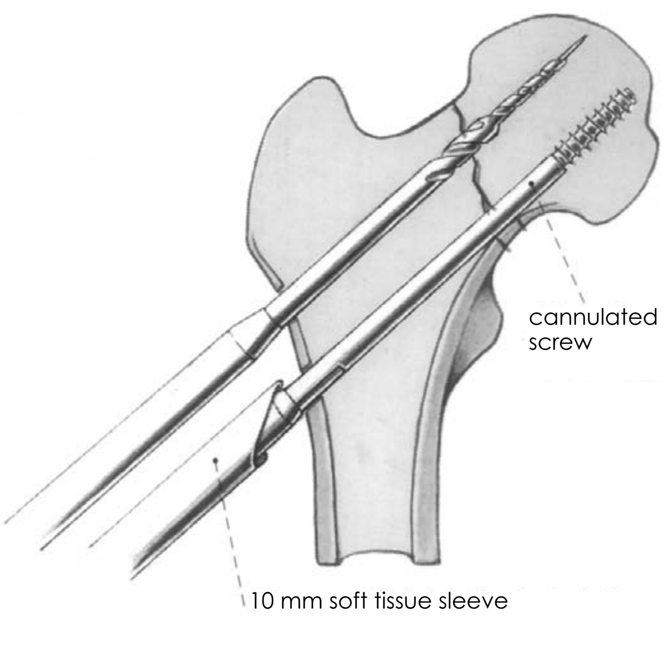


Fig. 205. Surgical technique (6).
Insertion of the caudal screw (Fekete et al, 2000b; Fekete et al, 2000c)

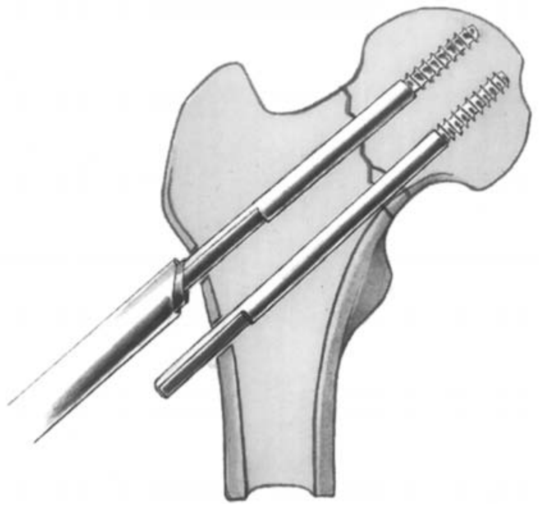


Fig. 206. Surgical technique (7).
Insertion of the cranial screw (Fekete et al, 2000b; Fekete et al, 2000c)

161 and 162). This means not only a simplification of the surgical technique and a better soft tissue protection (less movement of instruments in the wound) but also an improvement of the quality of internal fixation thanks to a better parallel guidance of screws. When using a slotted screw in younger patient tapping must always be done as otherwise the flute of the extension rod may be overloaded. The parallel guide remains in place until both cannulated screws have been inserted. It is only removed prior to application of the standard 2 mm two-hole plate.

A continuous light pressure should be exerted on the **T-wrench or handle** during each turn! At the end of screw insertion the T-wrench or the handle must lie horizontal, that is parallel to the femoral diaphysis. On one hand, it allows an optimal contact (buttressing) between the cranial and caudal surfaces of the drill holes in the lateral cortex and the convex quarters of the flattened screw shank. On the other hand, a tension-free apposition of the small standard 2 mm two-hole plate can only be obtained with this position.

(7) Through the soft tissue sleeve with the attached handle and the 10/7 mm guide the cranial step drill bit will be removed and the 10/8 mm guide inserted. Also **cranially the tap** coupled to the handle is advanced through the 10/8 mm guide. This step can be omitted in elderly patients with porotic bone. After removal of the tap and the 10/8 mm guide **the cranial screw is inserted** up to the bone-cartilage junction (Fig. 206). The handle of the long T-wrench must also lie parallel to the femoral diaphysis.

At this point the position of the screws are controlled and, if necessary, corrected. Both image intensifiers are centered on the femoral head. By internal and external rotation of the foot holder done by the circulating nurse we verify the subchondral position of the screws and that no perforation of the head cortex has taken place. If a slight diastasis of the fracture is visible, it can be corrected after removal of the longitudinal traction exerted on the foot holder and removal of the parallel guide **with slight blows on the lateral cortex with the adapter** inserted over the guide wire and screw.

(8) After removal of the soft tissue sleeve and the guide wires **the plate seating instrument** (see Fig. 195.2) **with the attached standard 2 mm two-hole plate** is inserted perpendicular to the bone over the end of the caudal cannulated screw by sliding it a bit proximal. The 3.2 mm drill guide (blue marking) is inserted in the seating instrument; the tip of the drill guide should be in the middle of the caudal hole of the two-hole plate. With a 300 mm long 3.2 mm spiral drill bit the distal hole for the cortical screw is made. During this process

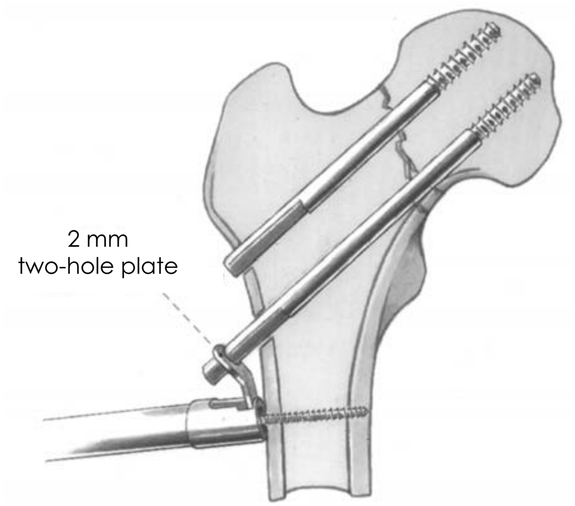


Fig. 207. Surgical technique (8).
Fixation of a 2 mm two-hole plate with the help of a seating instrument for plates (Fekete et al, 2000b; Fekete et al, 2000c)

the two-hole plate is pressed slightly against the femur and the seating instrument held cranially. Care must be taken that the plate does not jam the end of the cannulated screw. Drill bit and drill guide are now removed. **The depth gauge for the cortical screw** determines the length of the screw and its **exact length** is read on the gradation at the level of the seating instrument.

After tapping a 4.5 mm cortical screw is inserted. Alternatively, self-cutting screws may be used. Before tightening the cortical screw we loosen the attachment of the seating instrument and allow the plate to slide distally. The seating instrument is then removed and the screw tightened (Fig. 207).

If necessary, the 140° angle of the 2 mm two-hole plate can be changed using flat-nosed pliers. This allows a shorter screw to be employed in a slim patient. To avoid a jamming of the cannulated screw in the corresponding hole of the 2 mm two-hole plate the **angled portion of the plate must be oriented approximately perpendicular to the longitudinal axis of the cannulated screw.**

On each side of the screw ends we insert one **suction drain** (Ch 14). This is important as the modified cannulated screw drains the blood from the femoral head. In its absence, the danger of a subfascial hematoma exists. Suture with resorbable 0-threads. After skin suture adhesive dressing is applied. We do not use a compression dressing at the thigh as this may lead to venous stasis.

8.3.3 Frequent technical errors and ways to avoid them

Errors in reduction have been described in Sect. 7.5. In this section we only discuss problems arising during internal fixation. Our recommendations are based on our experiences and errors made while executing this technique.

- **Incorrectly placed incision.** Causes: shifting of soft tissues due to forced internal rotation or padding under the thigh; omission of marking the incision site before surgery.
  Solution: Extension of incision; if needed, new approach.
- **Breakage of the 3.2 mm spiral drill bit.** The broken bit must be removed as it can interfere with screw placement.
  Solution: the hole in the cortex is enlarged with the step drill bit at the site of the planned screw insertion. The broken bit can be reached through the 7 mm drill channel and extracted with the help of a straight mosquito forceps.
- **Problems with the 7 mm step drill bit.** Jamming, perforation of Adam's arch or femoral head (possibly also of acetabulum). If drilling reaches the fovea, the circulation in the femoral head may be at risk secondary to injury of the vessels in the round ligament. A much greater danger is screw migration in the drill channel with migration into the joint or little pelvis.

Solution: if the problem is detected in time, replace screw with a **9.5 mm screw.**

- **Inadequate soft tissue protection.** If the step drill bit, but more so, the tap or the screw are inserted without a soft tissue sleeve, fascia, muscle or vessels may stop any advancement, get wrapped around the instrument/implant or avulse. The result is severe tissue damage, defects or bleeding possibly followed by wound healing complications such as hematoma, necrosis of fascia and infection.
- **Incorrect screw placement:**
  - **Screws not aligned in a parallel fashion:** If convergence or divergence is pronounced, the screws may block any settling (adaptation), a prerequisite for bony consolidation. Diastasis or non-union may be the consequence.
  - **The caudal screw does not rest on Adam's arch or breaks the calcar:** risk of loss of reduction accompanied by severe varus or posterior tilting.
  - **The screws lie anterior or posterior** when viewed in the lateral projection or in the **cranial third of the femoral head** when viewed in the a.-p. projection: increased risk of loss of reduction or cutting-out of the screw.
  - **Exaggerated valgus or varus position of screws:** the varus position is dangerous as it may lead to an increase in varus tilting and thus to a loss of reduction.
  - **The distance between the screws is either too great or too small.** A smaller distance reduces the stability in rotation and thus may cause a loss of reduction. A too great distance may result in a placement of the cranial screw in the cranial third of the head and consequently damage the supplying blood vessels.

    Solution: in all instances the position of the screw must be corrected during the same sitting except in cases where the correction may lead to a severe loss of cancellous bone in the femoral head.
- **Incorrect screw length:** too **short** a screw can not be anchored in the subchondral bone thus reducing the stability of internal fixation. The danger of loss of reduction increases. Too **long** a screw may irritate the soft tissues during settling and give rise to symptoms. The patient is unable to lie on this side and experiences pain while moving.

  Solution: change of screw.
- **Errors made while positioning the 2 mm 2-hole plate.** If the plate is not placed perpendicular to the cannulated screw axis or if it is under tension, the jammed screw may perforate the femoral head or lead to a diastasis or non-union in younger patients.

  Solution: bending of the plate with flat-nosed pliers and positioning it correctly.

8.4 Guidelines for the assessment of internal fixation

Already during the analysis of the first 1000 patients with femoral neck fractures seen at our institute between 1940 and 1955 our team paid special attention to the early and late complications arising from the position of the implant (Manninger et al, 1961b). During the subsequent half century osteoporosis has led to major changes in bone quality of the proximal femur. Due to the ever increasing mean age of the population osteoporosis has become a national concern. The trabecular bone stock of the femoral head and more so of the neck has decreased or even sometimes disappeared (Forgon, 1967). Even the cortex, foremost the lateral, is thinned. On one hand, important developments were imperative in respect to internal fixation: use of three or more implants, identification of areas in the neck and head that contain a bone stock for adequate hold of the implant and reinforcement of the lateral cortex. On the other hand, a revision of our recommendations based on findings in much younger patients made 50 years previously became necessary. A regular assessment of early and late results of internal fixation with two cannulated screws rendered an analysis of the still current importance of the quality of internal fixation possible.

Table 6 constitutes a supplement to the assessment of reduction, listed in Sect. 7.6. We used the same four categories; **1 = good, 2 = acceptable, 3 = faulty, 4 = poor.** Also here we excluded from the assessment technically unacceptable and poorly centered radiographs. For scientific comparison we established the following parameters in the evaluation of internal fixation (Johansson et al, 1986; Cserháti et al, 1999):

- **SAD** (Screw-Adam's arch-Distance): **Distance between caudal screw and Adam's arch** (a.-p.);
- **SDAA** (Screw-Diaphyseal Axis-Angle): **Angle between caudal screw and diaphyseal axis** (a.-p.);
- **SCD** (Screw-Contour-Distance): **Distance between screw tip (foremost of the caudal screw) and femoral head contour** (a.-p.);
- **CDS** (Convergence or Divergence of the Screws): **Difference between the distance between caudal and cranial screws** (a.-p.).
- **SSD** (Screw-Screw-Distance): **Distance between both screws axes measured at the midpoint** (a.-p.);
- **CDH-LTD** (Caudal Drill Hole-Lesser Trochanter Distance): **Distance between the center of the caudal drilling and the mid part of the lesser trochanter measured perpendicular to the diaphyseal femoral axis** (a.-p.);
- **SSA** (Screw-Screw-Angle): **Angle between both screw axes, normal 0°** (lateral) (Fig. 208).

A few clinical examples are shown here in support of these parameters. For the sake of clarity all hips are shown as being left-sided. It is evident from the majority of errors that the incorrect screw position was the result of an inadequate reduction. Thus, a properly executed reduction has a crucial impact on the result of internal fixation (see Sect. 7.1) (Figs. 209–212).

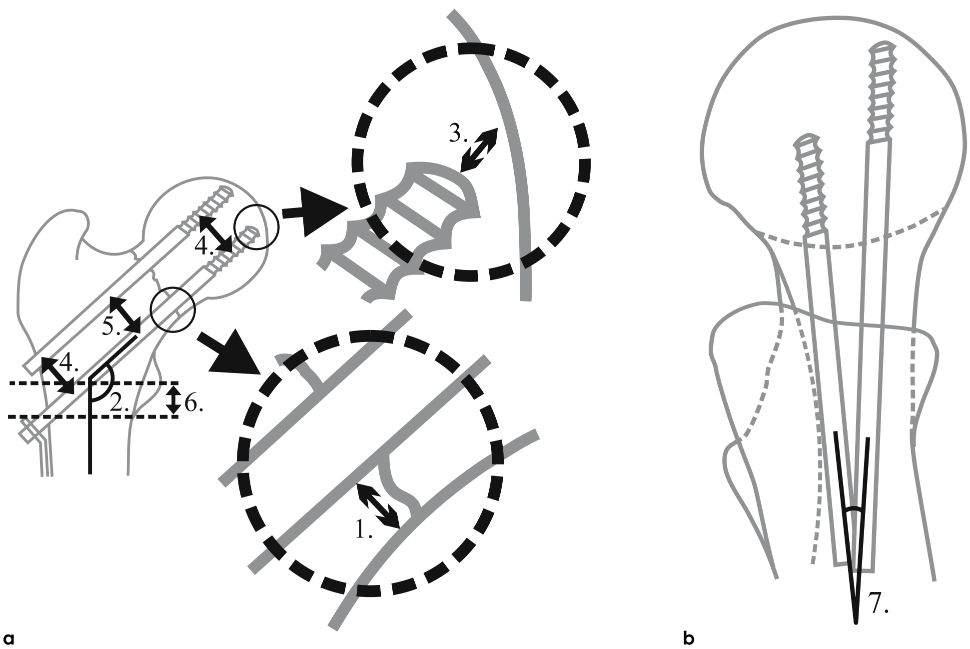


Fig. 208. Schema of parameters for the evaluation of internal fixation (For abbreviation see text.).
a. 1: SAD; 2: SDAA; 3: SCD; 4: CDS; 5: SSD; 6: CDH-LTD; **b.** 7: SSA (example of markedly divergent screws)

Table 6. Guidelines for the evaluation of internal fixation: 1 = good; 2 = acceptable, 3 = faulty, 4 = poor

a.-p. projection	lateral projection
1. good – SAD up to 1 mm – SDAA 135 to 145° – SCD up to 1 mm – CDS up to 2 mm – SSD 17 to 20 mm – CDH-LTD 5 to 15 mm – the caudal screw lies in the caudal third of the head – the cranial screw lies at the junction between cranial and middle third of the head (Fig. 209a–f)	– both screws lie in the middle third of the femoral head or at the junction between middle and posterior third – SSA 0 to 5°.
2. acceptable – SAD 2 to 3 mm (Fig. 210a) – SDAA 130 to 134° or 146 to 150° (with the exception coxa vara and valga) (Fig. 210b) – SCD 2 to 3 mm (Fig. 210a) – CDS 3 to 4 mm – SSD 21 to 22 mm or 16 to 14 mm (except when 14 mm parallel guide is used) (Fig. 210c) – CDH-LTD 0 to 4 mm or 16 to 20 mm (Fig. 210b) – caudal screw at the junction between middle and caudal third of head – cranial screw in cranial third of head close to the junction between cranial and middle third – small perforation: the screw is in the non-weight bearing zone and does not exceed the articular cartilage of the head (Fig. 210e–i)	– screw position in posterior third of head close to the junction between middle and posterior third or anterior and middle thirds – SSA 6 to 10° (Fig. 210d)
3. faulty – SAD 4 to 5 mm (Fig. 211a, b) – SDAA 125 to 129° or 151 to 155° – SCD 4 to 5 mm (Fig. 211a, b) – CDS 4 to 6 mm – SSD 23 to 24 mm or 13 to 12 mm – CDH-LTD –5 to 0 mm or 21 to 25 mm (Fig. 211a–b and c–g) – caudal screw in middle third of head (Fig. 211a, b) – cranial screw in the middle of the cranial third of the head – evident perforation: the tip of the screw lies in the weight bearing area and/or exceeds the femoral head's articular cartilage (Fig. 211h)	– screw position in posterior third of head close to the head contour or in the anterior third close to the border between anterior and middle third (Fig. 211i) – SSA 11 to 15°
4. poor – SAD > 5 mm (Fig. 212a, b) – SDAA below 125° or over 155° – SCD > 5 mm (Fig. 212a, b) – CDS > 6 mm – SSD > 24 mm or < 12 mm – CDH–LTD < –5 mm oder > 25 mm – caudal screw in the middle third of head close to the junction between cranial and middle thirds (Fig. 212a, b) – cranial screw in cranial third of head close to the head contour	– screw in anterior third of femoral head close to head contour (Fig. 212c–h) – SSA > 15°

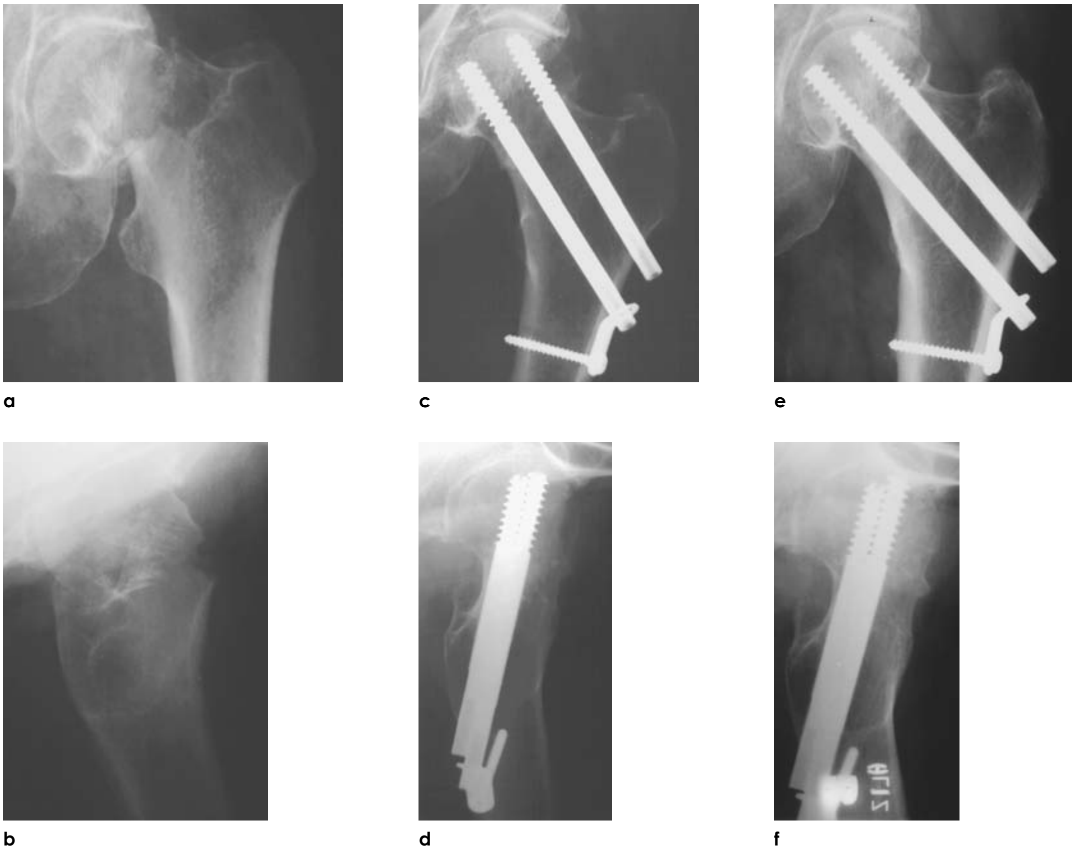
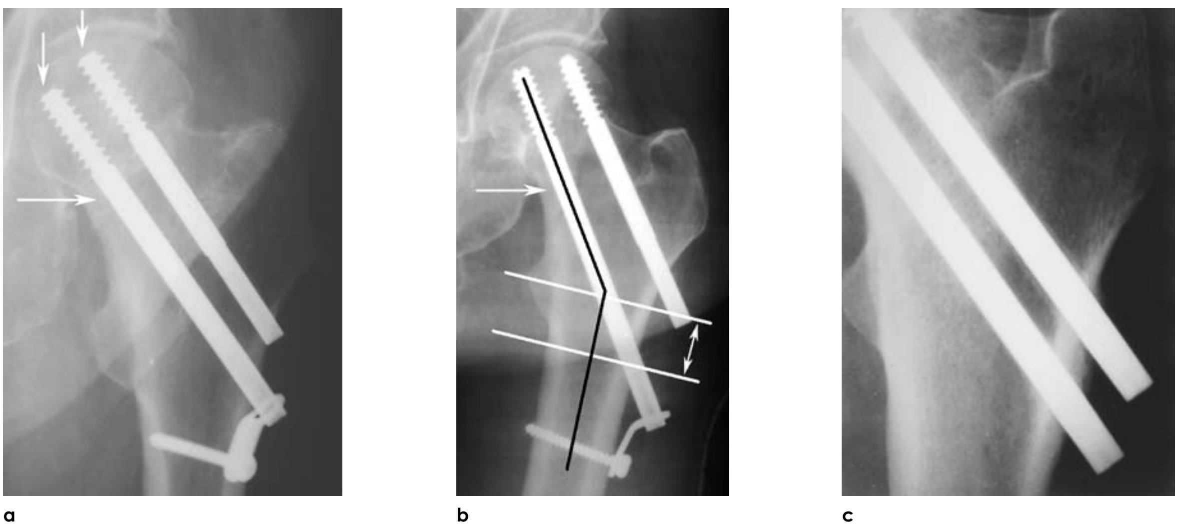


Fig. 209. Clinical example of an internal fixation judged as being "good".
This 75-year-old woman fell at home. **a, b.** She suffered a Garden-IV fracture; **c, d.** We performed a cannulated screw fixation 8 hours after the fall. Minimal (advantageous) position in valgus and antecurvature. The internal fixation deserves the attribute "good" in both planes; **e, f.** Three years later the radiographs show a bony consolidation after slight settling. There is no evidence of necrosis



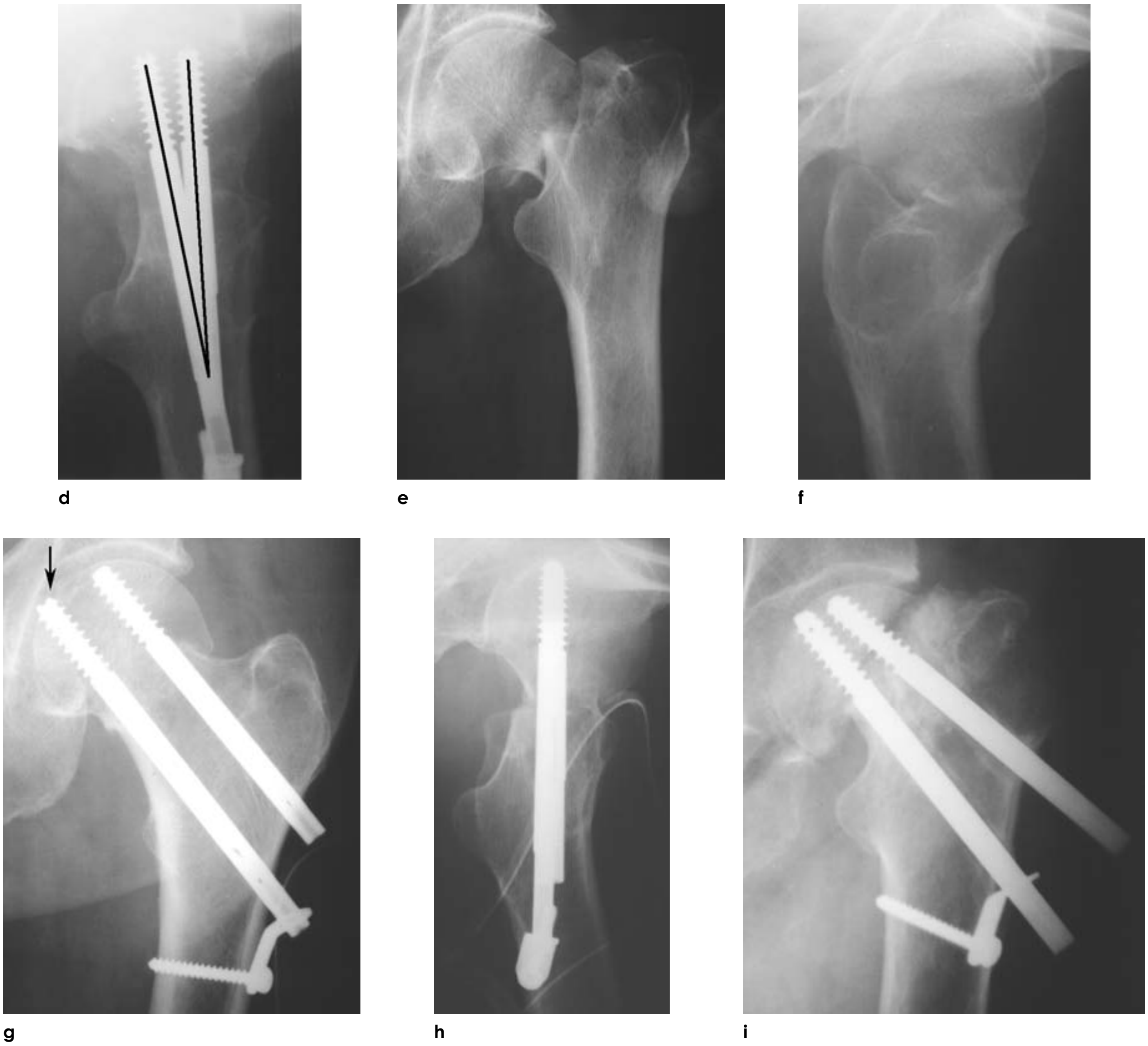


Fig. 210. Five clinical examples of an internal fixation judged as being "acceptable".

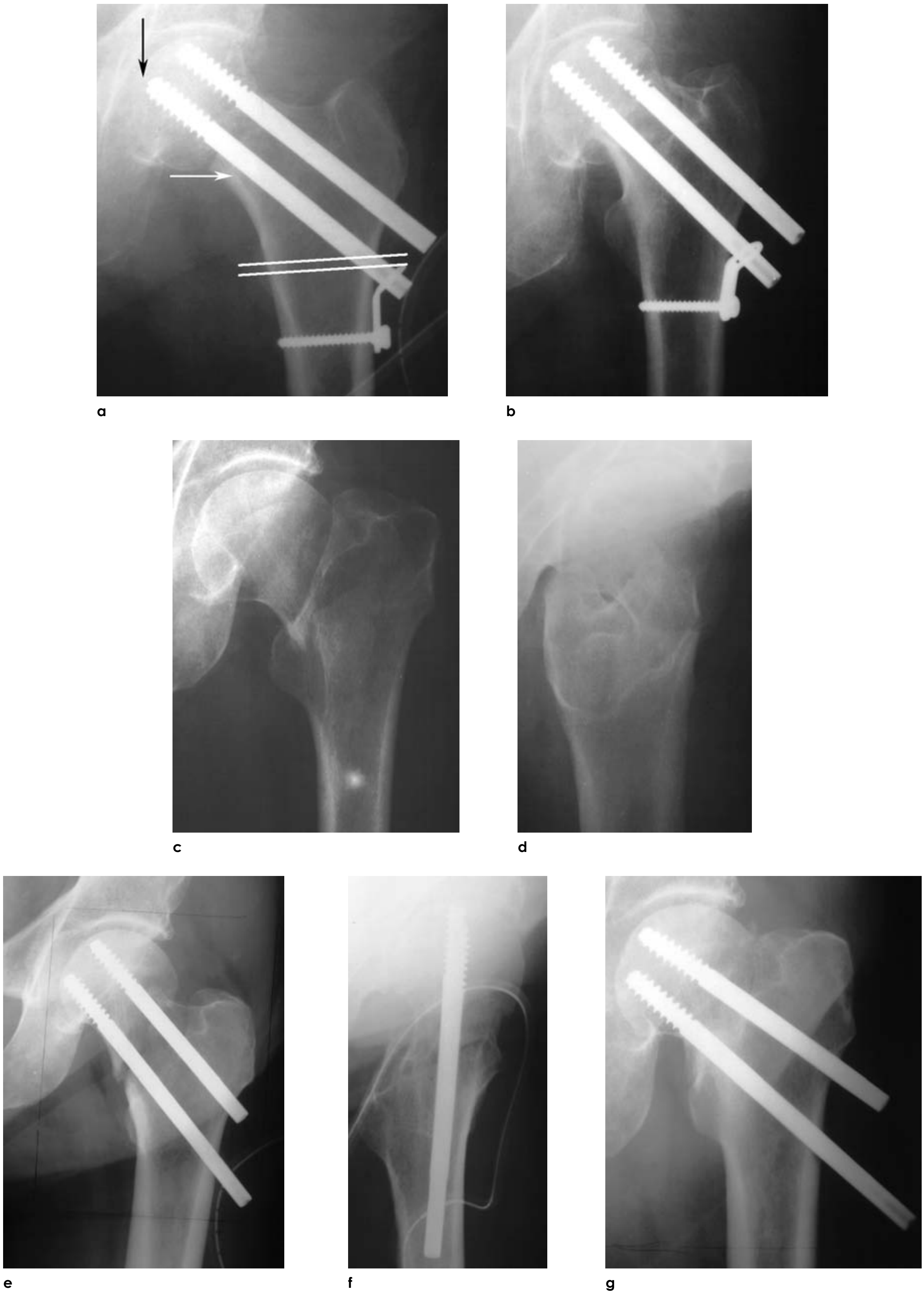
(1) **a.** This 65-year-old patient had a Garden-III fracture. After correct reduction both screw tips remain too far from the femoral contour. Moreover the caudal screw does not rest on Adam's arch (SCD and SAD 3 mm each).

(2) **b.** This patient has already been shown in Fig. 86. Several parameters reflect the too vertical screw position – SAD: 3 mm, CDH-LTD: 20 mm, SDAA: 150°. Symptoms occurring later necessitated a change of screws. Bony consolidation occurred only thereafter.

(3) **c.** This patient has already been depicted in Figs. 93 and 149. The distance between the screws (SSD) amounted only to 14 mm. This coupled with the omission of a 2 mm two-hole plate led to a decreased rotational instability causing most probably the **thickening of the lateral cortex.**

(4) **d.** This patient has already been shown in Fig. 158. Internal fixation resulted in a divergence of screws (SSA: 10°).

(5) **e, f.** 82-year-old woman who had suffered a Garden-IV fracture two days previously. On account of severe cardiac failure and state of confusion an internal fixation with two cannulated screws was done; **g, h.** The postoperative a.-p. radiograph shows that the caudal screw that does not lie in the weight-bearing zone has perforated the femoral head. We assessed the situation (screw position, high risk patient) and decided against an exchange of screws. Her general condition improved and she could be mobilized; **i.** Eight months later a migrating non-union had formed due to total avascular necrosis. The position of the caudal screw had not changed during the eight months. The patient's condition had improved to a point allowing us to perform a hemiarthroplasty


a
b
c
d
e
f
g

h

i

Fig. 211. Four clinical examples of an internal fixation judged "faulty".
(1) **a.** This patient has been described in Fig. 185h, i. The error in internal fixation: the caudal screw lies at a distance from Adam's arch and from the head contour (SAD: 4 mm, SCD: 4 mm). The screws had been inserted in a varus malposition (CDH-LTD: 3 mm); **b.** These errors together with the diastasis led to a loss of reduction.
(2) **c, d.** This 81-year-old patient suffered from a Garden-IV-Pauwels-III fracture; **e, f.** The fracture was only stabilized with two cannulated screws. Besides the over-distraction and the valgus position the cardinal fault does not lie in the fact that the screws were placed too cranially (CDH-LTD: 5 mm) but in the erroneous assessment of stability; **g.** Six weeks later a loss of reduction was diagnosed. In these days DCD plates were not available. It would have been preferable to insert the screws more vertical or at least to use a 2 mm three-hole plate.
(3) **h.** This neck fracture was seen in a leg deformed secondary to polio. Neither reduction nor internal fixation were correctly executed: only on the postoperative film it became clear that the tip of the caudal screw clearly exceeded the femoral head contour (approx. 3 mm); immediate screw exchange.
(4) **i.** This patient has been pictured in Fig. 105. Due to an exaggerated rotation the screws lie in the posterior third of the head. This could also have been the cause of the loss of reduction

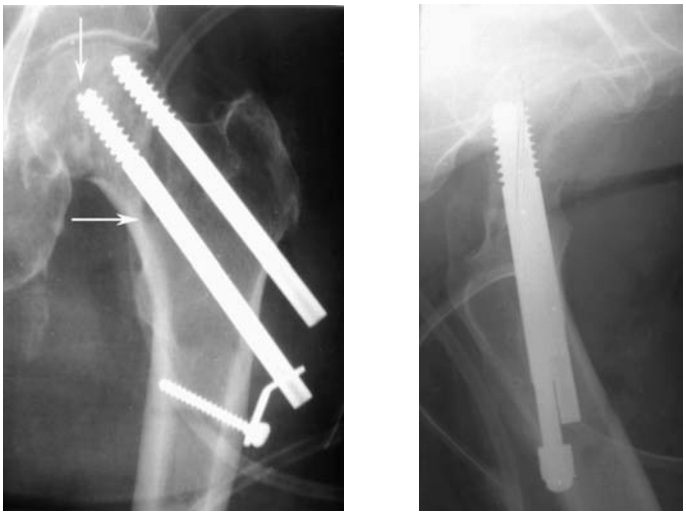


Fig. 212. Two clinical examples of an internal fixation judged "poor".
(1) **a, b.** This patient was shown in Fig. 87. Important mistakes in reduction led to an insufficiency of the internal fixation. As the screws could not be advanced further due to the forced overrotation, they are positioned too far away from Adam's arch and extremely posterior and cranial from the contour of the head.
(2) **c, d.** This patient was shown in Fig. 186g. The fixation of the Garden-IV neck fracture was done in extreme antecurvature (lateral alignment angle 120°); **e, f.** Therefore, the screws had been placed too anterior; **g, h.** The consequence was a cutting-out. The patient was treated with a hemiarthroplasty

8.5 Internal screw fixation with exposure of the femur

We perform an internal fixation with cannulated screws and exposure of the lateral femoral cortex, when the preoperative analysis of radiographs indicates the need for an increased stability of internal fixation (three screws with 2 mm plate or DCD plate or double DCD plate).

For the exposure we use the **retromuscular approach** originally proposed by J. Böhler and modified by us. It resembles the approach for the implantation of a DHS.

The straight skin incision runs from the tip of the greater trochanter caudally for a length of 8 to 10 cm when used with the 2 mm plate and of 8 to 12 cm when an insertion of a DCD plate is planned.

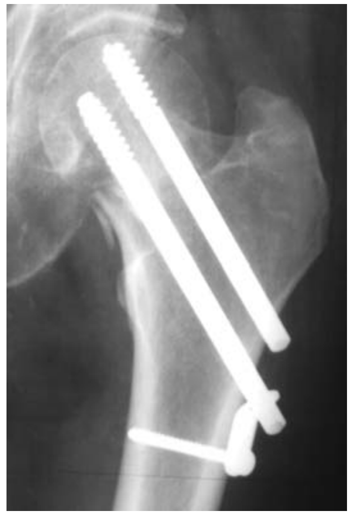
The subcutaneous tissue together with the fascia lata is sharply divided over the entire extent and a hemostasis performed. Care has to be taken not to cut the muscle fibers of the fascia lata. The fascia of the vastus lateralis is transversely cut 2 cm caudal to the innominate tubercle. This incision is prolonged caudally at an angle of 90° close to the origin of the intermuscular septum. The cranial flap of the fascia is mounted on stay sutures, caudally muscle fibers remaining attached to the fascia are detached sufficiently to insert the implants. Any unnecessary exposure of the femoral surface must be avoided. Blood vessels piercing the septum must be carefully coagulated. As the reduction has already been achieved before exposure of the femur, an exposure of the fracture is not necessary (see Sect. 7.2).

Some centers, particularly in Switzerland, have always performed an open reduction after arthrotomy and placed the screws under visual control. Advocates of the method felt an opening of the joint necessary to evacuate the intraarticular hematoma. Based on results of our intraosseous venographies and investigations of drainage we feel that an arthrotomy is not indicated.

On one hand, controversial opinions can be found in the literature in respect to the importance of intraarticular pressure increases and their relation to avascular necrosis (Soto-Hall et al, 1964; Arnoldi et al, 1970; Ewerwahn and Suren, 1970;


c


e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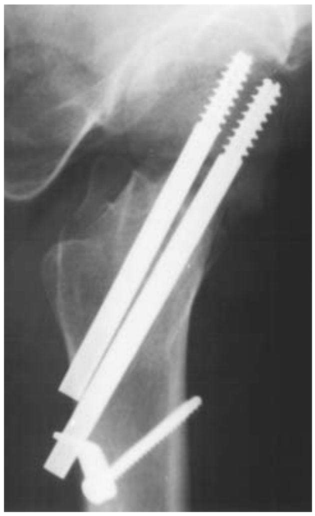
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h

Nagy et al, 1975; Drake and Meyers, 1984; Wingstrand et al, 1986; Vegter, 1987; Kazár and Manninger, 1993; Maruenda et al, 1997; Bonnaire et al, 1998). On the other hand, the hemarthrosis can empty spontaneously through the torn capsule into the surrounding tissues or the blood can drain along the implants. With the event of the modern image intensifiers a closed reduction is successful in the majority of cases. There is no need to open the joint, an act that for elderly patients constitutes an additional stress.

After stabilization of the fracture suction drains are installed beside the implant. The fascia of the vastus lateralis, the fascia lata, subcutaneous tissues and the skin are closed with interrupted sutures. Insertion of an additional drain above the fascia can become necessary in obese patients. As the entire operation is done under visual control, a meticulous hemostasis is possible. Definite disadvantages of the bigger incision are the additional trauma to soft tissues and the **more severe postoperative pain.** In addition, the longer operating time increases the **risk of contamination and thus of septic complications. For this reason, an internal fixation with exposure of the femur must be based on strict indications.**

8.6 Technique to increase the stability of internal fixation

8.6.1 Introduction

The standard technique described in chap. 8.3.2.3 is suitable for **the majority of fresh displaced femoral neck fractures** (70–80%) and for practically all undisplaced (Garden-I and -II) fractures. Patients in whom only a **primary arthroplasty** is indicated constitute an exception (concomitant severe osteoarthritis, avascular necrosis, rheumatoid arthritis, multifragmentary and comminuted fractures). An **increased stability of internal fixation** is required **when particular biomechanical peculiarities or an instability** are present. A more stable internal fixation is also needed during **revision surgery.**

Obviously, it is advantageous when the decision for the kind of internal fixation can be taken before surgery. However, the flexibility of the system allows to adapt the kind of internal fixation to **problems arising during surgery.** For example, in the presence of severe osteoporosis the standard screws can be replaced by 9.5 mm or flanged screws.

In summary, the indications for increased stability are:

- Severe osteoporosis;
- Coxa vara;
- Stress fracture;
- Pathologic fracture (cyst, tumor, metastases);
- Completely avulsed Adam's arch and/or calcar femorale;
- Multifragmentary or comminuted fracture;
- Vertical fracture (Pauwels-III);
- Base of neck fracture;
- Revision of internal fixation on account of screw migration (backing-out, perforation of head);
- Revision of internal fixation on account of loss of reduction.

In the latter two instances, the vitality of the femoral head should be evaluated before revision surgery with DS intraosseous venography, SPECT or in the presence of titanium implant with MRI.

An insufficiency of one buttressing point always results in **instability,** sometimes in combination with shortcomings and errors. The **technical steps** of possible **clinical proven methods** were described in a proper sequence in Sects. 5.2 and 5.3. Some procedures (bone cement, screws with longer section of threads) do not necessitate a separate description, as no special instruments are needed.

8.6.2 Screws with a 9.5 mm thread diameter

The difference with the standard technique consists **in the (earlier) removal of the parallel guide during step 5** (see Fig. 204). The **9.5 mm tap** attached to the handle can only be inserted through the 10 mm soft tissue sleeve for protection of the soft tissues. Thereafter, no particular deviations from the standard technique are required during the insertion of the caudal screw and the tapping and placement of the second (cranial) screw. As the shank diameter of these screws amount to 7 mm identical to the standard screws, attachment of a 2 mm plate or a double DCD plate is possible.

8.6.3 Flanged screw

Our experimental results and the first clinical experiences show that the flanged screw is particularly advantageous as a marked increase in rotational stability can be achieved **percutaneously** without larger exposure of bone. Surgery follows the technique described in Sect. 8.3.2.3 up to step 7 (see Fig. 206). The caudal screw is inserted in a way that its slit points cranially. Into this slit we introduce the **toothed chisel** attached to the driver (see Fig. 133a and Sect. 5.7.9). The **cutting edge of the chisel must point cranially.** With careful hammer blows the bed for the flange is prepared in the lateral cortex. Using the same **driver** the flange is advanced to the end of the slit (see Fig. 133c). A **flange is chosen that is 1.5 cm shorter than the screw** to allow settling. The cranial screw is inserted in a standard fashion and the 2 mm two-hole plate attached to the caudal screw.

8.6.4 Internal fixation with three cannulated screws

Today, we only employ three screws in a **modified order** usually for percutaneous, internal fixation (see Figs. 136, 140 and 162). The bed for the caudal and cranial screws is made according to the standard technique (see Sect. 8.3.2.3) with an 18 mm parallel guide. However, the cranial screw is not inserted **posteriorly** but **anteriorly under the cranial cortical thickening of the neck.** The **position of the third (middle-posterior) screw** is obtained with the use of the **new** parallel guide (see Fig. 163), to which a third barrel is attached on its left or right side (see Sect. 5.7 point 2). Into the bore of this third barrel the 10/7 mm guide (red marking) is inserted. Through this guide we predrill and insert a guide wire and a step drill bit **close to the posterior cortex of the neck.** After exchange for a 10/8 mm guide tapping and insertion of the slotted screw is done. The new, three-bore parallel guide is currently tested serially. Its use will facilitate and increase precision of the surgical technique.

8.6.5 Attachment of two screws to 2 mm plates

If each end of each screw is to be separately attached to one 2 mm two-hole plate (see Fig. 142), the standard technique is used. One must not forget that in this case **5 mm must be added to the measured length of the cranial screw.** It is equally important that **both screws do not lie in the same plane** as otherwise the caudal plate would interfere with the insertion of the cranial plate. As already mentioned the caudal screw should lie slightly anterior.

If, however, one **2 mm three-hole plate connecting both screws** is employed (see Figs. 143 and 154), both **screw ends must lie strictly parallel in one plane, that is the plane of femoral diaphysis,** as otherwise the plate cannot be attached without tension (see Fig. 156). One must also remember that the **length of the screws is reversed:** the cranial screw must be 5 mm longer as it is attached to the traction hole of the plate. To avoid a prominence of the caudal screw the length of the screw chosen must correspond to the measured length.

Surgery can be performed through a 5–6 cm long incision. If a **percutaneous** internal fixation is selected, two incisions, each measuring 2–3 cm, are adequate. Similar to the 2 mm two-hole plate the seating instrument for the plate is attached to the caudal hole of the three-hole plate. Surgery is continued as described in the standard technique.

The use of **slotted screws** and the new parallel guide (see Sect. 5.7 points 2 and 8) facilitate the precise parallel insertion of screws.

8.6.6 Simple and double DCD plates, satellite plates

The **DCD plate** (see Fig. 192a, e/3) **for the caudal screw** is used in instances where **the absent buttressing by Adam's arch is not accompanied by an increased rotational instability** (Pauwels-III or base of neck fracture) or when **compression of the fracture** (stress fracture) is warranted. It is **supplemented by a satellite plate** (see Fig. 192 b, e/4) for the treatment of unstable fractures accompanied by an increased rotational instability. The **double DCD plate** (see Fig. 192c, e/5) is employed for fractures with **severe instability** (zone of comminution, pathologic fracture, Pauwels-III fractures reaching to the lesser trochanter, revision surgery). The more slender DCD plates respond to the demand of **Willenegger:** "one should not use more and larger implants to achieve stability than absolutely necessary".

The correct placement of the caudal screw is also the key to a successful internal fixation when the lateral femur is exposed. Attention has to be placed to **the angle of the cranial DCD plate that will be slipped over the single DCD plate.** Here, the position of the screw should not be determined retrograde but with the help of the implant determined **antegrade** (from laterocaudal to mediocranial).

The precise aiming is done with the **DCD parallel guide,** that is positioned on the lateral side of the femur and that thanks to the wedges of 10 or 20° (see Fig. 196a) can be adapted to the desired angle. The standard guides and instruments are introduced through the DCD parallel guide. The channel for the caudal screw is prepared with the standard technique. When using the DCD plate the length of the **screws is chosen according to measurements with the depth gauge.** Therefore, **the end of the screw should lie at the level of the lateral cortex.**

If a **longer** screw is used, the junction between flattened and round screw shank would cause a jamming in the caudal part of the DCD barrel where the hole is flattened to prevent rotation. This would prevent a backing-out during settling. If a too short screw is chosen, its end may be blocked as it does not reach the flattened part of the bore of the DCD barrel and lead to a loss of rotational stability. In the presence of marked settling of comminuted fractures the already rotated screw cannot slide into the flattened part of the barrel but get jammed at its edge (see Fig. 192f).

In both instances a perforation of the head or diastasis of the fracture may happen (see Fig. 237). Therefore, **during insertion of the DCD plate one has to check whether the flattened screw end fits exactly into the flattened bore of the barrel.**

After tapping the DCD parallel guide is removed and the **11 mm crown drill bit** is inserted over the guide wire. The crown drill bit is advanced with a low revolution. Graduation at the surface of the drill bit allows determining the depth of drilling according to the length of the barrel. A new **crown drill bit** renders this step easier and more secure as the screw guides the drill bit (see Sect. 5.7, point 7, and Fig. 196b).

After removal of the drill bit the screw is inserted. During its final turn the T-wrench must lie parallel to the diaphyseal femoral axis. This permits an easy insertion of the angle-stable DCD plate that is then fixed to the femur with cortical screws. If desired, a compression screw supplied in two lengths (see Fig. 192d) can be used to achieve a careful **adaptation and compression** of the fracture. The cranial screw is inserted according to the standard technique.

Also for the fitting of the **satellite plate** (see Fig. 192 e/4) a **precise 18 mm parallel aiming** is mandatory to achieve a tension-free sliding of the plate over the protruding end of the cranial screw. As described above, the site for the caudally lying DCD plate is prepared first, the caudal screw inserted and a trial of plate fitting is done. After removal of the plate the **parallel guide** is slipped over the 10/7 guide (red marking) and attached to the screw. Using the standard technique the bed for the cranial screw is now prepared. When determining the screw length **5 mm must be added;** the screw is then inserted. Thereafter the **satellite plate** is first slipped over the cranial screw. The DCD plate is then put through the distal hole of the satellite plate over the caudal screw. The DCD plate is fixed to the femur with cortical screws.

The combination of the simple DCD plate with the DCD supplementary plate, thus creating a double DCD plate, allows to double the angular stability that can currently be obtained with cannulated screw fixation. The bed of the caudal DCD plate is prepared first as described above. The caudal screw is then introduced followed by the preparation of the channel for the cranial screw while **strictly respecting the parallelism** of the screws. Also the length of the cranial screw must be selected in a way that its end is flush with the lateral cortex. At the end of insertion of both screws, care has to be taken that **both screw ends lie parallel to the axis of the femoral diaphysis** as otherwise the double DCD plate cannot be apposed to the femur. Of equal importance is the requirement that the flattening of both screw ends must lie in one plane. The new special instrument helps to reach this position (see Sect. 5.7, point 8). Obviously, the bed for the cranial barrel must also be prepared. The DCD supplementary plate is completely pushed over the cranial screw. Through its distal hole the DCD five-hole-plate is placed over the caudal screw and fixed to the femur with cortical screws. With the double DCD plate a maximal extramedullary stability can be obtained.

Chapter 9

TREATMENT OF UNDISPLACED AND ATYPICAL FEMORAL NECK FRACTURES

9.1 Treatment of undisplaced femoral neck fractures (Garden-I and -II)

9.1.1 Introduction

Up to the present day, controversial opinions can be found in the literature regarding the treatment of femoral neck fractures either impacted in valgus or without displacement (Garden-I and -II). **The opinion of the different authors is usually based on their experience gained with the treatment of displaced neck fractures:** centers which favor a primary internal fixation (Scandinavia, Hungary and recently some institutions in USA) chose internal fixation also for undisplaced fractures (Phillips and Christie, 1988; Doran et al, 1989; Nilsson et al, 1989a; Manninger et al, 1990; Sernbo et al, 1990; Parker et al, 1991b; Strömqvist et al, 1992; Kyle et al, 1994). Centers, however, those treat patients older than 60–70 years with displaced neck fractures by an arthroplasty, prefer a **conservative** approach for undisplaced neck fractures (Riedl et al, 1989; Braun et al, 1991; Raaymakers and Marti, 1991; van Vugt, 1991; Berwarth and Schlickewei, 1992; Hui et al, 1994).

In general, a consensus exists, however, that **no clinical or radiologic parameters** (age, degree of osteoporosis, fracture type) **exist** allowing **with certainty to predict a secondary displacement** and thus a selective indication for surgery. We observed displacement of conservatively treated Garden-I fractures that showed initially a greater angle in the lateral view and have also seen **displacement of Garden-I fractures that were initially undisplaced in both projections** (Fig. 213) (Zolczer et al, 1970).

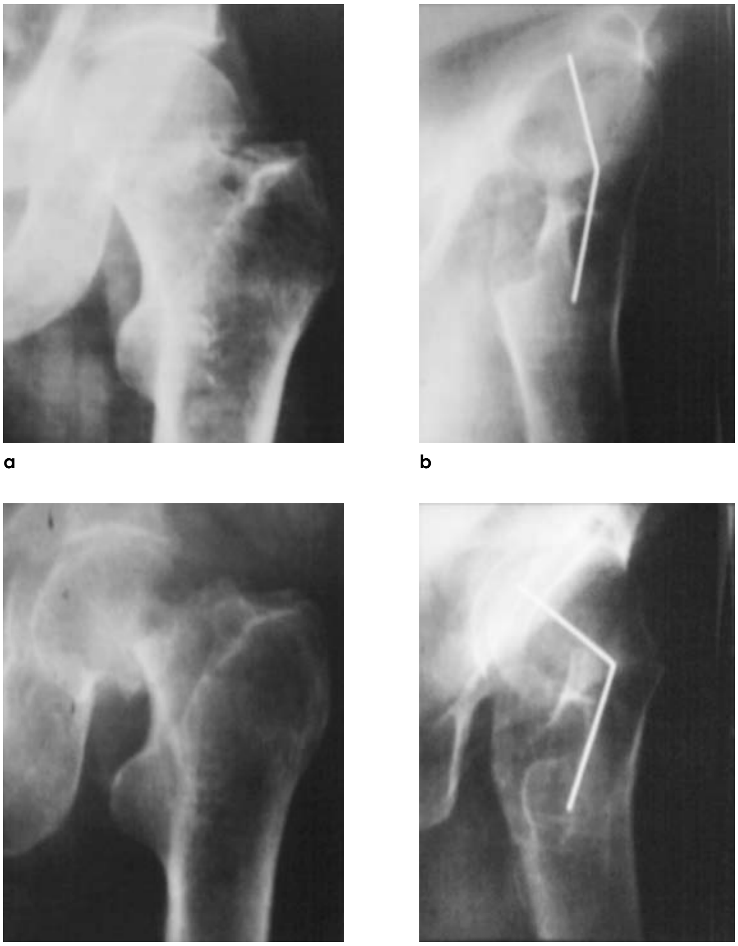
The incidence of fracture displacement during conservative management depends on the timing of mobilization. Some proponents of early mobilization and weight bearing reported an incidence of secondary displacement of 50% (!) (Otremski et al, 1990; Hvaal et al, 1992). We also found an increase in the incidence of displacement during the years where we had permitted conservatively treated patients to get up earlier (Cserháti et al, 1996). If, however, one prolongs the duration of bed rest, an increase in – often fatal – **complications** is the consequence. Due to their physical or mental status the majority of patients is **unable to ambulate effectively without bearing weight.**

The impact of secondary displacement on the **circulation of the femoral head is** identical for conservatively managed patients and for those who suffered a displacement initially. If internal fixation is properly executed respecting the state of the art, **no displacement will occur.** A marked antecurvature or a hypervalgus position can only be corrected **surgically.** With the correction of antecurvature a secondary displacement and with correction of hypervalgus an avascular necrosis can be avoided.

9.1.2 Treatment of undisplaced femoral neck fractures at the National Institute of Traumatology (Budapest)

Already during our first studies, an analysis of 1000 neck fractures treated between 1940 and 1955, we paid attention to impacted neck fractures (Kazár et al, 1959). In these days the conservative approach dominated. **If, however, the antecurvature exceeded 20° and if the fracture was considered to be unstable, we proceeded with internal nail fixation.** The initially favored immobilization in a spica cast or the traction using Unna's boot was rather quickly abandoned as this approach had more disadvantages than advantages: the fracture was not adequately stabilized, the care and personal hygiene were rendered difficult and the risk of bed sores was great.

During the sixties and seventies the first step of conservative care had been a bed rest for two to three weeks. The affected limb was elevated and the foot suspended in a sling preventing rotation. Exer-



a b c d

Fig. 213. Early displacement of a Garden-I fracture. **a, b.** Garden-I fracture appearing stable radiologically (alignment angle: a.-p. 170°, lateral 160°); **c. d.** Displacement at the beginning of mobilization within two weeks while in hospital

cises were done in bed. After subsidence of pain the patient was allowed to sit on the edge of the bed and to get out of bed and walk. **Up to the end of the third month** walking was permitted **without weight bearing using crutches.** Partial weight bearing was allowed thereafter. Radiographs were done at the beginning of mobilization, before discharge and after six, twelve and twenty-four weeks (as a rule five times). In spite of the very careful treatment we observed in **24% a displacement necessitating surgery** (Zolczer et al, 1970).

This outcome led in the **early eighties** to a **primary internal fixation** of undisplaced neck fractures in an increasing number of patients culminating at the end of the eighties in a surgical treatment of the majority of patients. Usually internal fixation was achieved with **three cancellous bone screws** attached to a reversed keyhole plate anchored to the lateral cortex; this plate exerted a tension band effect (see Fig. 124). To guarantee a parallel insertion of screws we developed a parallel guide.

Neck fractures that displaced during the period of conservative care were usually treated with two Smith-Petersen nails (see Fig. 123) similar to Garden-III and -IV fractures.

Since the introduction of **percutaneous fixation with two cannulated screws in 1990** we used this method for the treatment of Garden-I and -II fractures; it soon became the standard procedure. We perform this operation **as soon as possible** to forestall the imminent complications of prolonged bed rest. It happened, however, not infrequently, that surgery had to be delayed due to lack of access to the operating room particularly during nights, Sundays and holidays. For fractures displaced in hypervalgus we attempt a reduction and internal fixation within six hours (see Figs. 180 and 181).

Initially, we used for undisplaced fractures **the 2 mm plate only for special indications:**
– Multifragmentary fractures;
– Vertical Pauwels-III fractures;
– Garden-II fractures;
– In instances where after reduction a marked antecurvature (lateral alignment angle < 160º) or a hypervalgus (a.-p. alignment angle > 190º) were present;
– Severe osteoporosis;
– Increased risk of repeated falls (confusion, epilepsy, Parkinsonism, alcoholism) (see Fig. 94).

Nowadays, we employ **the 2 mm plate regularly in patients over 80 years suffering from undisplaced fractures.** If the technique is properly executed, the surgical trauma is only minimal.

The majority of patients in good general condition are allowed out of bed on day 1. After 2 or 3 days they are allowed to use a walker with weight bearing. After 4 to 5 days they can be discharged home into the familiar surroundings. In this case the sutures are pulled during the second week in the outpatient department. Radiologic controls are performed after mobilization (before discharge), after four months and, on the condition that the patient is symptom-free, after one, three and five years.

9.1.3 Results of internal fixation of undisplaced femoral neck fractures

In 1993/94, we analyzed the charts of 247 patients who underwent surgery in our institution for Garden-I and -II fractures between 1985 and 1990 (Cserháti et al, 1996). Between 1985 to 1988, conservative treatment predominated; in the years 1989 and 1990 we preferred internal fixation (exposure of the femur and cancellous bone screws with reversed keyhole plate) (Fig. 214).

No significant difference between both treatment groups could be found in respect to age, sex, presence of underlying diseases and frequency of Garden-I or -II fractures.

Internal fixation was done after an average of 4 days (4 hours to 11 days) after injury. In spite of the delay in surgery, the patients were allowed to use a **walker with weight bearing after an average of 10 days following admission.** In conservatively treated patients this was only reached at an average of **17 days when the patients were permitted to use crutches with only partial weight bearing.** Approximately **two-thirds** of the operated patients (62%) were weight bearing at the moment of discharge, contrary to **one-fourth** (24%) of the conservatively treated patients. The average length of hospital stay amounted for the operated patients to 17 days and for the conservatively treated patients to 23 days. All these differences were significantly in favor of surgery (Cserháti et al, 1996).

Among the conservatively treated patients four moribund patients died in hospital due to their underlying diseases, an additional six (4.9%) passed away between the tenth and twenty-first day due to pulmonary embolism, urinary sepsis or pneumonia. Of the operated patients two deceased (1.6%), one of them from a postoperative joint infection. A superficial wound infection was recorded in one patient, in two an evacuation of a hematoma became necessary and in one an exchange of screws was done on account of a perforation of the femoral head.

No loss of reduction occurred in the group of 122 patients operated between 1985 and 1990. Should it have happened, it would have **necessitated revision surgery.** In one instance the fracture healed in varus (a.-p. alignment angle 140º). A fracture displacement occurred in **one-fifth** of the conservatively treated patients (24/122 = 19.7%). Between the years 1985 and 1988 we mobilized the conservatively treated patients at an average of 19 days after admission. The incidence of **displacement was 16%.** In 1989 and 1990, we started the mobilization on day 13 and could observe an **increase in the incidence of displacement amounting to 30%.**

After 3 to 7 years we contacted the patients in whom questionnaires of the Multicenter Hip Fracture Study were initially filled in. For those who did not answer, we requested information from the division of the Interior Ministry responsible for the administration of data, registration and elections. This

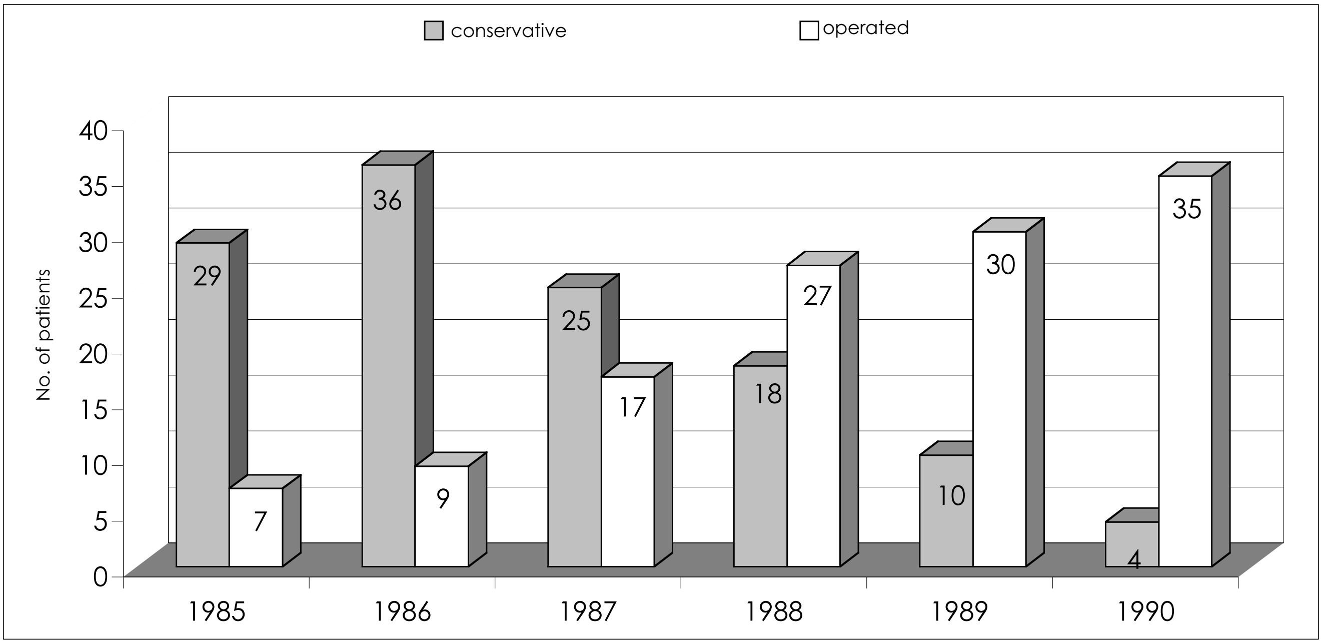


Fig. 214. Yearly distribution of frequency of 122 conservatively treated and 125 operated patients with undisplaced femoral neck fractures during the years 1985 to 1990.

allowed us to collect reliable data of three-fourth of the 247 patients (184/247 = 74.5%).

At the time of this study, 101 patients – 39 conservatively treated and 62 operated – were still alive (101/247 = 40.9%). As the number of operated patients increased in later years, it does not seem to be correct to compare the overall mortality but to compare the mortality for each year. If we exclude the four moribund patients suffering from underlying diseases from the conservatively treated group who died while still hospitalized, 10.6% from this group and 10.4% of patients who underwent surgery, died within one year (13 patients in each group). Similarly **no significant difference** was found in respect to the use of walking aids, walking ability and hip pain.

The study of the 101 surviving patients revealed a total of 15 avascular necroses (14.9%). A partial necrosis was seen four times, in the remaining patients (11) an arthroplasty had been done. Of the 30 patients with **hypervalgus fractures** (a.-p. alignment angle > 190°) 15 were alive at the time of follow-up. **Nine of these (60%) suffered from an avascular necrosis.** It occurred three times after conservative treatment. Two patients were initially treated conservatively but then operated on account of a displacement. A necrosis after immediate internal fixation occurred four times. **The incidence of necrosis** of the survivors was therefore fracture specific. **It was markedly more elevated after initial hypervalgus fractures** than after the other undisplaced fractures (Table 7).

Table 7. Frequency of femoral neck necrosis stage 3 and 4 in hypervalgus fractures in comparison to other Garden-I and -II fractures in 101 surviving patients. The difference is significant (Fisher's exact test: $p < 0.001$)

	Hypervalgus fractures	Other Garden-I- and -II fractures
N	30	217
Followed up for 3 to 9 years	15 (100%)	86 (100%)
Femoral head necrosis, stage 3 and 4 at follow-up	9 (60%)	6 (7%)

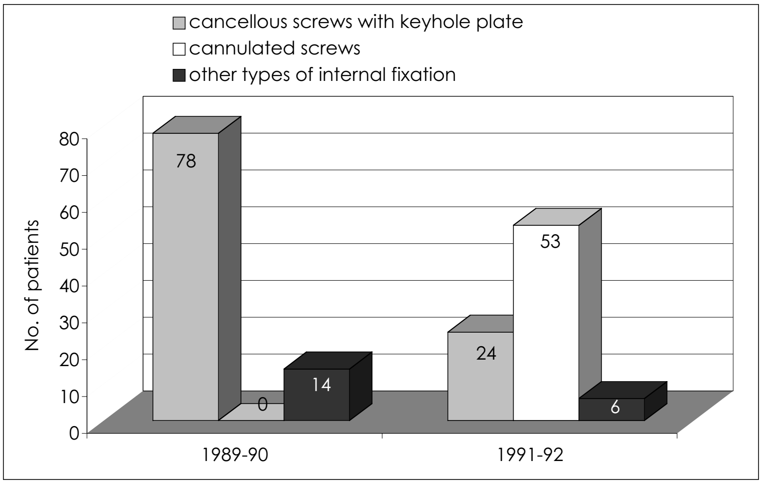


Fig. 215. Frequency distribution of internal fixation for Garden-I and -II fractures in the years 1988 to 1990 and 1991 to 1992.

Of the 24 patients initially treated conservatively and later operated on account of displacement 6 patients lived at the time of follow-up (24%). In two of these we observed an avascular necrosis. Contrary to the opinion of **Raaymakers and collaborators** (1991; 1993) who reported that **a secondary displacement after prolonged bed rest** (and the obligatory surgery) **does not negatively influence the patient's survival chances,** our data (Table 7) prove the opposite.

In 1991 and 92, we performed mainly **a percutaneous fixation with two cannulated screws** (Fig. 215).

We compared the results of **internal fixation with exposure of the femur** and three cancellous bone screws attached to a keyhole plate from the years 1988 to 1990 with the outcome of percutaneous fixation with cannulated screws from the years 1991 and 1992. We found out that the new surgical technique reduced the surgical time by **nearly half,** the need for transfusion **down to one-fourth** and the hospital stay by **four days.**

These investigations confirmed our tenet to treat even **Garden-I and -II fractures with an internal screw fixation.** In this way we obtain a stability permitting an early mobilization with a walker and weight bearing for elderly patients. We avoid early complications associated with prolonged bed rest, the cumbersome ambulation with crutches extending over months and the occurrence of secondary displacements. **The minimally invasive internal screw fixation** is particularly indicated for this purpose as it is associated with a **considerably reduced surgical stress** when compared to other methods of internal fixation (Rzesacz et al, 1995).

Also for budgetary considerations the surgical treatment is preferable as the **hospital stay is shorter, the need for radiographic controls reduced** and local and systemic **complications occur less often** (their treatment is often very expensive!).

9.2 Femoral neck fractures in young adults (20–50 years-old)

Femoral neck fractures frequently observed in elderly patients are seen relatively seldom in persons under the age of 50 years (3 to 4% of all fractures) (Protzman and Burkhalter, 1976; Zetterberg et al, 1982; Manninger et al, 1984; Swiontkowski, 1984; Johansson, 1990; Leun and Shen, 1991; Gray and Parker, 1994; Robinson et al, 1995; Gäutam et al, 1998). During the last years **its incidence seems to increase** amounting to 5.7% in 1993 to 1994 (Fekete et al, 2000b; Fekete et al, 2000c). This fact is associated with an increased alcohol consumption.

The majority of fractures occur in active persons with a normal bone stock after an adequate trauma (injury at work or traffic accident). The most important goal of treatment is besides restitution of the original physical condition **the ability to resume work.** In caring for the **polytrauma patient** the treatment of neck fractures should immediately follow the resuscitation. Missing the fracture or its late stabilization are of great consequence for the later quality of life (see Fig. 96).

The stability of internal fixation poses a smaller problem given the good bone stock of this age group. In patients under 40 years of age **cancellous bone screws** inserted with a parallel guide and resting on Adam's arch guarantee an adequate stability. The risk of loss of reduction and nonunions is less than in elderly patients. In our practice we use **two cannulated titanium alloy screws** (see Fig. 82). **Circulatory disturbances of the femoral head, however, are not less frequent** as the circulation in the femoral head does not change in adults with age. To the contrary, the **greater impact of trauma** increases the risk of circulatory disturbances. For this reason, internal fixation is **an urgent procedure, it must be performed within six hours.** The stronger, cancellous bone of the femoral head may cause difficulties during drilling, insertion of the guide wire and tapping. Particularly in **Pauwels-III fractures** the use of massive instruments (step drill bit, tap) into the femoral head may cause a tilting of the head or a gapping of the fracture. In these instances, it is advisable **to insert the cranial screw first and hold the head fragment during this time with a third Kirschner wire temporarily introduced anterocranially into the head fragment.**

The importance of immediate surgery in this age group is recognized worldwide since 15–20 years in view of the **difficulty to treat local complications.** In the event of loss of reduction we attempt **a revision of internal fixation** thus preserving the femoral head. **An arthroplasty** should be postponed to the moment of retirement. In younger patients the increased activity of daily living may require a **frequent exchange of the implants.**

In the presence of signs of avascular necrosis its localization and extent must be exactly determined. Functional radiographs, CT and – after possible change to titanium screws – MRI. If a collapse of the head did not occur, **transplantation of a pedicled bone graft harvested from the iliac crest** must be considered. In the majority of patients it will lead to **a revascularization of the femoral head** (Salacz et al, 1993; Hankiss et al, 1997). For collapse of the weight-bearing surface we recommend an osteotomy displacing the weight-bearing surface. The following procedures should be taken into consideration: a valgus, varus or rotational osteotomy or combined techniques. Following the consolidation of the osteotomy a revascularization is done. In some instances we could achieve a remodeling of the femoral head by performing in addition to a pedicle bone graft a **lifting of the collapsed segment and supporting it with autogenous, cancellous bone grafts** (Fekete et al, 1994).

An **arthrodesis,** favored in previous times, is only rarely done on account of the severe loss of function. It may be indicated in younger patients performing hard physical labor or unilaterally in the presence of severe damage to both femoral heads (non-traumatic bilateral avascular necrosis).

If the sum of the angle of necrosis exceeds 200º (see Sect. 3.2.2.8), there is no chance of restitution of circulation and congruence; a **total, uncemented joint replacement** is unavoidable.

A small percentage of femoral neck fractures in younger persons is caused by an inadequate trauma:

– Polio;
– Inactivity (amputated or paralyzed limb, longstanding confinement to bed);
– Early postmenopausal osteoporosis, bone loss due to chronic alcoholism);
– Bone cysts, bone tumors, or other localized or systemic skeletal diseases.

The treatment of the first three conditions is identical to the care of neck fractures in elderly patients. If possible, we perform the standard intervention with two cannulated screws within six hours after the injury.

In patients with early osteoporosis the **underlying cause** must be elucidated and treated. The therapy of bone cysts is described in Sect. 9.5.1 dealing with pathologic fractures.

9.3 Femoral neck fractures in children and adolescents

A neck fracture in persons under 18 years of age is even more seldom. For every 100 to 300 neck fractures in adults one accounts for one infantile neck fracture (Ratcliff, 1962; Zolczer et al, 1972; Böhler, 1981; Fornaro et al, 1982; Niethardt, 1982; Rüter and Krenczer, 1982; Schlickewei and Paul, 1993; Canale and Tolo, 1995). These fractures are caused by a great force and therefore often occur during a major trauma or polytrauma. The **serious complications** may lead to a life long incapacity. This danger can be reduced by immediate surgery done under the conditions that specialized and technical care is available (special implant, image intensifier). If these prerequisites are not met, the injured child should be **immediately transferred** to an institution specializing in childcare provided the child can be transported.

At the **age of one year** the ossific nucleus of the femoral head starts to develop. At **age four** the ossific nucleus of the trochanter appears. In this way **two physes develop that are continuous and surrounded by cartilage.** The **two physes separate at the age of 12 years.** The trabecular structure appears only **after end of puberty** (Fig. 216) (Manninger and Fekete, 1982).

These two important morphologic features distinguish the pathology of infantile injuries from that of similar fractures in adults.

(1) Up to the moment of formation of cancellous bone, the infantile bone of neck and head is **very compact.** Consequently, a fracture cannot be impacted during reduction. A good contact and stable position can only be reached with **a precise reduction.** For the same reason **no nail and no blade-plate** such as a 90 or 130° plate **should be used,** as they cannot be inserted without serious tissue damage and diastasis of the fracture.

In 1950 one of us (J. M.) assisted his chief during an open internal fixation of a neck fracture suffered by an 18-year-old boy. He observed that during nailing the fracture gap widened by 0.5 to 1 cm. Impaction led to a closure of the gap, but after resumption of hammering the gap reappeared. Radiographs showed that the nail tip had entered the head by only 1 cm. Removal of the nail to permit predrilling before reinsertion of the nail was unsuccessful in spite of the use of a very strong screw-like extractor. It was therefore decided to leave the nail in place. Follow-up radiographs taken after 16 years showed a complete bony consolidation (see Fig. 111). In spite of the successful outcome we do not recommend this technique. Nevertheless, this case documents the extraordinary compactness of adolescents' bone and the excellent purchase of an implant in bone.

Contrary to the nail, screws can be **easily inserted** after drilling and tapping and their holding power is reliable. Placement of a Kirschner wire or spiral drill bit preceding the screw insertion will prevent any rotatory displacement.

(2) The second major difference with bones of adults is the **blood supply to the femoral head in children** clearly shown by investigations of **Trueta (1957), Ogden (1974) and Chung (1976).** The bony nucleus of the epiphysis of children up to the age of 7 years receives only its blood supply from the **lateral epiphyseal vessels** that run along the femoral neck. In 8-year old children the vessels of the round ligament of the femur also contribute. Vessels of the metaphysis do not contribute as **they do not cross the physis in girls up to the age of 14 years and in boys up to the age of 17 years.** According to the studies of **Trueta** (1957) the vessels of the femoral head function like **end-arteries.** Anastomoses between the three areas of blood supply are only formed at the end of puberty (Chung, 1976) (Fig. 217).

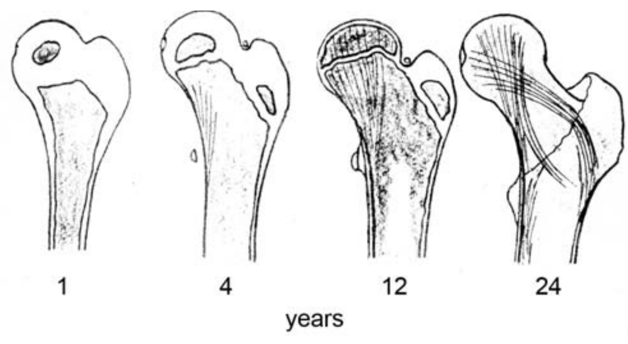


Fig. 216. Schema of the development of the ossific nuclei in the proximal femur (Manninger and Fekete, 1982).

Fig. 217. Arteries of the femoral head in children (Trueta, 1957). The corrosion specimen documents very well the absence of vessels crossing the physis. Vessels of the round ligament run separately

For this reason the **risk of avascular necrosis after neck fractures in children and adolescents is especially elevated:** no possibility of a compensatory blood supply. The absence of a metaphyseal drainage heightens the **importance of the hemarthrosis responsible for an intracapsular pressure increase:** the compression of the superficially running vessels, in particular the thin-walled veins, greatly limits the drainage of the congested blood from the head. Should an immediate surgery in children and adolescents with neck fractures not be possible, **a pressure-decreasing joint aspiration is mandatory.** Our experience has shown that a hemarthrosis empties spontaneously through the drill channel during immediate internal fixation. Therefore an arthrotomy or an evacuation of the blood is not needed during surgery.

In infantile neck fractures there is one positive factor as **M. Müller** emphasized during the AO-courses: **the regeneration potential of children's bones is markedly superior to that of adults' bone.** A timely intervention (internal fixation, osteotomy, pedicled bone graft) (see Fig. 218) may lead to healing and a normal function in instances of a partial necrosis (see Fig. 226).

Five main types of infantile neck fractures must be distinguished depending on their radiologic aspect:

– Transepiphyseal fractures with or without dislocation (usually corresponds to the Salter-Harris types I and II up to the age of 10 years);
– Transcervical fracture;
– Base of neck fracture;
– Cervico-trochanteric fracture;
– Pathologic fracture.

According to **Ratliff** (1962) the **transepiphyseal fracture** is characterized by **a small metaphyseal fragment** attached to the epiphysis (epiphyseal injury type II of the Salter-Harris classification). It may also happen that a small fragment of the epiphysis has broken off.

If a **fracture-dislocation** is present, **an immediate open reduction is obligatory.** If the reduction of small fragments proves impossible, they should be removed. The precise anatomic reduction, the **exact contact between the fracture surfaces** (adaptation), and the reliable internal fixation are indispensable for the regeneration of the broken epiphysis, even if it is has been completely separated (Fig. 218, see also Fig. 80).

The transepiphyseal fractures occur usually after a major trauma and their **prognosis is the worst.** Fortunately, they are very rare. They should not be confused with **epiphysiolyses** caused by hormonal or constitutional factors that are prevalent during puberty. Characteristic for an acute epiphysiolysis is the fact that it can be carefully and easily reduced and can heal well when stabilized with Kirschner wires; they are normally not accompanied by circulatory disturbances (Fig. 219).

The risk of circulatory disturbances is also elevated for **transcervical fractures** (Fig. 220).

The **base of neck fracture** that occurs most frequently runs extraarticular. For this reason its prognosis is usually favorable (Fig. 221).

Recently, the **cervico-trochanteric fracture** has been described; it runs cranially from the head-neck junction to the base of the neck or often distal to the lesser trochanter (Fig. 222).

For practical purposes a difference must be made between the above enumerated fractures and the **pathologic fractures** irrespective of the fact that they occur at the same levels than the other fractures (see Sect. 9.5).

The guiding principle in the treatment of these fractures is **the immediate reduction,** if at possible **within 1–2 hours** after admission. If a closed reduction is not met with success, an **immediate open reduction and internal fixation** is mandatory.

After successful closed reduction of a **transepiphyseal fracture** its fixation through the physis should be as atraumatic as possible. Consequently, we introduce **two to three parallel titanium Kirschner wires** that find a reliable hold in the compact bone. **Cancellous bone screws should not be employed** as they cause an unnecessary loss of cancellous bone. They cause injury to the physis that may cause a precocious bony bridging leading to growth disturbances.

For **transcervical and base of neck fractures in pre-school children** a fixation with three parallel inserted 2.5 mm or 3 mm titanium wires with delicate threads on their tips is sufficient; use of 2.8 mm or 3.5 mm cancellous bone screw may also be envisaged. For **children over 6 years of age we recommend implantation of two and, at the age of puberty, three parallel 4.5 mm cancellous bone screws.** (The use of 8 mm cannulated screws would render aiming more reliable but they are too thick in relation to the femoral head). **The physis should never be perforated with drill bits or screws.** The tip of the screw should **never be closer to the physis than 2 mm.**

In essence, the internal fixation during childhood and puberty for most fractures consists of **a screw fixation between greater trochanter and neck metaphysis.** To achieve this, **cancellous bone screws with a short threaded section** should be used. A longer threaded section that crosses the fracture gap will lead to a separation of the fragments interfering with fracture healing and possibly to screw breakage or non-union!

If the closed reduction is unsuccessful after one or two careful attempts, **one should stop.** A repeated manipulation puts the blood supply at risk. **The hip joint should be immediately opened through an anterior or anterolateral approach.** The reduction is then carried out under visual control.

During this intervention we have observed repeatedly such a high bone density that the tip of the Kirschner wire was deflected by the oblique proximal fracture surface. The wire should be inserted into the femoral head only after use of a spiral drill bit.

If an emergency operation of neck fractures in children or adolescents is impossible for any reason (polytrauma, poor general condition), **a reduction must be done immediately and the leg positioned in traction on a Braun splint. Aspiration of the hemarthrosis should not be forgotten.** After open reduction the blood from the femoral head can seep into the soft tissues through the fracture and beside the implant. If thereafter a persisting hemarthrosis is suspected, a sonography should be done early on and the blood evacuated by aspiration.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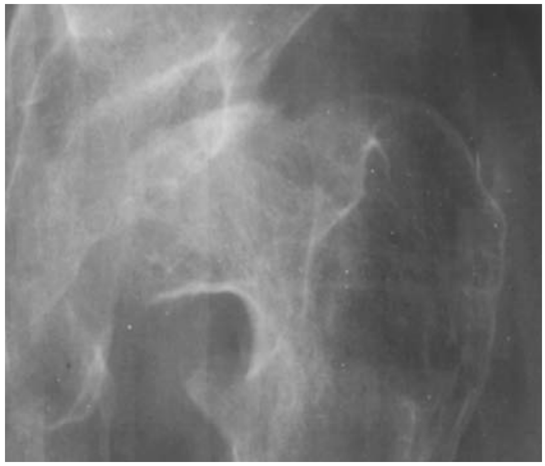

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Fig. 218. Transepiphyseal fracture-dislocation of the femoral neck (Stock et al, 1991; Stock and Hierner, 1994; Hankiss et al, 1995).
This 11-year-old girl sitting in the back seat of a car suffered an injury to the left hip, a commotion and multiple contusions when their car was hit from the left side; **a, b.** Left posterocranial transepiphyseal fracture-dislocation. The radiographs show well avulsed meta- and epiphyseal fragments; **c, d.** The joint was exposed during the emergency surgery, the totally isolated epiphysis was removed, rinsed and replaced. Stabilization with Kirschner wires for valgus tilt, translational displacement by half a bone width as seen in the a.-p. projection and antecurvature as seen in the lateral projection; **e.** Four months later consultation in our institution on account of delayed fracture healing. A tendency for subluxation was also diagnosed; **f.** At this time the femoral head could still be reduced by abduction (the reduced density of the femoral head is very well visible). We recommended continuation of physiotherapy and wait and see; **g.** After three months the symptoms increased. A deformation is starting as seen by the shrinkage and cranial subluxation. Even in abduction an internal rotation was not possible anymore. We opted for a varus osteotomy and fixation with a blade-plate and additional screw fixation; **h.** In spite of a satisfying congruence, the subluxation recurred after one month; **i.** A Chiari osteotomy was therefore performed apparently achieving a reduction of subluxation. Nevertheless, the symptoms persisted; the apparent cause being a progressing avascular necrosis. To assess the blood supply to the head a MRI was done (see Fig. 80) that showed an almost total necrosis; when compared to the unaffected hip. Only the neck and the posterocranial part of the head exhibited an acceptable blood supply. The three dimensional CT reconstruction showed a preserved head contour justifying a revascularization. As a pelvic osteotomy had been done previously we opted in favor of a free pedicled bone graft with the branches of the deep iliac circumflex artery and vein harvested from the opposite iliac crest. (This was the first free transplantation with microsurgical sutures performed in our institute by **Professor W. Stock,** Munich). After five major surgical interventions the girl had no more pain 21 months after the accident. The range of motion of the hip was identical to the opposite side, the limb shortened by 3 cm. She uses a walking aide and a 2 cm heel lift. She is able to bear weight partially and goes swimming; **j.** Radiographs show that the shrinkage of the head does not progress anymore and the joint has widened and is almost congruent, an evidence of regeneration. This is the most remarkable change when comparing the films to those taken before revascularization. Obviously future corrective interventions may become necessary to equalize the leg length discrepancy

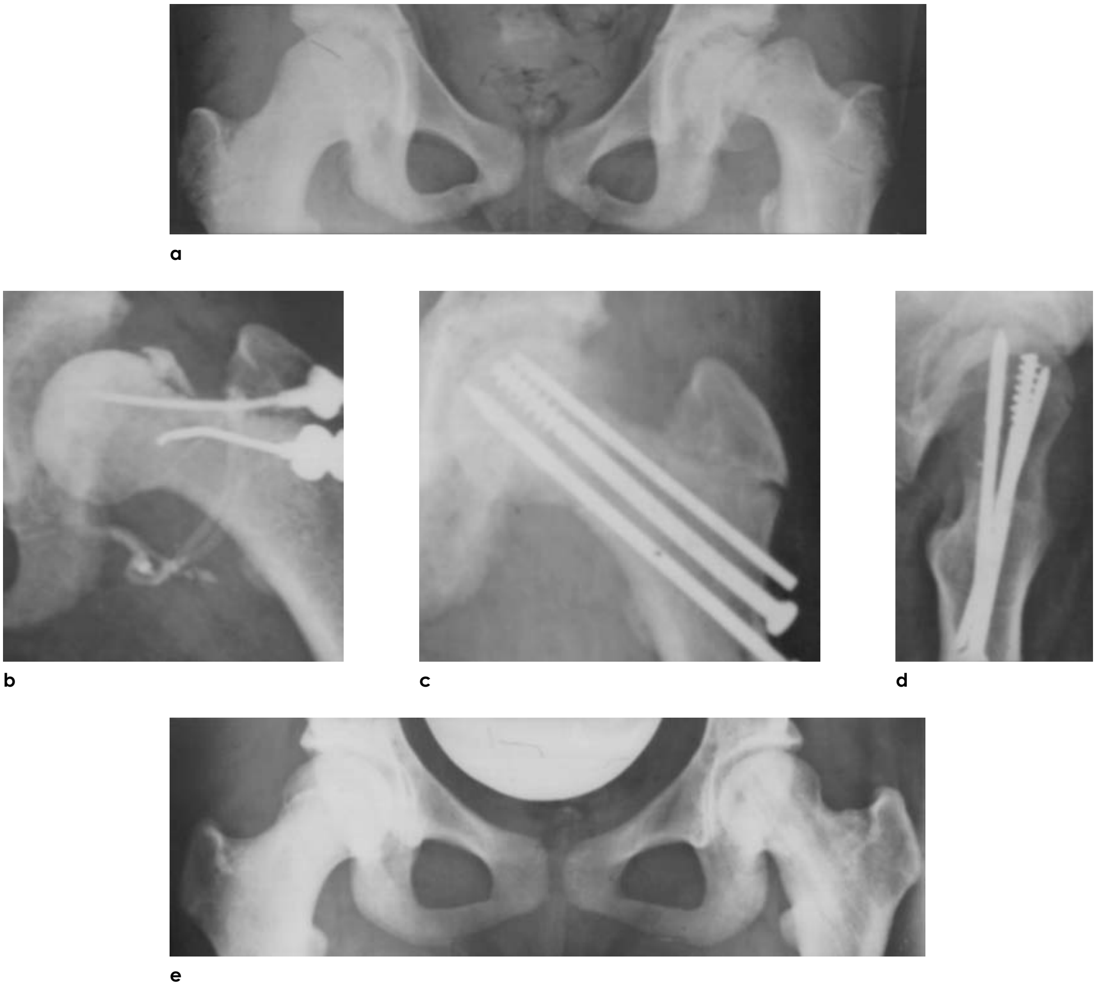

Fig. 219. Non-traumatic epiphysiolysis.
This 8-year-old girl took ballet lessons. For weeks she complained about increasing left hip pain to a point of being unable to walk; **a.** Radiograph shows an epiphysolysis with a varus displacement amounting to 50% of the width of the physis and antecurvature. She was treated by traction; **b.** Thereafter, a very careful reduction was done under anesthesia lasting 30 minutes increasing the traction to 40 kg. The reduction was found to be good. The blood supply to the head was checked with an intraosseous venography; it showed a good drainage through the circumflex vein without any noticeable stagnation; **c, d.** Stabilization with Kirschner wires and a small fragment cancellous bone screw; **e.** Four years later, the girl was symptom-free and the shape of femoral head and neck was identical to the opposite side

Fig. 220. Infantile, transcervical neck fracture.
This 11-year-old boy was run over by a car at the day of admission and admitted to a hospital elsewhere; **a, b.** Right transcervical neck fracture; **c, d.** Seven hours later an internal fixation was done with cancellous bone screws having a short threaded section. Slight valgus position and over rotation. The screw tips do not cross the physis (the lateral picture deceives); e. Five years later the fracture has consolidated in a slight valgus position. To compensate for the leg length discrepancy of 1 cm a lift has been described and the boy is symptom-free

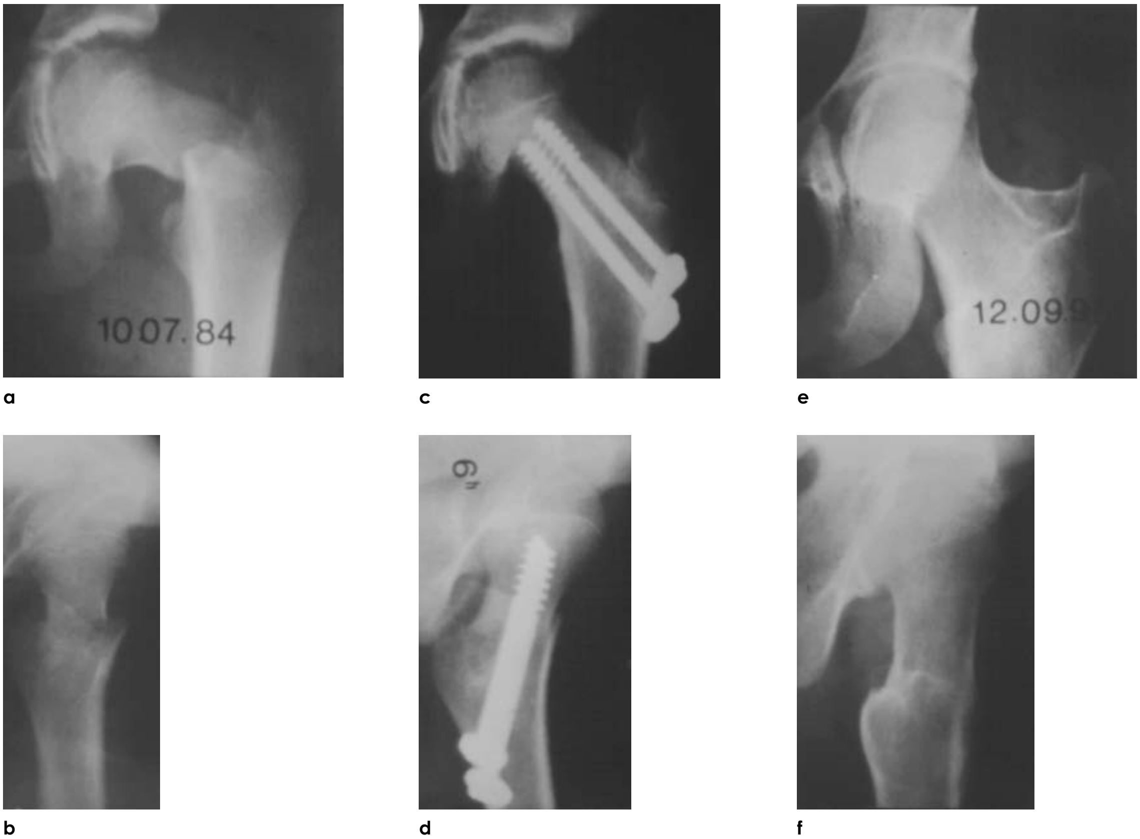

Fig. 221. Infantile, base of neck fracture.
This 5-year-old girl fell in a staircase and hit her left hip; **a, b.** Base of neck fracture; **c, d.** Within six hours closed reduction and fixation with cancellous bone screws, achieving a perfect position; **e, f.** Eleven years later the girl is symptom-free, the fracture has healed and the leg is not shortened

a

b

c

d

e

Fig. 222. Cervico-trochanteric fracture.
The 2 1/2-year-old boy was run over by a car. The initial treatment was done elsewhere and the boy transferred in a temporary cast to our institution; **a. b.** Right cervico-trochanteric fracture. During the stabilization of his general condition a traction was applied; **c. d.** On day 3 the fracture was reduced open and fixed with a cancellous screw and a Kirschner wire to achieve a tension band effect of the avulsed greater trochanter; **e.** Two years after the accident a minimal valgus position persists, position of head and neck is normal, the contours preserved

9.4 Treatment of stress fractures of the femoral neck

Many authors have elaborated on the **conservative treatment** of stress fractures of the neck and discussed the prerequisites based on clinical and radiologic findings (Jeffery, 1962; Ernest, 1964; Devas, 1965; Erne and Burckhardt, 1980; Kaltsas, 1981; Menoman et al, 1981; Sloan and Holloway, 1981; Ochy and Vogt, 1985; Tountas and Waddell, 1986; Meine, 1991; Kerr and Johnson, 1995; Bucinto et al, 1997; Parker and Tremlow, 1997).

Clinical criteria:
– Complete passive range of motion;
– Active lifting in extension.

Radiologic criteria:
– Good impaction in both projections;
– No displacement.

We believe that these criteria are only valid for the rare compression stress fracture. A distraction fracture without displacement can only be considered during the early phase; but these fractures are only rarely seen at that point. The **compression stress fracture consolidates normally without surgical treatment** after six weeks of non-weight bearing (Devas, 1965; Erne and Burckhardt, 1980; Menoman et al, 1981; Tountas and Waddell, 1986). In young active patients, in non-cooperating individuals or in instances where pain increases after the initial phase (progression), it is advisable to perform a minimally invasive stabilization with one or two cannulated screws or pins. The pain subsides rapidly after internal fixation and one can allow weight bearing without qualms (Fig. 223).

In our patient population the **distraction fractures,** be they transverse, lateral or cranial, predominate. In more recent years we stabilized them with two cannulated screws supplemented by a caudal 2 mm two-hole plate. Fractures with a marked displacement and thus a disturbance of head circulation and therefore candidates for an arthroplasty have not been observed by us during this time. Based on the history, however, we presume that some displaced neck fractures seen by us were originally stress fractures; however, at earlier times an elucidation of their pathogenesis had been impossible. Fractures treated by internal fixation always consolidated and we never observed instances of head necrosis secondary to vascular disturbances (Fig. 224).

In the varus position shown in Fig. 224 the lever arm to which the force is applied increases. This lever arm is defined by the distance between the center of the femoral head and Adam's arch; it leads to an increased loading of the third buttressing point. In this case the use of an angle-stable plate is indicated. Today, we use for stabilization of such a fracture a **DCD plate,** mostly of 120º. A further advantage of the DCD plate is the use of the compression screw that reduces or eliminates the gaping of the fracture. At the same time, it protects against forces causing a displacement (tilting) (see Figs. 145 and 146).

Finally in Fig. 225, we demonstrate a patient where an incorrectly performed surgical procedure was the probable cause of repeated stress fractures (Cserháti, 1991).

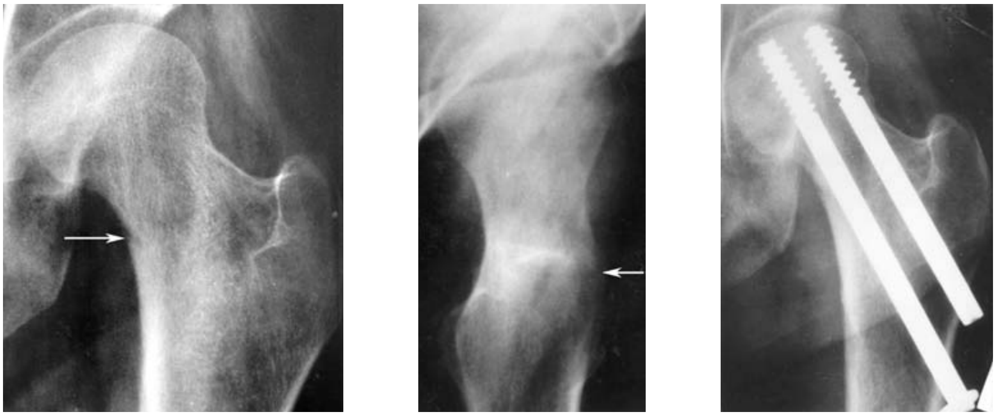

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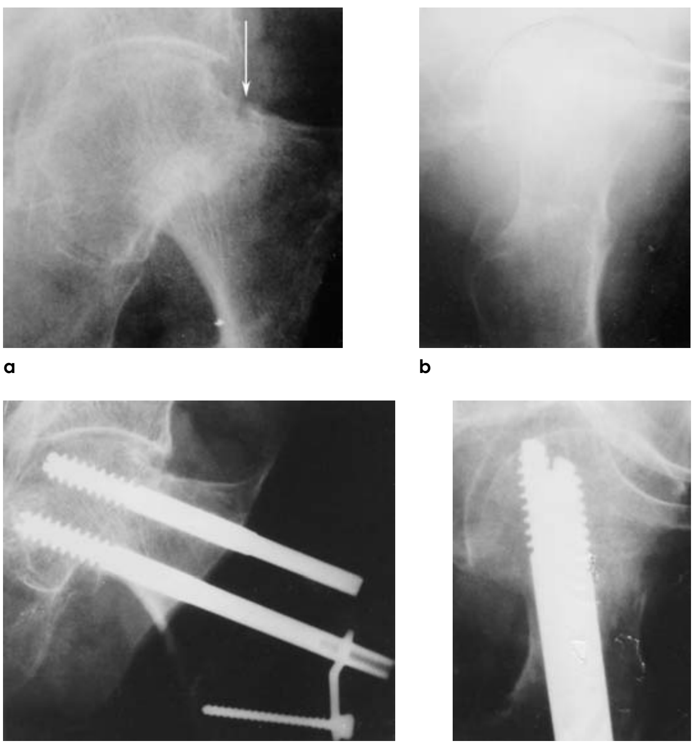
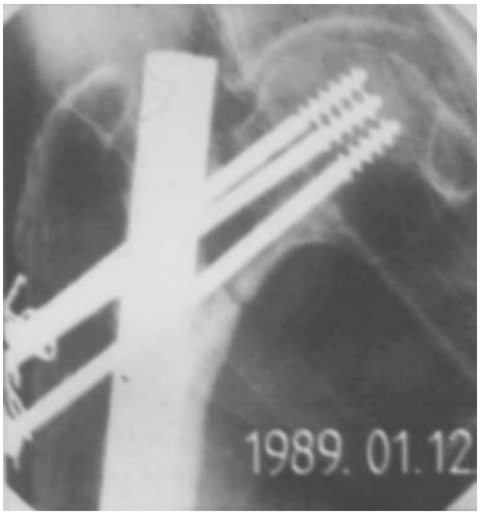
Fig. 223. Compression stress fracture.
This 41-year-old patient could not recall any accident. Since two weeks she felt pain in her left hip; **a, b.** Radiographs show a compression fracture at the level of Adam's arch (arrows); **c.** Two years after fixation with two cannulated screws the fracture is healed and the patient symptom-free



a b c d

Fig. 224. Distraction stress fracture.
This 72-year-old lady complained about an increasing vague pain of her left hip; **a, b.** Radiographs show a coxa vara most probably the cause of the distraction fracture (arrow). The varus displacement is minimal; **c, d.** One year after fixation with two screws the fracture has consolidated. Corresponding to the varus position the screws also lie in varus

Fig. 225. Repeated bilateral stress fractures.
This 56-year-old woman fell at work from the loading platform of a truck and broke her left femoral shaft. She was treated elsewhere with a 9 mm intramedullary Küntscher nail inserted retrograde. The guide wire was inserted through the fracture site in a cranial direction; **a.** A hypertrophic non-union developed. She used crutches and came to our institute nine months later; **b.** We exchanged the nail and after reaming inserted antegrade a 16 mm nail without opening the fracture site; **c.** Two years later the fracture had healed and the function was good. A shortening of 3 cm was compensated by a lift; the nail was removed; Eleven years later she fell while riding a bicycle and suffered a right femoral shaft fracture. An intramedullary nailing was again done in the same hospital using an identical technique. A technical error occurred intraoperatively: the guide pin was placed too medially and broke through the cortex of the neck. She walked with crutches and came to our institute after five months; **d.** The nail exceeded the tip of the trochanter by 7 cm causing pain in the right hip (the fracture was not healed); **e.** After removal of the nail we performed a closed reaming and insertion of a new nail through the base of the neck. She did not complain about her right hip anymore, but due to the use of crutches she overloaded her left hip that became again painful. Seven months later, a fatigue fracture of the left femoral neck was diagnosed. In yet



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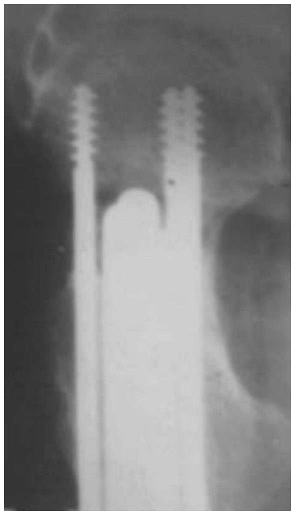
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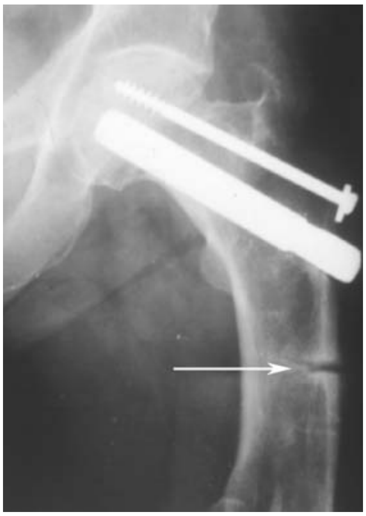
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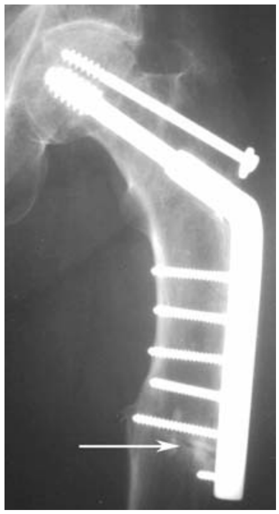
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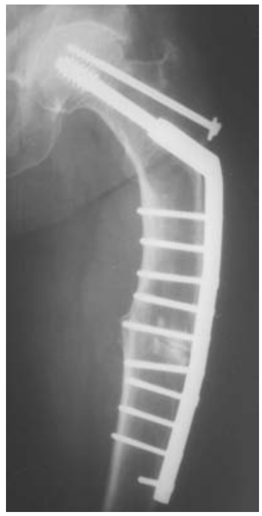
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another hospital this fracture was treated with a Smith-Petersen nail and plate and cancellous bone screw. Again while overloading the right hip using crutches, the right hip became symptomatic. On account of increasing pain the patient consulted us eight months later; **f.** Radiographs showed a right sided distraction stress fracture of the femoral neck with gaping (arrow); **g, h.** At the beginning of surgery while positioning the limb according to our protocol we heard a cracking. A complete fracture was seen on the monitor; it was not displaced as the limb had been fixed on the traction table. As it was too early to remove the intramedullary nail, we inserted next to it three cancellous bone screws and performed a cerclage wiring over their ends thus achieving a tension band effect; **i.** Ten months later the patients was symptom-free and the right-sided neck fracture had consolidated. As the plate attached to the Smith-Petersen nail gave rise to pain of the left hip, it was removed in the other hospital; **j.** Six months later, a femoral shaft stress fracture was diagnosed at the site of cortical screw. We performed a DHS plate fixation after removal of the Smith-Petersen nail; **k.** Subsequently, an undisplaced stress fracture developed at the site of the previous shaft fracture; **l.** We exchanged the DHS plate against a longer one. Only thereafter (after nine major interventions) did the patient become symptom-free. This case should direct our attention to the sequelae of errors made during the currently popular intramedullary nailing

9.5 Treatment of pathologic femoral neck fractures

Our subsequent discussion will be directed towards the treatment of various pathologic fractures and our surgical treatment aiming at the preservation of the femoral head in a sequence outlined in Sect. 2.3.

9.5.1 Treatment of pathologic neck fractures due to bone cysts

Our treatment approach is documented by clinical examples (Figs. 226–228).

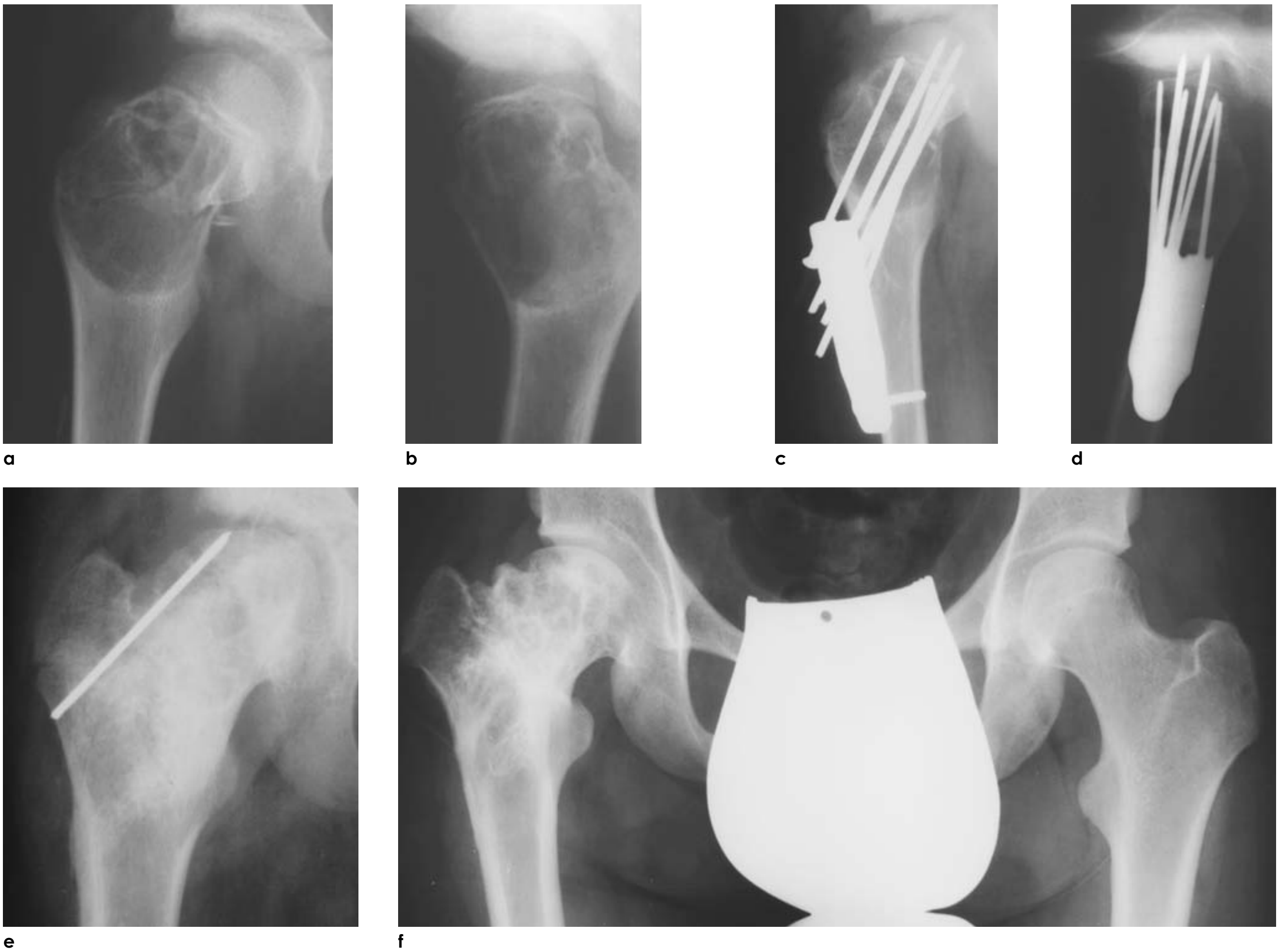
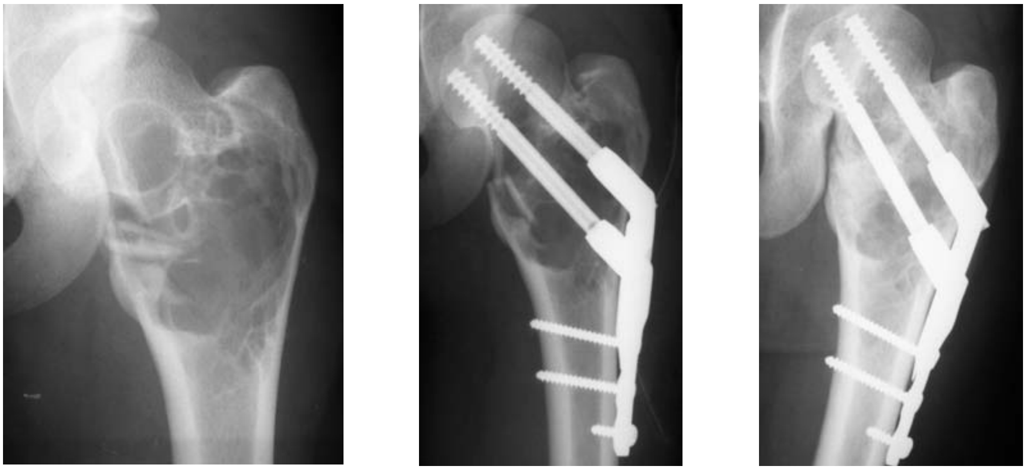


Fig. 226. Pathologic fracture caused by a juvenile bone cyst.
This 10-year-old boy fell during a soccer game; his right leg was in external rotation, he was unable to walk; **a, b.** Radiographs taken the next day showed a right-sided neck fracture in the presence of a large juvenile bone cyst involving neck and trochanter; **c, d.** During surgery a massive angle-stable Deyerle plate and three wires having threads at their tips were used. In addition, the epiphysis was fixed with two Kirschner wires. The cyst was curetted, exposing a large defect in the bone wall. The cavity was later filled twice with cancellous bone from the bone bank; **e.** One and a half year later, we observed a loss of head sphericity at the weight bearing area. We transferred to the neck and head a pedicled bone graft attached to the quadratus femoris muscle and stabilized it with a Kirschner wire; **f.** After 19 years the remodeling of the femoral head, its anatomic contour and the multiple small cysts and/or resorption cavities in head and neck are well seen. A shortening of the femoral neck by 3 cm is evident when comparing the neck length to the opposite side; it was compensated by the growth in length of the femur leading only to a 1 cm leg length discrepancy. The function is almost normal, due to the cranial migration of the trochanter a slight Trendelenburg sign is present. The patient played basketball for years. Today, 25 years after the initial accident, he is symptom-free and is completely able to function as a judge

Fig. 227. Pathologic fracture due to a bone cyst in an adult.
This 32-year-old woman felt a cracking of her right hip without a fall. Thereafter, she was unable to walk; **a.** Right pathologic neck fracture with an extensive bone cyst that reaches into the neck and trochanter; **b, c.** The cyst is particularly well seen after reduction and traction; **d.** The intraosseous venography showed a good drainage. The cavity in the head area is also filled with the contrast agent. It is evident that the femoral head consists only of a small half-moon shaped remnant; **e.** We stabilized the fracture with two Pugh nails and attached a plate to the cranial nail. The intraosseous venography after internal fixation remained positive; **f, g.** After one year we removed the caudal nail and implanted a bone graft from the bone bank. Later on, the second Pugh nail was replaced by a Smith-Petersen nail and the plate removed; **h, i.** Twenty-three years later we replaced the migrated nail by a titanium screw as a precaution. Her entire period of disability during all surgeries combined was less than one year. She is now symptom-free. The leg is 2 cm shorter, but the hip function is almost complete



a b c

Fig. 228. Pathologic fracture due to a bone cyst during puberty.
This 17-year-old girl fell from a horse; **a.** Extensive bone cyst in the left neck area, comminuted neck fracture and displacement of the head in varus. At the day of accident, internal fixation with two cannulated screws and double DCD plate under image intensification; **b.** This postoperative film demonstrates a stable internal fixation in slight valgus. The patient used walking aids with partial weight bearing for three months; weight bearing was gradually increased to a point after 6 months when she could walk with full weight bearing; **c.** Two years after the accident the fracture has remodeled, the femoral head is spherical and shows a normal trabecular structure. The joint is intact and the patient walks without a cane. When comparing to the opposite side the function of both hip joints is nearly identical. For the treatment of extensive bone cysts the choice of the DCD double plate has proved to be ideal

9.5.2 Compression fracture in osteomalacia

Rickets in adults (osteomalacia) and the resulting **Milkman's pseudo-fractures** are nowadays rare (Magilligan and Dulligan, 1952). Bones that have lost part of their mineral content and thus their strength buckle at the medioposterior aspect of the neck resulting in a varus position under load (similar to Looser lines in children suffering from rickets). According to **Devas** (1965) compression fractures due to osteomalacia belong to the group of stress fractures; they heal spontaneously with a large endosteal callus (Fig. 229).

9.5.3 Femoral neck fractures in osteopetrosis (Albers-Schönberg disease, marble bones)

The etiology is a congenital defect of the osteoclast function. The malignant osteopetrosis is a recessive autosomal disease that is seen in children and that usually leads to a demise during the first two decades of life (Hinkel and Beiler, 1955; Hasenhuttl, 1962). Progression is rapid mainly due to anemia secondary to the replacement of red marrow by bone and due to infection. A very dense, hard and brittle bone is the consequence of the hyperactivity of osteoblasts. Bone is also inelastic and fragile. The foramina where the cranial nerves exit at the base of the skull narrow and are responsible for visual and acoustic disturbances (Fig. 230).

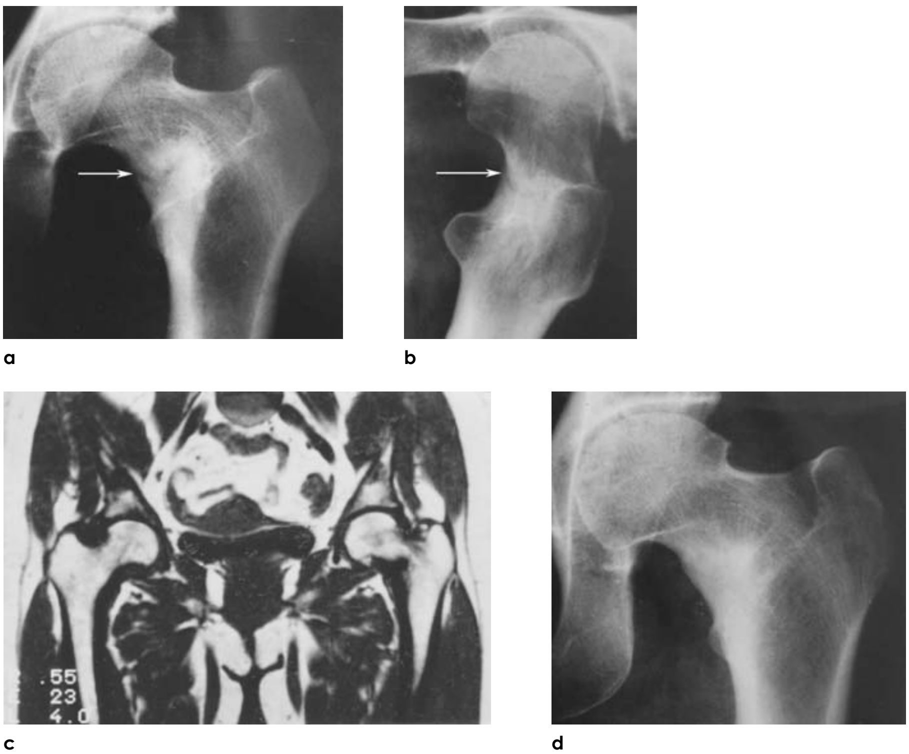


Fig. 229. Compression fracture of femoral neck in osteomalacia.
52-year-old woman. Complaints about both hips and other joints started six years ago. Radiographs, MRI and tests of metabolism confirmed the diagnosis of osteomalacia; **a, b.** At the level of the left neck caudal to the Adam's arch a broad bone density is seen surrounding a Looser's line (arrow). Coxa vara; **c.** MRI shows a low signal intensity at the level of the left Adam's arch and caudally at the neck. We started treatment with vitamin D and followed the patient regularly. After one year the zone of the pseudofracture narrowed; **d.** After three years the zone has remodeled spontaneously, no complaints were voiced anymore

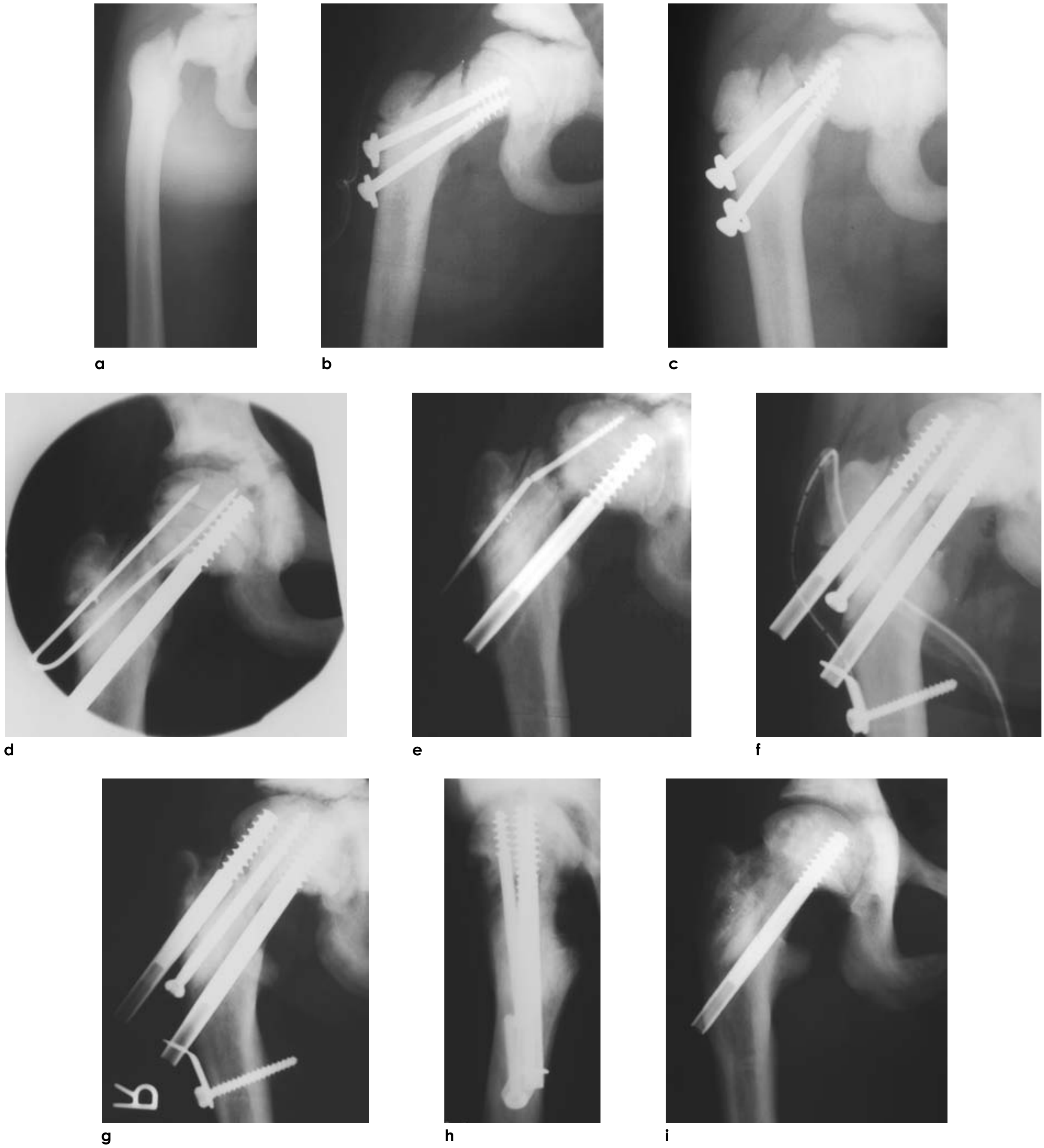


Fig. 230. Femoral neck fracture in osteopetrosis.
This 12-year-old boy is unable to walk and deaf on account of a known osteopetrosis. He fell at home; **a.** This radiograph shows a smooth, vertical fracture of a radiodense right femoral neck; **b.** The fracture had been operated twice elsewhere; **c.** No consolidation ensues, to the contrary a loss of reduction occurred; **d.** The third operation was done in our institute and consisted of an internal fixation with cannulated titanium alloy screws and two Kirschner wires; **e.** After one month we observed a breakage of the wire and a renewed loss of reduction. Based on the positive angiogram we decided in favor of a repeat internal fixation; **f.** For internal fixation we employed two cannulated titanium alloy screws and a cancellous bone screw; **g. h.** Two years later the fracture had remodeled, the implants were removed with the exception of one cannulated screw; **i.** Three years later head contour and joint space are preserved. The patient is pain-free. His condition is similar to that present before the accident

9.5.4 Femoral neck fracture in osteosclerosis

The generalized osteosclerosis is similar to the marble bone disease. The symptoms, however, are less pronounced. The disease usually starts in adulthood (Greene and Torre, 1985) and is due to an autosomal dominant transmission. Its course is symptom-free in 40% of patients (Figs. 231 and 232).

Both examples illustrate the problems arising during surgical treatment. Even more dramatic were the problems encountered in a tall, young man with a fracture of a markedly sclerotic femoral shaft we observed in the sixties. At two different hospitals attempts at an intramedullary nailing were done. In the first hospital the underlying disease was not recognized, even the pathologically narrowed medullary canal escaped their attention. The nail got stuck in the medullary cavity. After exposing the fracture site the tip of the nail was seen incarcerated in the proximal fragment. Attempts of freeing it were unsuccessful. All available extraction devices broke. Therefore the patient was transferred to a secondary care hospital, where attempts were as unsuccessful. Finally the patient was brought to our hospital in an ambulance, accompanied by the broken instruments. The nail end projecting 15 cm above the trochanter was severely deformed. Purulent wounds were present at the level of the fracture and beside the protruding nail. After a lengthy preparation we started surgery. Pelvis and feet of the patient were fastened to the operating table. A hollow rod was welded to the extraction device for Küntscher nails. The protruding end of nail was then drilled transversely with a special metal drill

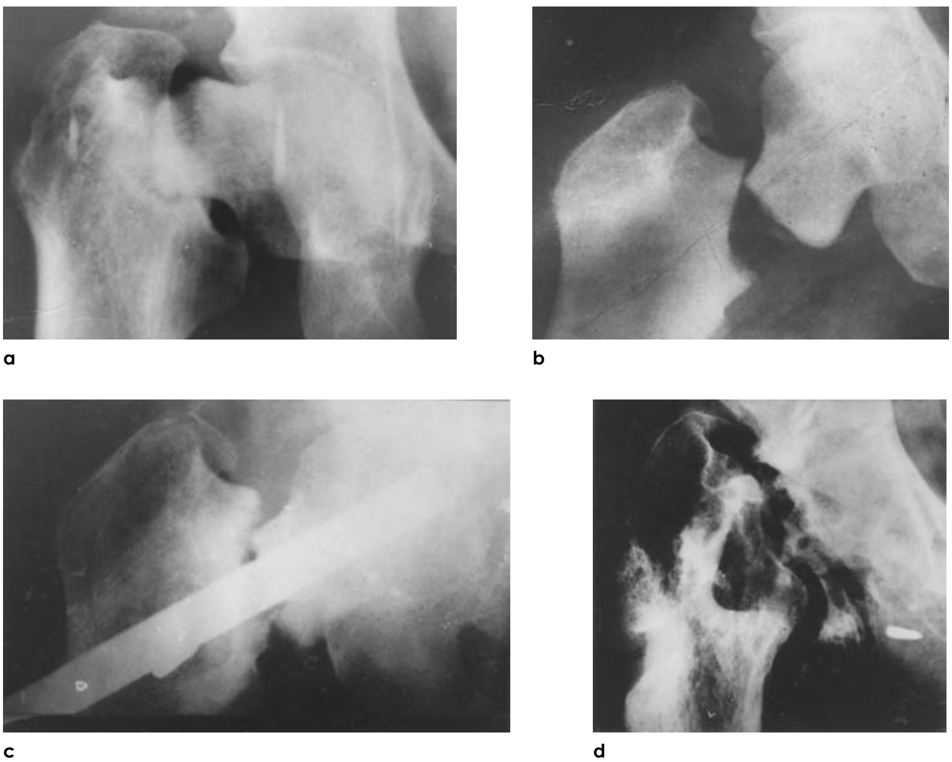


Fig. 231. Femoral neck fracture in osteosclerosis (Patient 1).
This 40-year-old woman suffered a pathologic neck fracture in 1960; **a.** The compact trabecular structure and the smooth fracture surfaces are characteristic for osteosclerosis; **b.** This is particularly well seen in radiographs with the limb in traction. The nail could only be inserted after drilling and even then with greatest difficulties. Its hold was inadequate; **c.** A loss of reduction occurred. One month postoperatively an infection developed with fistula formation, most probably a consequence of the very traumatizing intervention. Finally, nail and femoral head were removed; **d.** A serious deformity resulted. State after Girdlestone resection, painful limping

bit and the modified extractor riveted to the metal drill bit. Only then did we succeed with heavy blows of the slotted hammer to extract the nail. A consolidation of the diaphyseal fracture took place after months in traction. The patient was then discharged home. At a follow-up after many months a fistula was present. The fracture site was exposed. We found an abscess cavity in the heavily scarred tissue between the extensive callus bridges and extracted a 1.5m long gauze strip! We were convinced that in none of two hospitals this unusually big compress had been seen during the heroic operations. After its extraction the wound healed rather fast.

We learned from this experience:

- **In younger patients keep the diagnosis of osteosclerosis in mind;**
- **Even a tall person can have a narrow medullary canal.**

A more careful clinical examination and a proper analysis of the radiographs could have avoided such a difficult operation and also the serious complications. Meticulous history taking will furnish a reliable clue. Special attention should be paid to a marked radiodensity of the neck, a pathologic thickening of the cortices, a narrowing of the medullary

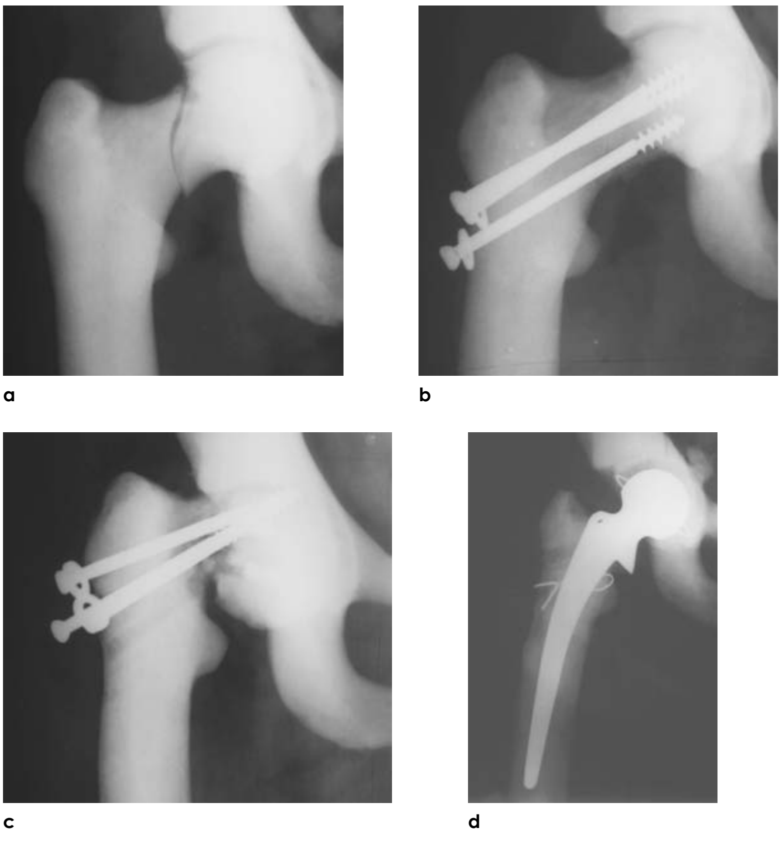


Fig. 232. Femoral neck fracture in osteosclerosis (Patient 2).
37-year-old woman with generalized osteosclerosis; **a.** Right, vertical neck fracture (coxa vara); **b.** Elsewhere internal fixation with cancellous bone screws; **c.** Loss of reduction; **d.** After transfer to our institute we reamed the medullary cavity and proceeded with a cemented total joint replacement. A cortical fragment, broken off during surgery was replaced with cerclage wires. Nowadays, we would treat such a fracture accompanied by a coxa vara differently: internal fixation with cannulated screws and DCD plate applying compression at the same time

canal and the smoothness of the fracture surfaces. A preoperative assessment of the circulation of the head may be helpful. Only thereafter should a stable internal fixation be done after drilling.

9.5.5 Femoral neck fractures after poliomyelitis

After the last great polio epidemic in 1957/58 we treated during the ensuing 15–20 years approximately 20 neck fractures in polio patients in our institute. Since then neck fractures in polio patients have only been observed sporadically (only two in 1998). We would like to submit our experience gained over decades: the femoral neck fracture of the atrophic limb is **less displaced,** most probably due to the muscle weakness. For the same reason a **distraction** of the fracture often occurs during reduction (see Fig. 175). Two screws give sufficient stability in the small bone. The **healing potential** of these fractures is excellent. Serious head **necroses were not seen in any of the followed up patients.** We believe that this is the consequence of the **reduced pressure exerted on the femoral head** as the atrophic muscles cannot pro-

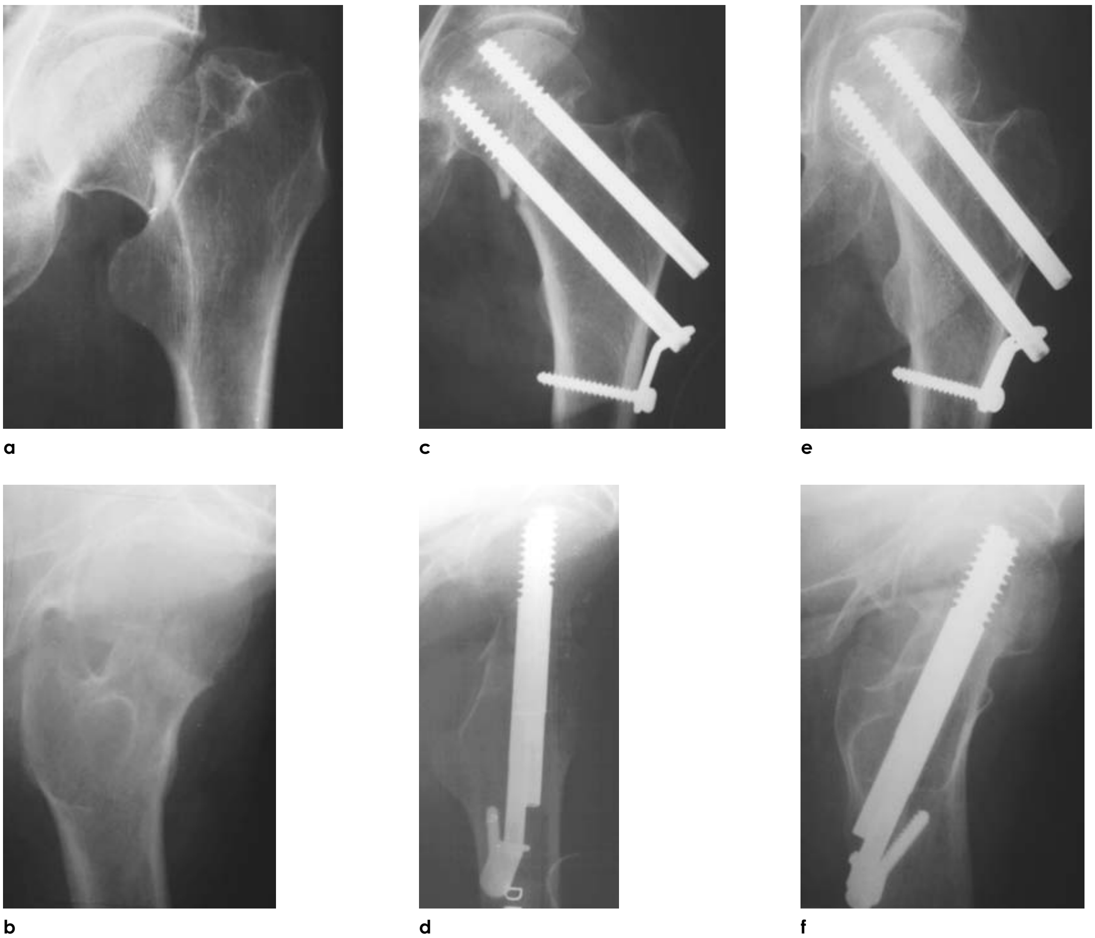


Fig. 233. Femoral neck fracture after poliomyelitis.
This 65-year-old woman had polio as a child. She was able to walk with two canes and fell on the day of admission; **a, b.** Left Garden-IV neck fracture; **c, d.** Stabilization with cannulated screws in valgus position, distraction and over rotation. Eight days later the fracture gap has closed after mobilization; **e, f.** Three years later the fracture has healed, the femoral head is spherical and the joint space preserved

duce any force. Should a partial necrosis occur, it will not lead to a head collapse. As a rule the young bone has sufficient time to regenerate (Fig. 233).

9.5.6 Femoral neck fractures in osteogenesis imperfecta

Osteogenesis imperfecta is a connective tissue disease that is usually characterized by autosomal dominant transmission (the autosomal recessive type leads to death in early childhood). Similar to osteopetrosis a congenital and a later appearing form are known. The congenital form can be recognized by intrauterine fractures and by bone deformities already apparent at birth. Typical for this disease is the absence of periosteal bone formation. Symptoms include a transparent blue sclera, deafness, deformation of the vertebral column and foremost the **extreme fragility of bone.** Later appearing forms can imitate a juvenile or postmenopausal osteoporosis (Fig. 234).

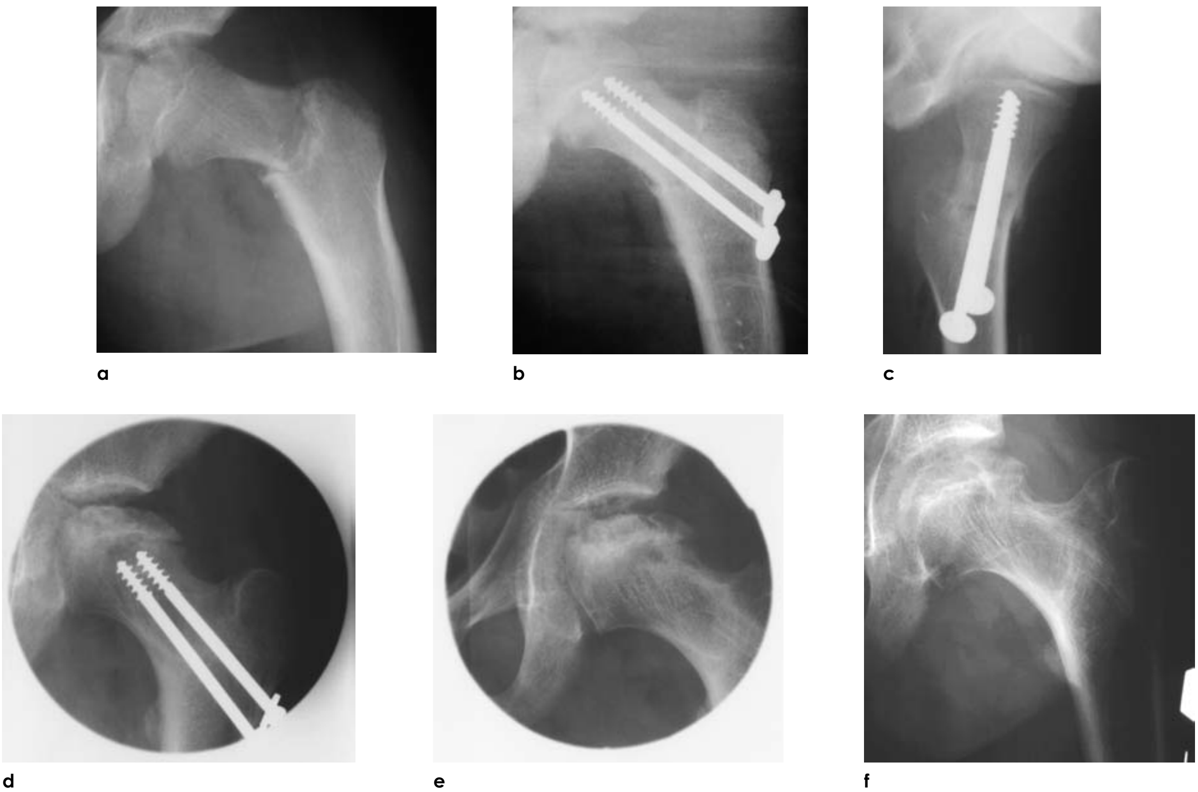


Fig. 234. Femoral neck fracture in osteogenesis imperfecta.
This 13-year-old boy with a known osteogenesis imperfecta is deaf, both limbs are deformed (genu varum), he walks with a cane. During a fall he injured his left hip; **a.** Base of neck fracture, displaced in varus; **b. c.** After transfer to our institution we stabilized the fracture in proper position with cancellous bone screws four days after the accident; **d.** The fracture consolidated but after one year we observed signs of an epiphyseal necrosis, the screws were removed; **e.** Three months later the necrosis had progressed.
No weight bearing was permitted; **f.** 2.5 years after the injury the head was almost remodeled, the contour spherical, the joint space remained congruent. The boy returned to his normal activities of daily living

9.5.7 Femoral neck fractures due to primary tumors or metastases

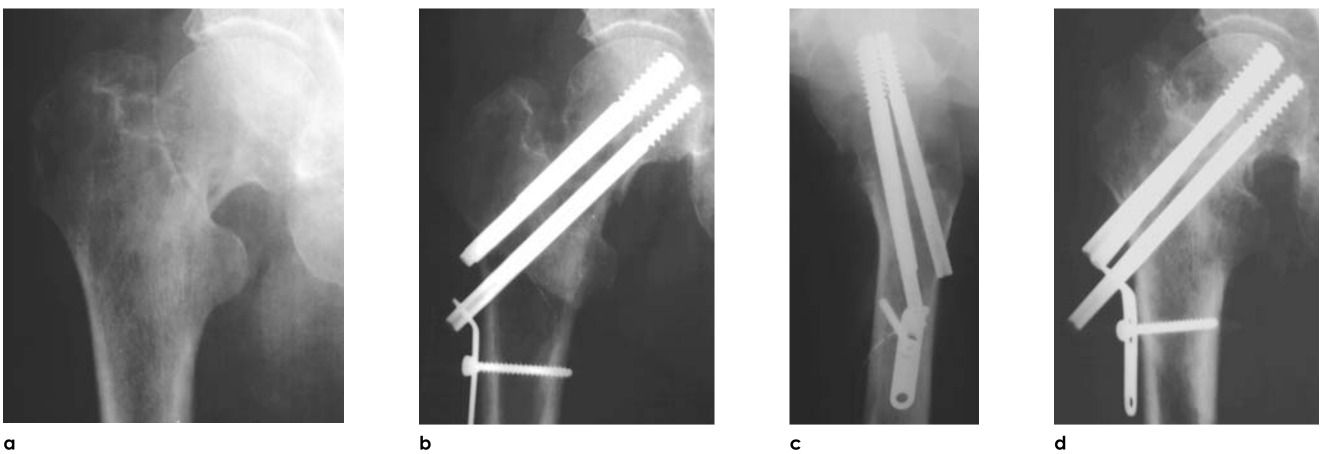
The treatment of fresh femoral neck fractures due to metastases poses many problems (Tachdijan et al, 1959; Ehlers and Grimschl, 1960; Poigenfürst et al, 1968; Cotta and Roche, 1984; Berentey, 1989; Mutschler et al, 1989; Friedl, 1995). In the presence of **disseminated metastases** a solution must be sought that will facilitate the **care** of the patient. We recommend **internal fixation with two or three cannulated screws, possibly supplemented by bone cement or bone substitute material.**

If the diagnosis of the primary tumor cannot be established right away, we recommend for high-risk patients with fresh neck fractures due to metastases a **minimal internal fixation** with two percutaneous screws done under local anesthesia. The primary goal is relief from pain. If a chance exists for even a temporary mobilization, **supplementary procedures for the improvement of stability** should be considered: internal fixation with two or three cannulated screws and 2 mm plate or angle-stable DCD plate or double DCD plate.

The percutaneous screw fixation can and should be done in the presence of **severe pain,** even when a cure of the underlying disease or a healing of the fracture cannot be expected and when the patient is in poor general condition. **A suffering person is entitled to an adequate pain relief, not only achieved with medication but also with a minimally stressful stabilizing internal fixation.**

We also might be dealing with a fracture secondary to a primary femoral neck tumor or more frequently to a solitary metastasis. If more detailed investigations (bone scan, tumor markers) exclude other metastases and if it seems possible to remove the primary tumor, a **hemiarthroplasty or a tumor prosthesis is indicated** for the sake of a complete resection of the tumor (Poigenfürst et al, 1968; Berentey, 1989; Mutschler et al, 1989; Friedl, 1995; Baktai et al, 1998).

Contrary to earlier decades, where rickets and poliomyelitis predominated, we recently see an in-



a b c d

Fig. 235. Multifragmentary neck fracture due to metastasis.
The 76-year-old patient had been treated for a prostate cancer for three years. He has a permanent indwelling urinary catheter. Three months previously he suffered a pathologic fracture of the left sixth rib. At the day of admission her tripped in his apartment, but did not fall. He felt a cracking at the right hip and was unable to walk; **a.** Garden-III fracture with fragments avulsed from the anterior and posterior cortex and Adam's arch. The suspicion of a metastasis was raised by shadows of increased translucency in head and neck and the ill-defined structure of the fragments; **b, c.** Internal fixation with three screws, the caudal screw was attached to a 2 mm three-hole plate. In spite of the slight distraction the position is acceptable; **d.** Up to the time of the only follow-up after two months the patient was able to ambulate with a walker. The shortening of the femoral neck is due to a marked settling (10 mm) without loss of reduction. His subsequent fate is unknown to us

creasing number of pathologic neck fractures due to metastases of carcinomas. These fractures present biomechanical challenges. In the first year after introduction of cannulated screws we had no procedures at our disposal to increase the stability. Later on, we were able to achieve the ability for the patient to walk at least temporarily with weight bearing, even in the presence of multiple metastases.

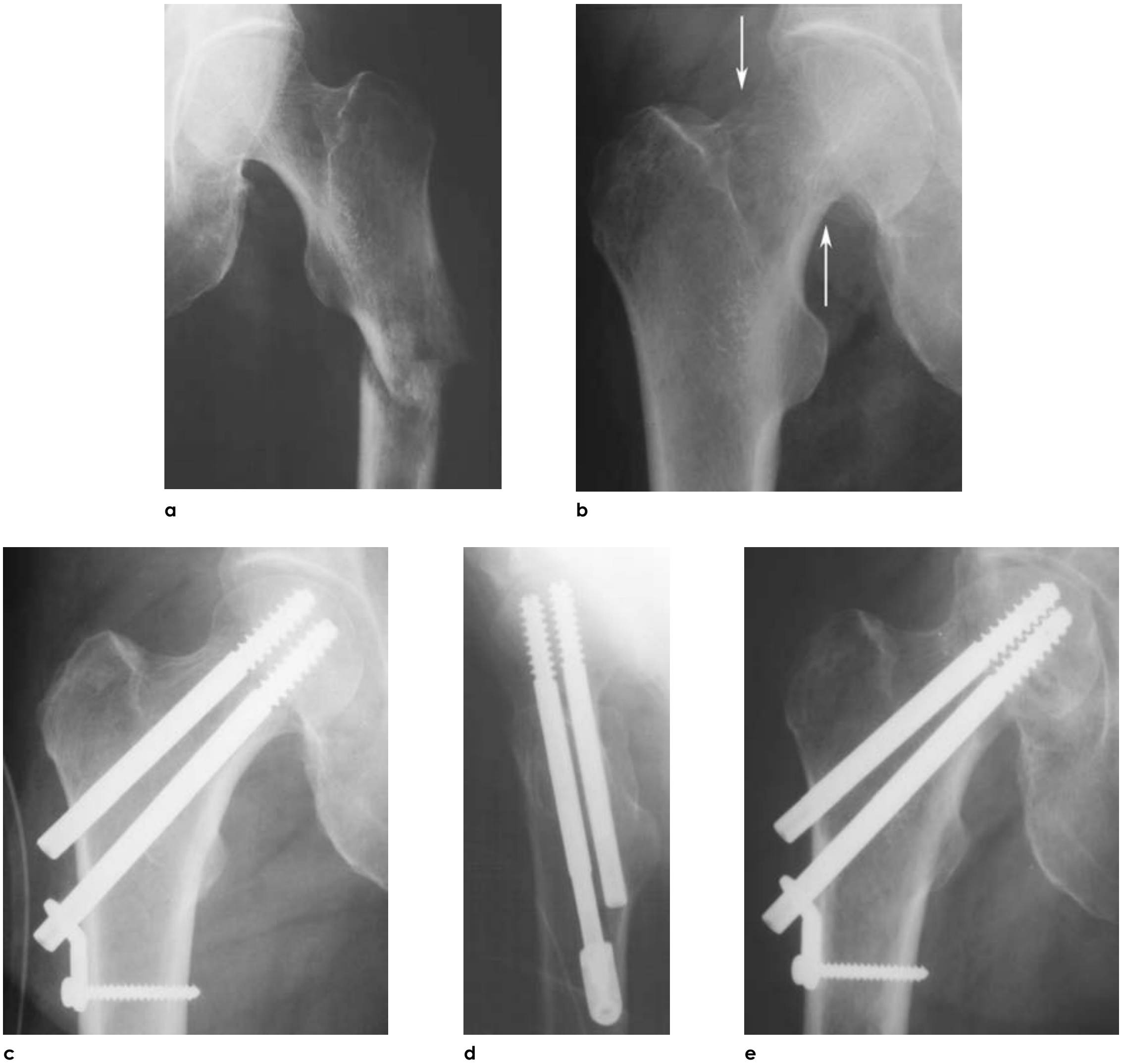


Fig. 236. Undisplaced femoral neck fracture due to a metastasis.
This 63-year-old woman had a left mastectomy for cancer one year previously. At the time of her fracture she was treated for multiple metastases. While sitting down at home she felt a cracking at her left thigh and was unable to walk; **a.** At the time of admission a left pathologic subtrochanteric fracture was diagnosed. While preparing the patient for surgery, she mentioned pain in her right hip, present for some weeks; **b.** A.-p. film showed a barely displaced right neck fracture slightly tilted in varus. The cranial straightening of the "S" (see Fig. 179) and the caudal kinking are well seen (arrows), the delicate subcapital trabecular structure (irregular line) is interrupted and resembles a stress fracture. The disappearance of trabeculae in the cranial part of the neck is easily recognized (arrows). The radiologic findings speak in favor of a pathologic process; **c, d.** The right hip was stabilized with cannulated screws and the left subtrochanteric fracture with a blade-plate. Histologic examination of the biopsies harvested through the drill channels confirmed on both sides the diagnosis of metastases; **e.** Five months later the position of the femoral neck fracture remained unchanged. The patient circulated with a walker

The stabilizing procedures include a 2 mm two- or -three-hole plate, fixation with three screws and use of a DCD plate or double DCD plate (see Figs. 139 and 143).

Advanced metastases can also appear as **multifragmentary fractures** (Fig. 235).

Sometimes it is difficult to diagnose a fracture and its underlying disease process. Due to multiple metastases the patients voice complaints at multiple sites and mostly severe pain. They are often admitted in poor general health after chemotherapy or radiation, perhaps in a state of a paraneoplastic syndrome or they are under the influence of narcotica (Bickel et al, 1961). In these instances particular attention has to be given to make certain that the hip pain is not due to a femoral neck fracture. An internal fixation is much easier done at that moment than before a displacement of the fracture has occurred (Fig. 236).

Chapter 10

POSTOPERATIVE TREATMENT, EARLY COMPLICATIONS

10.1 Early postoperative treatment and problems encountered during this period

10.1.1 Postoperative regimen

A prerequisite for an uneventful healing is a meticulous postoperative surveillance and care. State of consciousness, blood pressure, heart rate, respiration, fluid intake and output and laboratory tests have to be checked.

The patient's body temperature usually **falls** in the air-conditioned operating room in spite of many precautions. The duration of transport from the operating to the recovery room or to the ward should be as short as possible. The postoperative warming up on the ward is often accompanied by a slight shivering. This shivering can increase considerably the oxygen consumption. Heart and lungs of the elderly patients are unable to meet the oxygen requirement due to their reduced function resulting in **hypoxia. Humidified oxygen delivered through a mask** is of great help in elderly patients who are often in a poor state of health.

After surgery under **general anesthesia** the decreased body temperature may lead to a delayed action of the administered drugs and to a delayed return of protective reflexes. Anesthetic agents still retained by the body may **prolong the time to wake up** resulting in **hypoventilation.** Due to inadequate cough reflexes a **retention of secretion** in the airways may occur; it could lead to **atelectases** and later to **pneumonia.**

For these reasons one should attempt already during surgery to keep the heat loss to a minimum (warming blanket, warming pads and mattress, insulating sheet on the table or operating table with heat pad). If the heat loss cannot be prevented completely in spite of these measures, shivering must be eliminated as soon as possible.

Elderly patients often reduce the fluid intake after surgery under **local anesthesia.** Depending on the extent of surgery intravenous fluids have to be administered. Quantity and composition of the necessary fluid replacement are prescribed according to the general condition of the patient, the blood pressure, pulse rate, urinary output and laboratory findings.

After surgery under **spinal anesthesia** a strict horizontal positioning is not necessary in elderly patient. Headaches after spinal anesthesia are rare in patients over 60 years of age. Horizontal positioning is disadvantageous for respiratory function. As soon as the effect of anesthesia has ceased, the patient is allowed to move all four limbs and to sit up for drinking and eating.

A **urinary retention** may happen after general or regional anesthesia. A distended bladder gives rise to marked symptoms, sometimes appearing like an acute abdomen. The retained urine may become a source of infection. This is another reason for checking the urinary output. In general, diagnosis and treatment do not pose any difficulties. Percussion will reveal the size of the bladder. Voiding may be helped by encouragement (noise of running water), abdominal compression with warm sandbags and the administration of antispasmodic medication. If unsuccessful, an indwelling catheter should be inserted.

When selecting an **analgesic,** it is important to avoid drugs that suppress the vital functions. Administration of a strong pain medication may result in a **delayed respiratory depression.** Normally, a strong analgesic is not required as the pain threshold in the elderly is rather high. Simultaneous administration of a light sedative will allow reducing the amount of analgesics.

10.1.2 Early systemic complications; their prevention and treatment

10.1.2.1 Cardiovascular complications

Postoperative **hypotension and hypovolemia are usually the consequence of an inadequate fluid replacement during and after surgery.**

Postoperative **hypertension** is not limited to patients with high blood pressure. Treatment with antihypertensive drugs is indicated once hypoxia, hypercapnia, shivering, pain and urinary retention have been excluded.

Cardiac failure can be initiated by limited functional reserves secondary to various causes such as surgery, anesthesia, fluid loss, hypotension, hypoxia, secondary to postoperative hypoventilation, increased need for oxygen when fever is present, pain, shivering and improperly applied fluid therapy resulting in an exhaustion of reserves, in tissue hypoxia and under extreme circumstances in death.

Thromboembolic complications are the most serious sequelae of pre- or postoperative immobility. The decreased muscle tone and hypoxia irrespective of their cause increase further the risk of developing this complication. For its prevention, **anticoagulants should be administered already on admission to hospital;** they should be continued up to the moment of mobilization with weight bearing.

Of considerable importance are also **mechanical means** (elastic stockings, pneumatic calf compression etc.). Preoperatively we wrap elastic bandages around both feet and legs. We have discontinued wrapping thighs and abdomen as the bandages often slip and cause constrictions that rather promote than prevent thrombophlebitis. To repeat: **the most efficient prevention of thromboembolic complications is the speedy mobilization of the patient after an immediate internal fixation.**

10.1.2.2 Neurologic complications

During the early postoperative phase **restlessness, confusion, disorientation and – less frequently – coma** are seen frequently in elderly patients. The main causes of these complications are:

- Delayed metabolism and excretion of anesthetic agents;
- Hypoxia and hypercapnia due to respiratory insufficiency;
- Hypothermia;
- Hypovolemia, hypotension;
- Dehydration, disturbances of the water and mineral metabolism;
- Prolonged hypotension during surgery or the early postoperative phase;
- Confusion due to preexisting dementia and other neuropsychiatric diseases (decrease of visual or acoustic abilities, inability to make social contacts).

Restlessness may also be caused by strong pain provoked by movements between the broken bones (crepitation), unstable internal fixation or hematoma under tension.

To treat these complications successfully the cause of the confusion must elucidated. If hypoxia is due to delayed action of the anesthetic agents or muscle relaxants, the corresponding antidot have to be given. The proper treatment of hypovolemia, dehydration and disturbances of electrolytes together with stable fixation often leads already within a few hours to a marked improvement of the mental condition. Dementia should not be treated by benzodiazepine or promethazin-hydrochloride but haloperidol may be effective.

10.1.2.3 Additional systemic complications

The cause of **increased temperature** often occurring during the early postoperative phase is difficult to pinpoint. Temperatures up to 37.5°C during the first to three postoperative days should not give rise to worries. The causes could include intraoperative blood transfusion or resorption of smaller hematomas. In the presence of higher temperatures or persisting fever, particularly following an afebrile period, a more thorough examination is mandatory. Of course, local causes (hematoma, infection) have to be excluded first. Also the following illnesses have to be taken into consideration:

Urinary infections: These are the most prevalent infections during a hospital stay as documented by reports from specialists in infectious diseases and epidemiologists (Losonczy, 1989). Heat loss during surgery and difficulties in voiding in a supine position predispose to urinary retention. This affects mostly women, who represent the majority of patients with hip fractures. The pathogens spread rapidly in the short urethra. An indwelling catheter is often indicated: before and during surgery in the presence of incontinence and after surgery for urinary retention.

Strictly respecting rules for asepsis is mandatory as otherwise a urinary infection accompanied usually by very high temperatures, renal dysfunction or even a generalized sepsis will result. To avoid these serious complications the **indwelling catheter should only remain in place as long as absolutely necessary,** although it makes life easier for patients and for the caretaker.

If an indwelling catheter becomes necessary, it must regularly be checked, rinsed and exchanged under sterile conditions. If an infection of the urinary tract is suspected and if bacteria are found in the urine, a culture and sensitivity study should be ordered. Irrespective of the outcome administration of antibiotica or chemotherapeutic agents should be started immediately. We propose to use a drug to which gram-negative pathogens are responding and that is excreted through the kidneys. Depending on the report of the culture and sensitivity studies this therapy is continued or changed. Under these circumstances an increased attention should be given to the inspection of wounds as in elderly patients the high temperature may as well be caused by a wound infection and not by a symptom-free bacteriuria.

Decubitus: Since the introduction of immediate surgery and early mobilization the incidence of bedsores, be they at the gluteo-sacral region or at the heels, are less often observed. This complication is rather seen in elderly patients transferred from other institutions or from home (where they were lying on the floor for many hours). Patients with a secreting sore should be hospitalized in a separate room.

The causes of decubitus include a poor general or local circulation in the older patient, dry, atrophic skin, reduced muscle tone, possible overweight, and prolonged immobility (stroke, contracture). Poor care (omission of personal hygiene, of regular turning and of regular bowel function) in addition to preexisting factors will hasten the development of this complication. At the onset the involved area is only hyperemic: it is followed by necrosis, first characterized by cell death and then mummification. At the junction between necrosis and healthy tissue a rim of inflammation is present, known as line of demarcation. Bedsores often involve cutaneous and all subcutaneous layers.

The progression of this process can be arrested **during the early stages of the process** by improving the local circulation (rubbing with alcoholic solution) and by avoiding further tissue compression (regular turning, mobilization, cushions to remove local pressure). If the necrosis is of limited depth and extension, a debridement followed by treatment to stimulate epithelialization or the use of anti-decubitus foil is indicated. A decubitus involving deeper layers can only be treated by a rotational flap, if the general condition of the patient allows such an intervention.

Pneumonia: for reasons already outlined above (inadequate expectoration, hypoventilation) atelectasies and subsequent **pneumonia** do not occur infrequently. Additional predisposing factors are: other acute or chronic diseases of the respiratory system, smoking etc. Regular and meticulous examinations will detect the disease before radiologic signs become evident. Pneumonia is treated with antibiotics usually administered parenterally. Respiratory exercises play an important role in the prevention and treatment of pneumonia.

We cannot repeat often enough the cardinal role early mobilization plays in the prevention of the above-enumerated complications.

Thrombophlebitis: occasionally the cause of postoperative fever is **thrombophlebitis. Abscesses** at sites of **phlebotomy** for drawing blood and intravenous injections (often surrounding a venous line) are a further source of elevated temperatures. This simple etiology should not be overlooked as diagnosis and treatment are easy.

10.2 Early complications of the surgical wound

10.2.1 Hematoma

10.2.1.1 Clinical and diagnostic aspects of postoperative hematomas

During the last decades our approach to the management of postoperative hematomas has become more proactive. If a clinical suspicion exists (subfebrile temperatures, swelling, slight secretion at the site of a removed drain) and if sonography confirms the presence of larger cavities (>10–20 ml), we recommend **surgical evacuation**: "ubi haematoma, ibi evacua" (Fekete et al, 1997a). Aspiration is only successful at early stages when the collection is still in a liquid state.

Postoperative **hematomas** are subdivided in **epifascial and subfascial.** The epifascial hematoma normally forms in the subcutis. It is clinically more obvious than deeper collections close to bone or implants. Subfascial hematomas are more serious as they are prone to lead to infections affecting joints. The cannulated screw fixation occupies a particular place as the protruding screw end connects both layers. In this way the screws permit a spread of the hematoma and thus of a possible collection of pus.

An atraumatic surgical technique and a meticulous hemostasis help to avoid the occurrence of hematomas. Besides, the **preparation of the patient** plays an important role. Special attention must be paid to a possible congenital thromboembolic disease or an anticoagulant therapy both creating a hypocoagulability. In such instances surgery must be postponed until the coagulation parameters have returned to normal values as otherwise intra- and postoperative bleeding can cause serious problems.

If an exposure of the femur is done during internal fixation with cannulated screws, the hemostasis is identical to that performed in other hip surgeries: attention must be paid to vessels crossing the intermuscular septum and to branches of the circumflex artery that surrounds the base of the neck.

The percutaneous internal screw fixation differs markedly not only from open internal fixations but also from other closed procedures in traumatology (pinning of wrist and shoulder, external fixateur). The larger implants and the longer instruments must often be advanced with great precision through a 6–10 cm long soft tissue channel (in obese patients 8–15 cm long!). To exclude or to detect a possible source of bleeding in the narrow wound may prove to be problematic, particularly as the different layers may be offset. Important amounts of blood from the femoral head or the fracture drain through or beside the implant into the superficial layers. Infection of the superficial tissues can spread toward the joint. If the instruments are incorrectly inserted without soft tissue sleeves, the tissue may wrap around the threads, they may avulse or get contused. The traumatized tissues become necrotic. Should a hematoma get contaminated, the infection easily spreads in dead tissues. The small size of the wound created during the percutaneous technique may look innocuous, **the use of soft tissue sleeves and a meticulous drainage are mandatory to avoid formation of hematoma.**

Besides the possibility of a hematoma the differential diagnosis of a **postoperative edema** must be taken into consideration during the first 3–24 hours. An edema is characterized by a diffuse tissue change as revealed by palpation and ultrasonography. A surgical intervention is not required. Local cooling and administration of non-steroidal anti-inflammatory medication and occasionally diuretics will rapidly lead to a decrease of swelling. If a hematoma is present, alternating palpation with two fingers will reveal a **fluctuation.** A **harder consistency** is felt when the hematoma is under tension. A further sign of a hematoma may be a prolonged, unusually strong **wound pain** that is often accompanied by a feeling of tension or pulsation. A throbbing pain is rather a sign of an infected hematoma. It is not relieved by local application of ice. Inspection of the fever curve may be helpful: infected hematomas cause only subfebrile temperatures.

A permanently **slight discharge** from a previous inconspicuous site of drain insertion should direct the attention to a hematoma. This applies especially to deep hematomas. An elevated sedimentation rate, a higher number of thrombocytes and a deterioration of the blood count are **unspecific laboratory findings.**

Nowadays, the clinical diagnosis is supplemented by a **sonogram** that is highly reliable. Sonography not only depicts a well-defined cavity filled with fluid but also its exact **depth and extent.** The procedure is of enormous help and allows to determine the optimal moment of intervention. It is the only non-invasive and easily repeatable method to diagnose a deep hematoma under a considerable soft tissue layer, sometimes close to bone. Even a specialist well versed in palpation with two fingers may find it hard to differentiate a deep hematoma from an edema.

10.2.1.2 Treatment of a postoperative hematoma

If the sonogram shows a fluid collection (liquid hematoma), an aspiration is indicated. Next to the surgical wound the skin is pierced with a scalpel. If the sonogram shows an organized hematoma, a surgical evacuation must be done. The sutures should not be removed in a room reserved for dressing changes and the coagulated blood should not be squeezed out but evacuated. This is done under general or regional anesthesia after appropriate laboratory tests have been performed (availability of stored blood).

Before proceeding with asepsis and draping a **swab** of the wound should be taken. Further swabs must be taken from the hematoma and all tissues that look suspicious. The sutures are removed in the area concerned and the surgical wound inspected. Careful separation of the tissue layers (not only the subcutaneous fat) without creating new cavities. Sutures of the fascia should be removed to exclude the presence of a deep hematoma. A liquified hematoma is aspirated. If several days since primary surgery have passed, the hematoma is partially coagulated and organized; its removal necessitates the use of a curette. After curettage the cavity is carefully inspected to exclude possible sources of bleeding. Once satisfied with the result, the wound is copiously irrigated and, depending on the situation, one or several suction drains are inserted.

The drain should be placed at the lowest point of the cavity to allow drainage of the accumulated secretion. To reach this goal, an incision has to be placed occasionally beside the opened wound.

The surgical wound is closed in layers, skin closure with interrupted stitches. No cavities should remain. Under most favorable conditions uneventful healing can be expected. Points to be considered during the subsequent care: the drain(s) should be removed once the secretion has stopped and the result of culture is negative.

10.2.2 Wound infection

10.2.2.1 Clinical presentation and diagnosis of postoperative soft tissue and joint infection

In general, the risk of infection after cannulated screw fixation is lower than after conventional surgery exposing the femur. The duration of potential contamination is markedly reduced and the surface of the wound less extensive. More frequent occurrences are hematomas due to an inadequate hemostasis or an insufficient drainage as well as an untreated or delayedly treated hematoma. Bleeding may also be the consequence of absent soft tissue protection or of too tight sutures causing a tissue trauma thus creating a “locus minoris resistentiae”.

If exposure of the femur is planned during screw fixation we always administer **perioperatively an antibiotic** for prevention. We prefer **one shot** of a broad-spectrum antibiotic preoperatively (second generation cephalosporin).

If a history and physical examination will point to a disease predisposing to infection such as diabetes, liver cirrhosis, pneumonia, tuberculosis or to local changes (colostomy, psoriasis etc), we also resort to prophylactic antibiotics when performing a percutaneous screw fixation.

If a wound infection is suspected, an antibiotic therapy should not be started without opening the site of infection. Giving antibiotics in these cases would cover the symptoms and mask a latent joint infection. The symptoms of an infected hematoma are different from those of a sterile blood collection.

The **swelling** at the site of infection is normally accompanied by **hyperemia.** The patient complains of a throbbing **pain.** Instead of subfebrile temperatures a **septic fever** is seen. The first and most reliable sign is the **elevated sedimentation rate** and the sudden increase in C-reactive proteins. Imaging modalities play a foremost role in the diagnosis of a late asymptomatic joint involvement. The **narrowing or even disappearance** of the subchondral bone of the acetabulum as seen on standard radiographs must be taken as an early sign of an intraarticular infection. **The disappearance of** the joint space is a late sign of infection (see Fig. 156) whereas the **subluxation of the femoral head** is a definite sign (Nagy et al, 1977). In uncertain or latent circumscribed infections a **scintigraphy** is of help as the increased metabolism of an infection is accompanied by an accumulation of the isotopes.

10.2.2.2 Treatment of postoperative wound infections

An **early superficial wound infection** must be immediately exposed and treated in the same way as a hematoma. The **approach** must be **extended** in direction of wound pockets. If the wound edges are necrotic, they must be excised. The affected area must be well visible. After repeated swabs for culture and sensitivity the infected hematoma or the abscess are aspirated. **All necrotic tissue is excised with a scalpel.** Should the infection reach into deeper layers close to bone, **the stability of the implant should be tested.** If needed, the screws must be tightened or exchanged. **Only a stable internal fixation device** ensures **a freedom from local mechanical irritation,** a prerequisite for the cure of infection. For deeper sutures resorbable threads are used. The skin is closed with loosely tightened interrupted sutures. **No cavities should remain.** Depending on the extent and severity of infection wound revisions are repeated every 48 hours.

In addition we prescribe parenterally administered broad-spectrum antibiotics. Once the culture results become available, the kind of antibiotic is adjusted accordingly.

The deep infection, also involving the joint, **is a serious complication of surgery of the locomotor system.** In the majority of patients a removal of the femoral head, also known as resection arthroplasty or Girdlestone procedure, is unavoidable. It entails grave consequences for the patient including permanent disability.

Often the clinical symptoms are very discrete. In the presence of pain imaging and laboratory examinations can confirm the suspicion of a purulent process. The exposure of the hip constitutes a major stress for the elderly patient who is often in poor health. Surgery requires a meticulous preparation that should however not delay the intervention. The first step is a revision of the approach used for screw fixation. The screws are then removed, the incision extended cranially and the hip joint opened from anterior.

If the septic process has involved the joint, removal of the femoral head is unavoidable as a necrosis of the head affected by a preceding vascular disturbance must be expected. Any sequester left in place will maintain the infection. It may happen that the femoral head of younger patients in good general health appears vital during the first exposure (drilling of the head with a spiral drill bit leads to bleeding from bone) and that the internal fixation is stable. Under these circumstances, we refrain from the resection of the femoral head and treat the infection (see Fig. 239). The excision of soft tissues, drainage and wound closure are performed as described for superficial wound infections.

In respect to the **post-Girdlestone treatment** the opinions vary considerably (Miller et al, 1989; Forgon et al, 1990; Nilsson et al, 1993b; Sárváry et al, 1997). Surgeons on one end of the spectrum perform in one sitting the resection and the implantation of a total joint stabilized with antibiotic-laden cement (one-stage procedure) to prevent contractures and later disability. On the other end of the spectrum the surgeons believe that a joint replacement is impossible. They aim for a gait with partial weight bearing after the subsidence of the inflammation. The acetabulum supports the stump of the femur. If necessary, an arthrodesis is performed later. The majority of authors prefer a two-stage procedure, whereby the **joint replacement is performed** three to five months after head removal. Nowadays, the trend is to shorten this interval. This depends on the severity of the initial infection, the success of the excision and the type and resistance of the bacteria. The second stage of the procedure, the joint replacement, is done after a long-term antibiotic treatment and meticulous preparation at the time when the symptoms of inflammation show a definite trend to decrease (lowering of the sedimentation rate, negative scintigram).

The major problem during reconstruction is the marked **shortening of the limb caused by the proximal migration of the femoral stump** giving rise to a retraction of the periarticular muscles. Therefore, some authors place a spacer after a Girdlestone resection. This spacer can be in the shape of a femoral head made from bone cement or plastic. Insertion of antibiotic-laden chains into the articular cavity is another choice. Other authors prefer a prolonged traction before implantation of an artificial joint. It is known, however, that the Girdlestone resection performed after a prolonged septic process leads to a minimal proximal migration as major displacements are counteracted by marked scar formations.

10.3 Mobilization, follow-up care

Our views in respect to the cardinal importance of early mobilization in the prevention of complications are in full agreement with those of other authors (Abrami and Stevens, 1964; Ainsworth, 1981; Parker et al, 1991b; Koval et al, 1995; Day et al, 1997; Koval et al, 1998a; Koval et al, 1998b). A cooperative patient can begin respiratory exercises already **hours after surgery.** Once the anesthetic agent has worn off, all four limbs should be moved. If the elderly patient is unable to do so due to his mental or physical condition, attention must be paid to **passive movements and to turning of the patient.** We allow the patient to **sit in bed on the day following surgery.** Having done exercises under the guidance of a physiotherapist the patient is permitted **to sit on the edge of the bed.** We even allow him to **get up** and **walk a few steps** with a walker. Elastic bandages reaching up to the knee are applied before leaving the bed. The goal of physiotherapy is the strengthening of muscles, the decrease of venous congestion and the improvement of the general condition. Generally we remove the suction drain(s) on day 2 in the course of a dressing change (if secretions have not ceased, we leave the drain for a few more days). Thereafter, we increase not only the intensity of exercises but also the duration of walking.

The internal fixation with two cannulated screws causes little stress and only slight wound pain in the majority of patients; it allows weight bearing depending on fracture configuration and on bone stock. The patient can ambulate with two canes or a walker with weight bearing on the third day. In the presence of a multifragmentary or comminuted facture, a Pauwels-III fracture, severe osteoporosis or other bony changes (cyst, metastases) rendering the internal fixation less solid, the **amount of weight bearing is determined individually.** In general, we allow walking with **forearm crutches or crutches reaching to the armpits** and **loading of the limb not exceeding the weight of the limb (10–15 kg as determined by the use of a bathroom scale).** In the absence of pain weight bearing is gradually increased after 3 to 6 weeks. If pain recurs, radiographs should be ordered.

The majority of patients begin ambulating with a **walker** while in hospital. This is safe, secure and comfortable. **Younger** patients (under 60 years of age) can start walking immediately with forearm crutches or even with a cane. As long as the patient is insecure, he should always be supervised while walking and exercising. Once he feels secure, he can do so on his own.

The second postoperative set of radiographs is taken after walking with weight bearing, usually after 5 to 7 days. These films allow determining the amount of settling. One can also assess the risk of a loss of reduction. If the patient's circumstances permit, he can be discharged home. Sutures are removed between the 8th and 10th day.

As a rule the first follow-up examination is scheduled at **four months.** It is followed by another visit at **12 months.** Thereafter, we recommend follow-ups **every two years** given the risk of avascular necrosis. Visits after five years are only required when symptoms are present. Problem cases should be followed up more closely.

All follow-up a.-p. radiographs must be taken in a correct, internally rotated position and lateral films must be properly centered. Only in this way can they be **compared to previous radiographs.** Moreover, they allow the early detection of complications such as loss of reduction, perforation of the head, migration of the implant and femoral head necrosis.

The family physician plays a major role during the follow-up examinations (Kazár et al, 1995) as he is in constant contact with the patient. The hospital-based physician is not in a position to maintain a continuous control given the limited displacement ability of the elderly patient. **The family physician in collaboration with the home care nurse and the physiotherapist** checks the general condition of the patient and the state of the wound. He treats concomitant medical problems and follows the healing, the ability to ambulate and the patient's activity. Should the patient's condition worsen (increasing pain, inability to continue walking), he can arrange examination in the hospital. In the absence of such a collaboration complications are either recognized too late or not at all resulting in serious consequences, a prolonged suffering or even death.

10.4 Local mechanical complications after internal fixation with cannulated screws and their treatment

The following mechanical complications can arise after internal screw fixation of femoral neck fractures within a year and **necessitate revision surgery:**
- **Loss of reduction;**
- **Migration of the implant (cutting-out from the head, perforation of the head, sliding out);**
- **Delayed healing or non-union** due to distraction or other causes;
- **Novel fracture next to the implant;**
- **Fatigue fracture of the implant.**

It is sometimes difficult to recognize and to differentiate from each other various forms or combinations of complications. We are of the opinion that a **displacement** diagnosed within three months and necessitating revision surgery should be termed **loss of reduction.** It is usually accompanied by an obvious displacement of screws (rotation of screws against each other, loss of parallelism). These displacements are not necessarily accompanied by perforation or sliding of the screws.

Cutting-out is a phenomenon also observed with DHS or gamma nails; it gradually leads to a loss of reduction. The femoral head "falls off" the improperly placed screw, be it inserted too cranially or too anteriorly. The screw cuts through the bone close to the porotic spherical head.

Migration of the screw medially **(perforation)** or laterally **(backing-out)** is not always accompanied by a loss of reduction. The backing-out must be distinguished from settling that occurs during adaptation of the fracture surfaces. During settling the screw ends protrude laterally secondary to a resorption of avulsed fragments causing a shortening of the neck. The position of the threaded part of the screw in the femoral head remains unchanged (see Sect. 5.6). During backing-out the screw tip disengages from the head fragment.

A delayed consolidation is diagnosed when the neck fracture has not consolidated **after 3 to 6 months.** It is often due to a **new trauma** causing a displacement of the partially healed fracture.

Absence of consolidation after six months is termed **non-union.**

Avascular necrosis develops as a rule after consolidation of the fracture, usually after one year but within five years. Necrosis and non-union may occur together, a condition known as migrating non-union (Böhler, 1996) (see Figs. 142 and 210e–i). Our research team has analyzed a vast collection of late complications with particular attention to pathology and treatment (this analysis will be published separately).

Fracture of a cannulated screw has been observed by us three times (0.09%) in 3185 internal screw fixations (see Fig. 146 showing a bent and partially broken screw).

10.4.1 Loss of reduction

A loss of reduction of the reduced fracture necessitating revision surgery is **mainly due to an unstable internal fixation secondary to technical errors made during reduction and internal fixation:** inadequately corrected varus tilting or antecurvature, faulty placement of screws (away from Adam's arch, calcar or chondro-osseous junction of head). In other instances the **fixation of an unstable fracture has been insufficient;** either a proper implant was not available or the initial assessment of the fracture was wrong (poor radiographs did not allow to recognize a multifragmentary fracture). These errors combined with a severe **osteoporosis** are particularly responsible for a loss of reduction (Zetterberg et al, 1985; Gyárfás et al, 1988; Muirhead and Walsh, 1989; Nilsson et al, 1989a; Eliasson et al, 1990; Nilsson et al, 1993a; Zetterberg et al, 1994).

The question up to which point **circulatory disturbances in the femoral head** are associated with the development of loss of reduction is still open to discussion. Our experience has taught us that properly placed screws find adequate hold for some time in a femoral head that became avascular during the initial trauma or the early postoperative phase. No resorption around the screws can take place in the absence of blood supply. As a rule the patient can walk on an avascular head. This complication becomes only symptomatic 6 to 12 months after the injury (see Fig. 142). In instances of incomplete vascular disturbance an early stable internal fixation in good position promotes restoration of blood supply. If nevertheless avascular necrosis sets in as seen by loss of sphericity of the weight-bearing surface followed by flattening and finally collapse, the time elapsed since the initial trauma will usually be one to five years.

It is therefore preferable to call **complications characterized by a displacement** occurring during the first three months a loss of reduction, those seen between three and six months a delayed union and those appearing later a non-union **but not to interpret them as being signs of impending necrosis.** Occasionally one can observe a similar course in instances of severe osteoporosis or remote fractures. The cause, however, in instances of severe osteoporosis was an inadequate fixation and in remote fractures an improper surgical indication.

It is not always easy to distinguish between **loss of reduction and settling** (based on only one radiologic follow-up). Attempts to establish a limit between both as determined either in grades or centimeters are futile. Even in instances of a marked varus tilt (a.-p. alignment angle < 150º) or of a shortening of 1.5 to 2 cm (settling), a consolidation is possible. The distinction must rest on the dynamism of the situation. A loss of reduction is a **sudden** event accompanied by pain and inability to walk. Settling, on the other hand, is a gradual event, the femoral head slowly finds a new position on the neck. In the latter instance we recommend **radiologic controls at shorter intervals.** Ambulation with walking aids has also to be prolonged.

If a loss of reduction has occurred in patients **older than 60 years, we perform a cemented total hip replacement. In patients with a physiologic age over 75 years we choose a hemiarthroplasty,** on the condition that the acetabulum is unaffected. Implants for a revision of internal fixation will not find sufficient purchase in a porotic head damaged by tilted and loosened screws.

In patients younger than 60 years we **attempt to salvage the head** and perform a revision of internal fixation: the younger the patient, the stronger our determination. Before surgery the vitality of the femoral head must be investigated with a DS-intraosseous venography (possibly SPECT or, in the presence of titanium screws, an MRI). If the outcome is positive, a **revision** is performed. To **increase the stability** of internal fixation we use three cannulated screws or two 9.5 mm screws. If needed, a DCD plate is added. The use of an angle-stable plate is particularly indicated when a (valgus) **osteotomy** is done at the same time (Marti et al, 1989; Schmelzeisen, 1993).

Should the investigations show a marked disturbance of the head circulation, a **non-cemented total hip replacement** must be taken into consideration in patients **older than 50 years. In younger** patients we recommend a **revision of internal fixation** possibly supplemented by an osteotomy as well as a **prolonged period of non-weight bearing.** If the clinical course and imaging results document a progression of avascular necrosis, a **revascularization** procedure should be contemplated after consolidation of the fracture (Fekete et al, 1994; Hankiss et al, 1997). The patient is still able to walk on and even work with the deformed but preserved head for years with minimal complaints until he reaches the age for a total hip replacement (Manninger et al, 1967; Barnes et al, 1976). When **Ehalt** visited our institute he stated: "The older the necrosis the better the outcome; the older the joint replacement the worse the outcome".

10.4.2 Migration of the implant

In the following we discuss screw movements that either lead to a **perforation of the head** or to a **backing-out without causing a loss of reduction.** When combined, they usually will result in a loss of reduction.

The **perforation of the head** is almost always due to a technical error at the time of internal fixation. At the time of inception of this method we used 4.5 mm DC plates for lateral reinforcement. A jamming of the caudal cannulated screw in the sharp-edged hole of the massive plate happened repeatedly when tightening the cortical screw. This prevented a sliding of the cannulated screw causing a perforation of the femoral head during settling (see Table 18). For this reason we have replaced the compression holes with round holes in the new plate (see Fig. 166a, b).

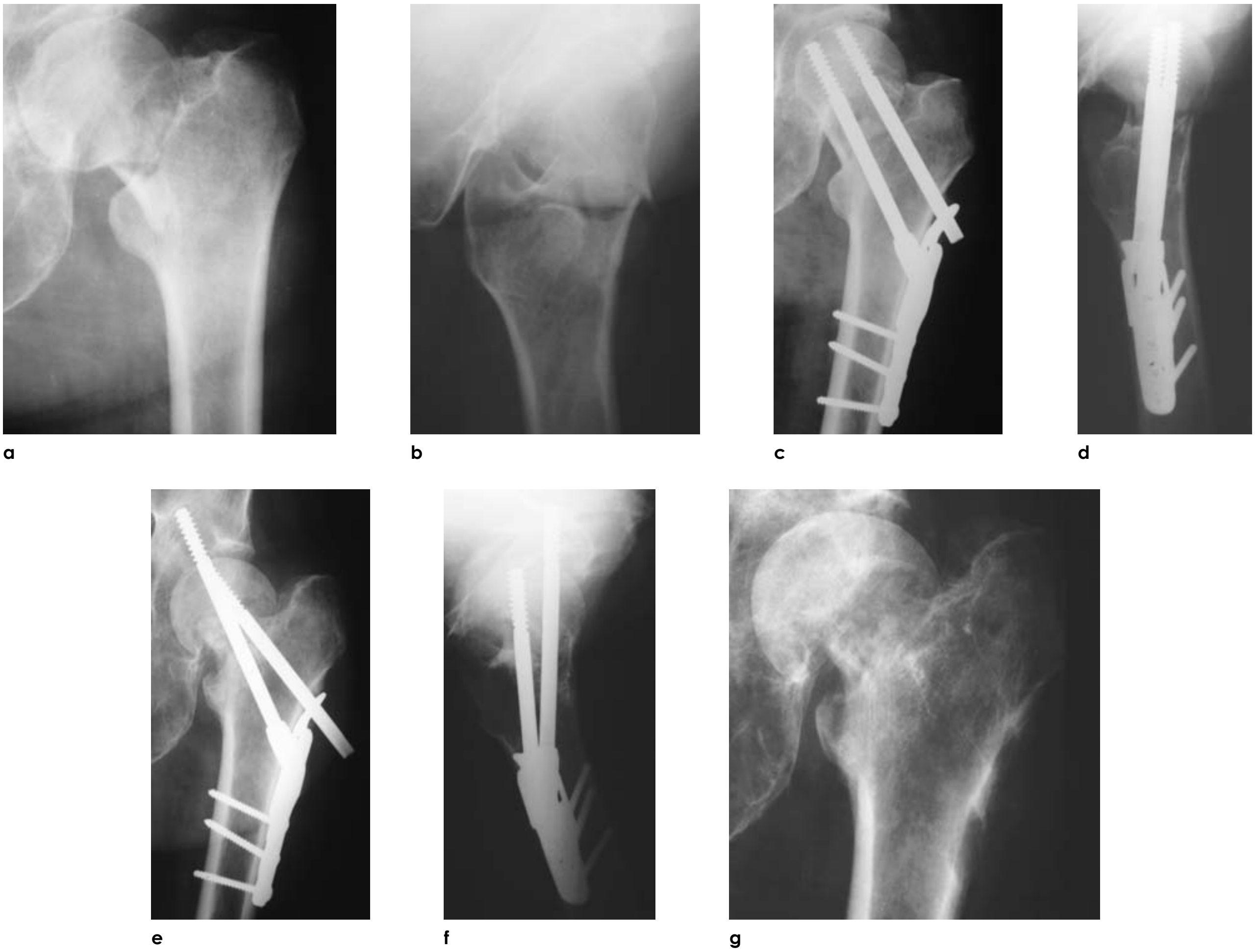
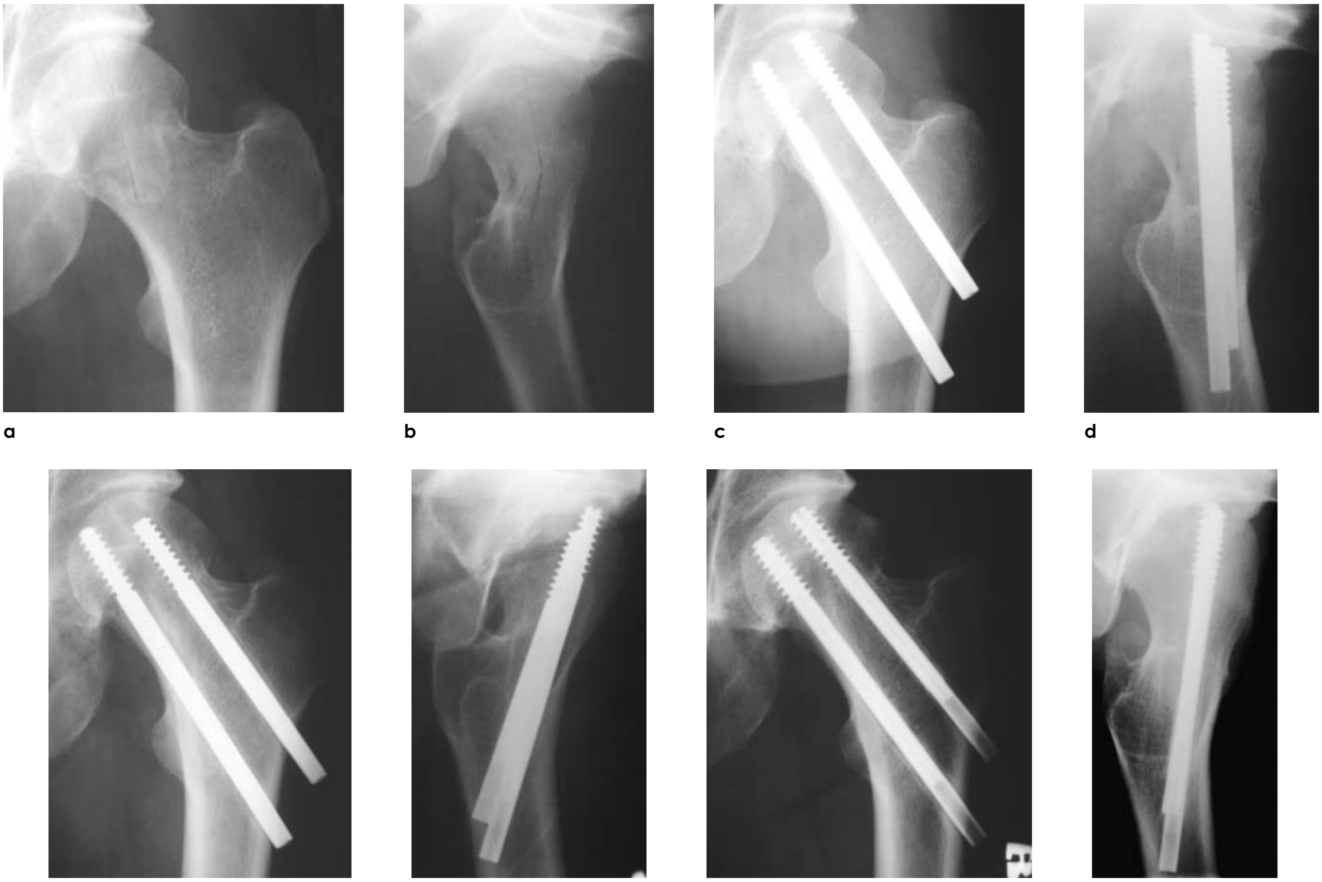


Fig. 237. Jamming of a too short caudal screw in the barrel of a DCD plate with subsequent femoral head perforation.
This 58-year-old man fell from a 2 m high scaffolding and injured his left hip; **a, b.** Garden-IV comminuted fracture; **c, d.** Eight hours after the accident an internal fixation with two cannulated screws and a DCD plate with satellite plate was performed. The reduction was rendered difficult by the fracture's configuration. In the a.-p. projection a slight tilting in valgus and an exaggerated traction effect are visible. The position as seen in the lateral view is acceptable (slight antecurvature). The patient did not report back for a considerable time; **e, f.** Five months after the initial surgery the patient was transferred from the medical ward. The cause of hip pain was attributed to a perforation of the femoral head. The neck was markedly shortened. The too short caudal screw could not follow the settling, since the end of the screw got stuck on the edge of that part of the barrel that had been designed to prevent rotation. Based on the positive result of the intraosseous venography an implant removal was done. After months of ambulation with crutches and evident consolidation we allowed weight bearing; **g.** Eighteen months later the limb shortening of 3 cm was compensated by a shoe insert. The patient performed light duties. External and internal rotations were slightly limited.
Lesson learned: when using a DCD plate, the end of the cannulated screw must be flush with the level of the lateral cortex; this avoids the described complication

Fig. 238. Migration of a cannulated screw into the pelvis after accidental drilling through head and acetabulum.
This 74-year-old woman fell at home on the day of admission and injured her left hip;. **a, b.** Garden-IV fracture with two small cortical fragments; **c, d.** Eleven hours after the accident a cannulated screw fixation was done. In the a.-p. film one can recognize the spot (arrow), where the tip of the cranial screw had perforated accidentally the femoral head and the acetabulum. The screws converge and the reduction is inadequate: in the a.-p. projection a tilting in varus and effects of insufficient traction are seen. In the lateral projection an exaggerated rotation can be recognized; **e, f.** At follow-up 10 weeks later a marked tilting in varus and settling were seen. The position of the cranial screw in relation to the head contour is still unchanged; **g, h.** Eighteen days later (!) the family doctor requested her admission to our hospital as the patient was unable to walk. Radiographs show an extremely migration of the cranial screw into the pelvis. We removed the screw and implanted a total hip prosthesis. On the 7th postoperative day the patient was mobilized; **i.** The filling of the previous screw channel with bone cement is easily recognizable. We had planned her discharge from hospital, when the patient suddenly felt ill, developed dyspnea and cardiac failure. In spite of reanimation efforts lasting several hours the patient died. Autopsy revealed a lung embolism



a b c d e f g h

Fig. 239. Sliding of a screw in the femoral head due to a latent, encapsulated infection.
This 40-year-old patient had a bicycle accident and injured his left hip. He reported to our Institute the next day on account of hip pain. He was able to walk; **a, b.** Radiographs show a Garden-I fracture in good position with jagged fracture surfaces and a beak (a.-p. alignment angle: 180° valgus, lateral alignment angle: 170°); **c, d.** Four days later we performed an internal fixation with two cannulated screws. The slight angular deviation was not corrected. Discharge five days later. During the postoperative phase subfebrile temperatures were registered. He attended regularly the follow-up visits and never complained of pain; **e, f.** After six months the cranial screw had migrated laterally by one cm. The patient, an engineer, had resumed his work two months after the accident. We wondered whether a strong electromagnetic field at his workplace could have been the cause. Biophysicists excluded this possibility. As we feared that the thin bony layer of the weight-bearing surface of the femoral head overlying the channel made by the previous position of the screw could break in, we decided in favor of a revision surgery with screw exchange. Surgery was performed one month later. In the mean time the first 9.5 mm titanium screws were manufactured. During surgery we made a swab of the screw bed that appeared bland. After irrigation of the channel we inserted the new 9.5 mm screws. The culture revealed a mixed growth (staphylococcus aureus, enterobacter sp., proteus mirabilis). The patient took ciprofloxacin for one month; **g, h.** Five years after the initial screw fixation a normal shape of the femoral head is seen. The screws remained in their original position and the patient is symptom-free

The 2 mm plate led to similar problems when inserted **under tension.** The same can happen with the use of the DCD plate when the cannulated screw is too short or too long (Fig. 237).

A particular and most dangerous happening is the accidental **perforation of the head with the stepped drill bit** during surgery. It may entail a **lesion of the acetabulum.** In doing so we create a tunnel through which the screw can **migrate into the pelvis.** Several similar instances have been described with the use of the Upsala screw that has spikes at the tip (Sundgren and Persson, 1994; Adolphson, 1995; Olerud et al, 1995). We observed this severe complication twice in 3185 interventions (Fig. 238).

The mechanism, by which the cranial screw not attached to a plate that prevents its rotation, migrates into the pelvis, remains to be elucidated. Most probably the rotational movements of the head during walking advance the implant into the existing channel.

The only proper solution is **prevention.** An accidental perforation of the head (and the acetabulum) with the stepped drill bit or the tap should not be considered a trivial happening. An immediate change in technique is mandatory. **Instead of standard screws 9.5 mm screws should be used.** One may also use a compression screw and interpose a washer between the compression screw and the cannulated screw while omitting the use of the DCD plate; this protects against cranial migration of the cannulated screw.

A small percentage of head perforations do not require a revision surgery, only radiographic **controls should be done at shorter intervals.** The perforation is usually seen at the caudal screw that is protected against rotation by the 2 mm plate. Although the screw tip perforates the important cartilage layer, it is situated in the neutral non-weight bearing zone (see Fig. 210e–i). If, however, the screw tip exceeds the cartilage, a **replacement of the screw with a 9.5 mm screw is mandatory given the risk of damage to the acetabulum** (see Fig. 211h). We believe that the **simple turning back of the screw is not sufficient** as the implant may again migrate through the channel by the mechanism already described.

Should the perforation occur by the wrong placement of the **2 mm plate,** a **repositioning of the plate** must be done in addition to changing the screw.

The **disengagement of the threaded screw tip from the head,** not being part of settling or loss of reduction, occurs far more seldom with screws than with the Smith-Petersen nail thanks to the good purchase of the threads in the head. A latent infection may cause a slight screw sliding (Fig. 239).

A moderate screw sliding in the head should raise the suspicion of a latent infection.

10.4.3 Femur fractures after internal fixation

Since the preparation of the lateral femoral cortex for screw fixation is considerably less traumatic than the chiseling necessary for the insertion of a Smith-Petersen nail, femur fractures usually occurring later are nowadays rarely observed. If they happened, they are the consequence of osteoporosis or metastases (see Fig. 148). In the past, when a fracture happened, we used to change the technique and employed an internal fixation with a DHS or a 95° blade-plate. However, it is often difficult to find an appropriate position for the stabilizing new implant in the head previously perforated by screws.

In isolated instances, such as after novel subtrochanteric fractures, we replaced the well positioned standard 8 mm screws **with 9.5 mm screws** and attached them to a **long angle-stable DCD double plate** and could thus achieve a consolidation of the fracture (see Fig. 148). Based on these encouraging results we decided to use this method for other (extracapsular) hip fractures (see Fig. 145).

Chapter 11

TREATMENT RESULTS

11.1 Introduction

Between November 1, 1990 and December 31, 2002 a total of 3185 internal fixations with cannulated screws were performed at the National Institute of Traumatology (Budapest) and between June 1, 1997 and May 30, 2000 a total of 205 cannulated screw fixation were done at the Trauma Department of the Hanover Medical School, Hanover-Germany (Bosch et al, 2002). The results obtained with this technique and their analyses are subdivided according to the groups outlined in the preceding chapters.

- Comparison between double Smith-Petersen nailing (1990) and percutaneous cannulated double screw fixation (1993–94);
- Analysis of the causes of loss of reduction;
  - Quality of reduction and internal fixation;
  - Influence of multifragmentary and comminuted fractures on outcome;
  - Influence of age (osteoporosis);
  - Importance of the 2 mm plate;
- Comparison of results of cannulated screw fixation between the years 1993–1994 and 1997–1998.

11.2 Comparison between Smith-Petersen nailing and cannulated screw fixation

The goal of this analysis was to find out possible differences between the two techniques of internal fixation performed in the seventies and eighties. In 1993–1994, treatment of neck fractures with cannulated screws predominated (see Fig. 125). We assume that at that time the technique of screw fixation was mastered by all surgeons involved. We would like to add that in these years no methods to increase stability (9.5 mm screws and DCD plates etc) were yet available.

The number of patients with femoral neck fractures having undergone a nailing with two Smith-Petersen nails between January 1, and December 31, 1990 amounts to 165. Considered in this analysis were patients forming part of the Multicenter Hip Fracture Study. Not only were their questionnaires available, but the patients were also followed up at four months, one and five years (Cserháti et al, 1992; Laczkó et al, 1992; Laczkó et al, 1993; Cserháti et al, 1997; Kazár et al, 1997; Cserháti et al, 2002a).

The patient group treated with percutaneous cannulated double screw fixation includes 489 patients; they were operated in 1993 and 1994. Their data were collected in a similar fashion and the follow-up examinations were done in 1997 and 1998 (Fekete et al, 2000b; Fekete et al, 2000c).

In the following years, the numbers of conservatively managed patients and of those treated by primary hip replacement were markedly lower. In 1990, a higher number of patients were treated with other methods of internal fixation. The reason for

Table 8. Treatment of femoral neck fractures at the National Institute of Traumatology (Budapest) during 1990 respectively 1993–1994

	01.01.1990 – 31.12.1990	01.01.1993 – 31.12.1994
Total number of femoral neck fractures	312 (100%)	596 (100%)
Conservatively treated	24 (7.7%)	9 (1.5%)
Primary hip replacement	75 (24%)	64 (10.7%)
Internal fixation with 2 Smith-Petersen nails	**165 (52.9%)**	–
Percutaneous fixation with 2 cannulated screws	–	**489 (82%)**
Other techniques of internal fixation	48 (15.4%)	34 (5.7%)

this fact is that we used three cancellous screws and stabilization with the keyhole plate for fractures impacted in valgus or for undisplaced fractures (Garden-I and -II) (Table 8 and Fig. 124).

Data for the two patient groups are listed in Table 9. They are comparable in respect to their basic parameters being almost similar (average age, sex, incidence of various fracture types). The patient group treated with Smith-Petersen nailing consisted of fewer Garden-I and -II fractures since in these years we treated those fractures with cancellous bone screws and keyhole plates.

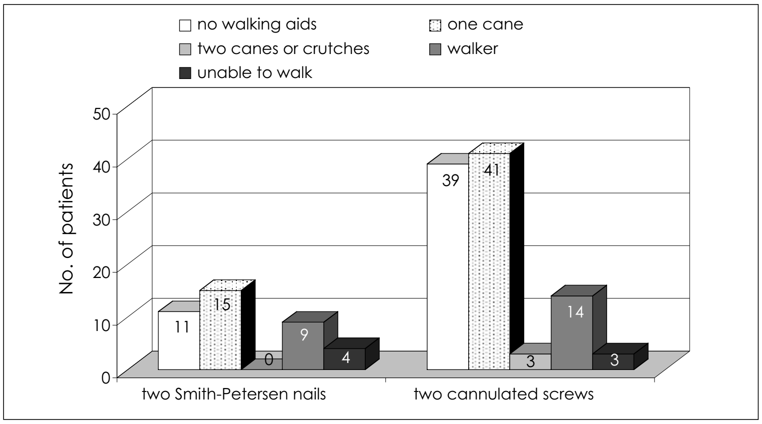
To obtain data for patients who failed to return the questionnaires in spite of repeated requests, we asked the Ministry of the Interior, Data collection, Registration and Elections for pertinent information. This permitted us to keep to a minimum the number of patients for whom no data were available after discharge.

Duration of surgery and length of hospital stay were **significantly shorter** for patients having undergone a percutaneous screw fixation; the incidence of immediate and late mortality was slightly less.

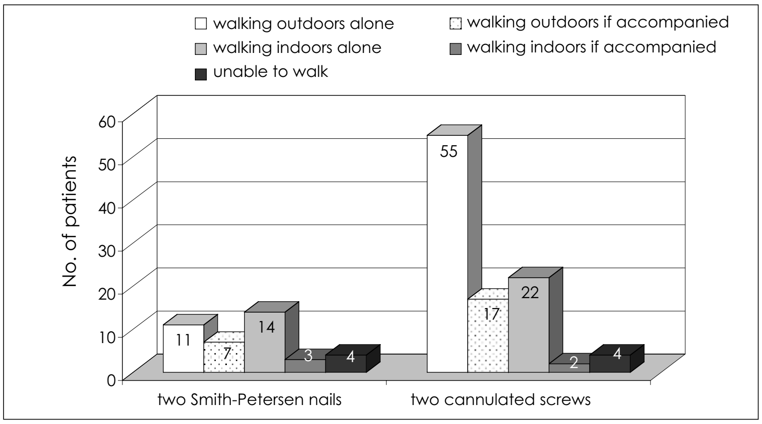
We also compared the functional capacity of those patients who were able to answer this questionnaire themselves at five respectively three to four years after the accidents (Fig. 240).

Table 9. Results with the preferred method of internal fixation during the two periods

	2 Smith-Petersen nails 1990	2 cannulated screws 1993–1994	Significance T = *t*-test C = χ^2-test)
Number of patients	165 (100%)	489 (100%)	
Women	116 (70.3%)	363 (74.2%)	p = 0.484 C
Average age (years)	78.4 ± SD 9.18	76 ± SD 10.38	p = 0.072 T
> 80 years	72 (43.6%)	191 (39%)	p = 0.299 C
Garden-I und -II	18 (11%)	82 (16.8%)	p = 0.0705 C
Garden-III und -IV	147 (89%)	407 (83.2%)	
Surgery within 6 h	61 (37%)	96 (19.6%)	p = 0.441 C
Surgery within 24 h	–	306 (62.6%)	
Mean duration of surgery (min)	55 ± SD 13.48	41.3 ± SD 16.34	**p < 0.001 T**
Length of hospital stay (days)	14.9 ± SD 8.04	12.1 ± SD 8.5	**p < 0.001 T**
Early mortality	14 (8.5%)	30 (6.1%)	p = 0.297 C
Mortality at 4 months	33 (20%)	86 (17.6%)	p = 0.487 C
Mortality at one year	52 (31.5%)	121 (24.7%)	p = 0.088 C
Mortality at 3–4 years	–	223 (45.6%)	
Mortality at 5 years	93 (56.4%)	–	
Fate unknown	5 (3%)	44 (9%)	**p < 0.05 C**



a



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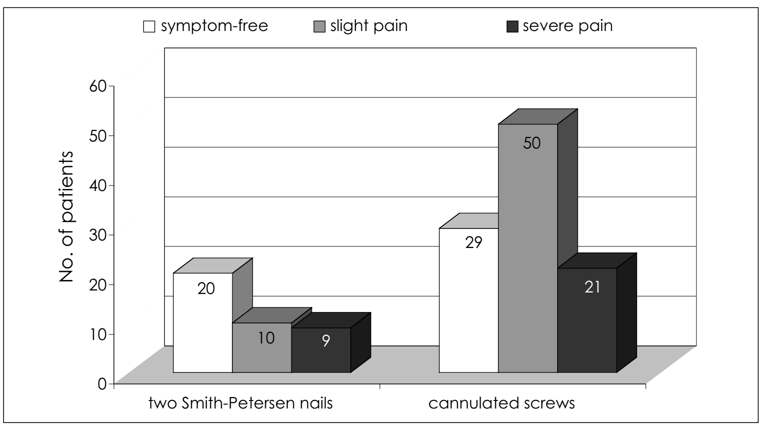

c

Fig. 240. Functional results of 39 Smith-Petersen nailings (as assessed five years post-injury) and of 100 cannulated screw fixations (3–4 years after trauma) based on responses to questionnaires of the Multicenter Hip Fracture Study.
a. Use of a walking aid, no significant difference between both methods (Mann-Whitney test $p = 0.083$); **b.** Significant difference in favor of cannulated screws was found in respect to the level of walking ability (Mann-Whitney test $p < 0.01$); **c.** No significant difference between both methods was found as it related to hip pain (Mann-Whitney test $p = 0.114$)

Table 10. Early complications after Smith-Petersen nailing (1990) and after cannulated screw fixation (1993–1994)

a. Total number of early complications

	2 Smith-Petersen nails 1990	2 cannulated screws 1993–1994	Significance (χ^2-test)
Total number	165 (100%)	489 (100%)	
Hematoma	4 (2.4%)	12 (2.4%)	
Soft tissue infection	2 (1.2%)	5 (1%)	
Joint infection	3 (1.8%)	7 (1.4%)	
Hematomas and infections	9 (5.5%)	24 (4.9%)	p = 0.782
Revision on account of implant migration, perforation	6 (3.6%)	22 (4.5%)	p = 0.636
Loss of reduction	5 (3%)	29 (5.9%)	p = 0.147

b. Incidence of loss of reduction in Garden-III and -IV fractures

	2 Smith-Petersen nails 1990	2 cannulated screws 1993–1994	Significance (χ^2-test)
Garden-III and -IV fractures	147 (100%)	407 (100%)	
Loss of reduction within 4 months	4 (2.7%)	20 (4.9%)	p = 0.263
Total number of loss of reduction	5 (3.4%)	28 (6.9%)	p = 0.127

The level of walking ability was **significantly better in patients** with cannulated screw fixation than those who underwent nailing. The majority of patients with cannulated screw fixation were able to ambulate either without a walking aid or with only one cane; in the same group the incidence of patients confined to bed was lower, they also complained less about strong hip pain. On the other hand, the number of patients who were free from pain was greater after nailing. It can be assumed that some patients treated with screw fixation and examined after longer intervals and had been of poor general health at the time of injury were still living.

The incidence of complications (Table 10) as it relates to the invasiveness of the type of surgery (hematoma, infection) was slightly reduced. We believe that this is partly due to the better drainage from the femoral head along the cannulated screw than along the nails. It is worthwhile to note that at this time the use of suction drains in the small wound was not used routinely. Also soft tissue sleeves were not in common use. Both factors may explain the observation that the number of complications after percutaneous cannulated screw fixation, mostly due to tissue damage, did not decrease appreciably (see Sect. 11.4.1).

Screw migration developed mostly in instances where no 2 mm plates were used. **The marked increase in loss of reduction,** particularly for Garden-III and -IV fractures, seems to be due to the different biomechanical characteristics of both implant types. These results led to further investigations with the goal to increase the stability of internal screw fixation.

Assessment

Once the technique had been mastered, the cannulated screw fixation met in part our expectations shortly after the start of the investigation. Duration of surgery and hospital stay were reduced. The mortality rate and the late function were more favorable to a certain extent. On the other hand, the number of complications reflecting the invasiveness of the procedure did not decrease. The analysis of the causes of hematomas and infections pointed to the importance of soft tissue protection and wound drainage.

Further investigations and tests with the goal to increase stability became necessary to reduce the incidence of the increasing number of loss of reduction.

11.3 Score results of the analysis of reduction and internal fixation

We investigated the **role of the technical execution** of internal fixation and also the importance of biologic and biomechanical factors (osteoporosis, fracture type) with the goal to reduce the incidence of loss of reduction. The majority of scoring systems in orthopedics and traumatology compare the functional (at best also the social) state before and after surgery. They are supposed to allow a conclusion as to the efficacy of the method used and to permit a comparison with other methods (Parker and Maheshaer, 1997). Such a comparison raises doubts, in particular, when material has been collected from two or more hospitals or even from different countries. If the quality of execution is not taken into consideration and if errors have been excluded, one cannot

Table 11. Assessment of complications after cannulated screw fixation done during the years 1993 and 1994 using our scoring system

	good	acceptable	faulty	poor	total
n	**135**	**159**	**103**	**8**	**405**
Hematoma	1 (0.7%)	3 (1.9%)	3 (2.9%)	1 (12.5%)	8*
Infection	3 (2.2%)	2 (1.3%)	3 (2.9%)	2 (25%)	10*
Backing-out of screw	1 (0.7%)	1 (0.6%)	3 (2.9%)	0	5*
Head perforation	1 (0.7%)	5 (3.1%)	6 (6%)	0	12*
Loss of reduction	1 (0.7%)	6 (3.8%)	16(15.5%)	5 (62.5%)	28*
Mechanical complications, total	3 (2.1%)	12 (7.5%)	25 (24.4%)	5 (62.5%)	45
Non-union	2 (1.5%)	1 (0.6%)	3 (2.9%)	0	6*
Necrosis**	32 (23.7%)	35 (22%)	13 (12.6%)	0	80*

* Additional complications were seen in Garden-I and -II fractures (see Table 10).

** Listed here is the total number of partial and total (88) necroses that were recorded at the 3–4 year follow-up. This number includes necrosis in patients who had deceased in the meantime. Excluded are eight patients with Garden-I and -II fractures (see Fig. 173g, a graph that lists only the incidence of necrosis of 222 patients still living in 1997–98).

This table lists only patients with Garden-III and -IV fractures (407 patients). A reduction of Garden-I and -II fractures (82) was only performed when a hypervalgus position was present; in addition, the stabilization rarely caused problems. In two patients an evaluation of the findings was impossible on account of incomplete data. The all-over assessment **good** was attributed when reduction and internal fixation as judged in a.-p. and lateral projections reached not more than once the attribute **2** (the point score was therefore either **1111 or 1112**) (see Tables 5 and 6). The assessment **acceptable** denotes a point score where at least twice an attribute **2** but never a **3** was reached **(1122, 1222, 2222).** As **faulty** we defined outcomes where at least one **3** was given and as **poor** where patients had at least one **4**. The share of patients whose fate was unknown did not show a difference between the four groups (the number of patients in the category poor was small and the percentages were only added for a better comparison).

determine beyond any doubt **whether the difference found between both methods is due to factors inherent to the method or to faulty execution by one or the other participating institution.**

When introducing a new procedure, it is of paramount importance to detect hidden technical difficulties and to develop ways to avoid them. An exact analysis and description of these problems to attract the attention of surgeons to possible pitfalls has to be done.

Therefore, we made every effort **from the beginning on** to **analyze extensively** problems that arose from the change from hip nailing practiced over decades to cannulated screw fixation. During the first years we assembled a **questionnaire containing 88 points.** This questionnaire was based in most details on the standard questionnaire from the Multicenter Hip Fracture Study; the aim of the latter study was the documentation of findings made initially and at the 4-months follow-up. In particular, they related to treatment and rehabilitation (Thorngren et al, 1990; Thorngren et al, 1994). We added a few points that related to findings at the 1- to 5-year follow-ups as well as 16 points assessing the quality of reduction and internal fixation (see Tables 5 and 6). We like to emphasize again that these complicated score tables were used primarily for scientific purposes. Lessons learned from the assessment were obviously also of help in our daily practice.

The members of the research team for femoral neck fractures working on the admitting wards presented the postoperative findings and radiographs of patients usually admitted during off-hours. The team analyzed the findings and attributed a score. **To avoid any subjectivity** the identity of the surgeon was only revealed once the score had been made. We used the same approach when analyzing patients operated in 1993–1994. Retrospectively, it proved advantageous when assessing the score of all patients later on (Table 11).

The distribution of mechanical complications is based on the assessment of reduction and internal fixation. The incidence of mechanical complications was considerably lower in the group judged as being good than in the groups with an outcome acceptable or faulty. No similar correlation was observed in respect to femoral head necrosis.

Assessment

The score is suitable for assessment of the quality of reduction and internal fixation.

11.4 Analysis of the causes for loss of reduction

11.4.1 Importance of proper reduction and internal fixation

We executed this analysis with the goal to find out a possible correlation between the frequency of loss of reduction and errors made during surgery. Other authors have made similar attempts (Johansson et al, 1986; Nilsson et al, 1991; Parker et al, 1994). To achieve this goal we divided 489 patients operated in 1993 and 1994 by 42 surgeons at our institute into **two groups.** One group consisted of 309 patients that were operated by 18 members of our research group (femoral neck team), the other group consisting of 180 patients that were operated by 24 surgeons not belonging to this team (Table 12).

The composition of the two groups of surgeons did not show an appreciable difference. A significant difference, however, existed in interventions performed by various members of the two groups. The senior surgeons of the femoral neck team performed surgery less often. The team leaders, on the other hand, operated more often. In the group of surgeons not belonging to the femoral neck team more interventions were done by non-specialists. Members of the team treated slightly more displaced fractures.

The members of the research group analyzed their mistakes, the causes and the possibilities to avoid such errors during a group discussion led by the team leader (Table 13).

Patient characteristics (frequency distribution of age and sex, walking ability, concomitant diseases, fracture morphology) and details of surgery (duration, need for transfusion) did not show **significant differences** between both groups.

Three-quarters of patients (total 75.3%) operated by team members were judged good and acceptable, whereas **two-thirds** of patients (total 68%) operated by non-team members met only this score. In other words, 24.7% respectively 32% were assessed as being faulty or poor when comparing these two groups.

The significant difference may also be the result of the fact that more team members were experienced team leaders and that fewer non-specialists were involved when compared to the other group.

To exclude a possible statistical error, we thought that a comparison of groups **having approximately the same surgical experience** should be undertaken on the condition that the number of surgical interventions is sufficient. Consequently, we chose the group of **younger specialists not yet in a leading position.** As can be seen from table 13 the results of this group were below the average, reflecting their lesser experience. In addition, **the results achieved by the younger non-team specialists were also significantly inferior.** Among them the incidence of faulty or poor outcomes was 50% higher than among young team members.

The difference in points is also reflected by the significant number of complications (Table 14).

It should be pointed out that **being a member of the research team had a favorable influence on the incidence of local wound complications.**

The difference in results is even higher when one considers the Garden-III and -IV fractures operated by young specialists (see Table 14b). The incidence of **early mechanical complications** (screw movements, perforations, loss of reduction) was twice as high among the non-members. **The frequency of loss of reduction shows a significant difference between both groups.**

Assessment

Errors in reduction and/or internal fixation play an important role in the pathogenesis of the loss of reduction.

Table 12. Composition of the two groups of surgeons, frequency distribution of surgical interventions

	Team member	Non-team member	Significance (χ^2-test)
Total number of surgeons	**18 (100%)**	**24 (100%)**	p = 0.720
Senior surgeon	2 (11.1%)	5 (20.8%)	
Team leader	3 (16.7%)	2 (8.4%)	
Specialist	10 (55.5%)	12 (50%)	
Non-specialist	3 (16.7%)	5 (20.8%)	
Surgical interventions	**309 (100%)**	**180 (100%)**	**p < 0.001**
Senior surgeon	18 (5.8%)	25 (13.9%)	
Team leader	110 (35.5%)	13 (7.2%)	
Specialist	162 (52.4%)	109 (60.6%)	
Non-specialist	19 (6.1%)	33 (18.3%)	
Garden-I and -II	**49 (15.9%)**	**33 (18.3%)**	p = 0.480

Table 13. Assessment of quality of surgery of all cannulated screw fixations for displaced femoral neck fractures performed by both groups of surgeons taking only specialists into consideration

	Good	Acceptable	Faulty	Poor	Total
Members of team, total	92 (36.1%)	100 (39.2%)	60 (23.5%)	3 (1.2%)	255 (100%)
Non-members, total	43 (28.7%)	59 (39.3%)	43 (28.7%)	5 (3.3%)	150 (100%)
Team member specialists	46 (33.1%)	57 (41.0%)	34 (24.5%)	2 (1.4%)	139 (100%)
Non-member specialists	23 (25.3%)	32 (35.1%)	33 (36.3%)	3 (3.3%)	91 (100%)

As in Table 11, only Garden-III and -IV fractures that could be evaluated were considered. Significant differences in favor of the femoral neck team in all 405 patients and also in 230 patients operated by specialists (t-test in both instances $p < 0.05$).

Table 14. Frequency distribution of early surgical complications

a: after all interventions of the two groups of surgeons

	Team member	Non-team member	Significance (χ^2-test)
Total number of patients	309 (100%)	180 (100%)	
Hematoma	5 (1.6%)	7 (3.9%)	
Soft tissue infection	2 (0.6%)	3 (1.7%)	
Joint infection	3 (1.0%)	4 (2.2%)	
Hematomas and infections	10 (3.2%)	14 (7.8%)	**$p < 0.05$**
Femoral head perforation	11 (3.5%)	4 (2.2%)	
Backing-out of screw	4 (1.3%)	3 (1.7%)	
Loss of reduction	14 (4.5%)	15 (8.3%)	$p = 0.086$
Mechanical complications, total	29 (9.4%)	22 (12.2%)	$p = 0.63$

b: after treatment of Garden-III and -IV fractures only by specialists

	Team member specialist	Non-member specialist	Significance (χ^2-test)
Garden-III and -IV fractures	139 (100%)	91 (100%)	
Hematoma	3 (2.2%)	1 (1.1%)	
Soft tissue infection	2 (1.4%)	3 (3.3%)	
Joint infection	2 (1.4%)	3 (3.3%)	
Hematomas and infections	7 (5.0%)	7 (7.7%)	$p = 0.41$
Femoral head perforation	3 (2.2%)	6 (6.6%)	
Backing-out of screw	3 (2.2%)	1 (1.1%)	
Loss of reduction	9 (6.5%)	13 (14.3%)	**$p < 0.05$**
Mechanical complications, total	15 (10.8%)	20 (22.0%)	**$p < 0.05$**

11.4.2 The influence of fracture morphology on the occurrence of loss of reduction

11.4.2.1 Garden classification

Among the 489 patients operated for femoral neck fractures between 1993 and 1994 we experienced loss of reduction 29 times (5.9%). In one patient a Garden-II fracture was initially overlooked and displaced later (see Fig. 105). This loss of reduction occurred postoperatively in a fracture that had become in the meantime a Garden-III fracture. (This patient was excluded from later assessments).

If one excludes 82 Garden-I and -II fractures, the postoperative loss of reduction of 407 Garden-III and -IV fractures amounts to 6.9% (28 instances). More reliable results can be obtained when we only consider the number of **definitely followed up patients.** The fate after discharge of 37 out of 407 patients with Garden-III and -IV fractures is unknown. One loss of reduction in the group of 37 occurred while still in hospital. Therefore, **the incidence of loss of reduction in followed up patients** amounts to 7.3% (28-1/407-37).

The fate of seven patients among the 82 patients with Garden-I and -II fractures is unknown. Among the followed up patients **no loss of reduction was observed.**

11.4.2.2 Pauwels classification

Of 489 patients five could not be evaluated (Table 15).

No correlation could be found between Pauwels classification and the incidence of loss of reduction. Even for **type III fractures,** considered by many authors as being unstable, **the incidence of complications was not higher.** If one deducts the Garden-I and -II fractures, the incidence of loss of reduction of Pauwels-I and -II is higher (type I 13.6%, type II 7.7%, type III 5.7%). Other authors published similar data (Kazár et al, 1960; Hulth, 1961; Böhler, 1996; Marti and Jacobs, 1993; Parker, 1994).

A reasonable explanation could be the better healing tendency of Pauwels-III fractures in spite of the possibility of injury at Claffey's point. **The caudal beak that remains attached to the femoral head is located extracapsular.** This fracture can consolidate thanks to the preserved blood supply and the periosteal callus.

Angle-stable implants reduce markedly the action of the shear and tilting moments described by Pauwels. Our data confirm that even in Pauwels-III fractures a sufficient stability can be obtained. For this reason we use **caudally a screw with longer threads.** This results in a better purchase in the bigger fragment. On the other hand, it is **advisable to add a DCD plate.** This plate should not only substitute for the loss of Adam's arch but also should effect a **compression:** by careful tightening of the small compression screw that fixes the cannulated screw to the DCD barrel. The improved adaptation of fragments increases the stability of the fracture and thus prevents tilting of the femoral head (Voorhove, 1992).

Table 15. Correlation between Pauwels classification and loss of reduction in 484 patients who could be evaluated

	Type I	Type II	Type III	Total
Total number of patients	61	381	42	484
Followed up patients	57 (100%)	347 (100%)	36 (100%)	440 (100%)
Loss of reduction	**3 (5.3%)**	**23 (6.6%)***	**2 (5.6%)**	**28 (6.4%)**
Followed up Garden-I and -II fractures	25	48	1	74**

* Among the 24 patients was one in whom the loss of reduction occurred after the already described overlooked Garden-II fracture

** The eventual fate of seven Garden-I and -II fractures is unknown; an additional patient did not fit the Pauwels classification.

11.4.2.3 State of fracture surfaces

According to our own previous publications and to other published data we **classified our patients in five categories depending on the fracture morphology:**

(1) Smooth surfaces;

(2) Avulsed fragment;

(3) Multiple fragments;

(4) Zone of comminution;

(5) Jagged, beak like fracture surfaces (Scheck, 1959; Fekete et al, 1989b; Alho et al, 1992; Parker and Pryor, 1993; Pannike, 1996) (Table 16).

If one adds up the categories of unstable multifragmentary and comminuted fractures as documented on radiographs, the sum will amount to one third of all patients (159/442 = 36%). More than half of the observed losses of reduction occurred in this groups (15), thus bringing the incidence of complications to 9.4% (15 out of 159). In **stable fracture types that comprise two-thirds of all fractures** (283/442 = 64%), **the incidence of loss of reduction is only half: 4.6%. This difference is significant.**

Assessment

The tendency to loss of reduction of Garden-III and -IV fractures (contrary to the undisplaced fractures or those impacted in valgus) becomes clearly evident when at the same time a multifragmentary or comminuted fracture is present. In these incidences a routine internal fixation with two cannulated screws is insufficient. To compensate for the loss of Adam's arch an angle-stable plate must be added.

Such a correlation between loss of reduction and Pauwels classification could not be shown.

11.4.3 Correlation between age (osteoporosis) and loss of reduction

While analyzing the data of 489 patients, operated in 1993 and 1994, we noticed that the percentage of elderly patients who had suffered a loss of reduction was markedly above the average of our patient population (Fekete et al, 2000a; Fekete et al, 2000b; Fekete et al, 2000c; Szita et al, 2002). Above 80 years

Table 16. Correlation between fracture morphology and loss of reduction in 486 patients who could be evaluated. The difference between stable and unstable fractures is significant (χ^2-test, $p < 0,05$)

	Total number of patients	Followed up patients	Loss of reduction
n	486 (100%)	442 (100%)	28 (6.6%)*
Smooth fracture surface	142 (29.2%)	129 (29.2%)	4 (3.1%)
One avulsed fragment	152 (31.3%)	137 (31%)	8 (5.8%)
Jagged, beak like fracture surface	19 (3.9%)	17 (3.8%)	1 (5.9%)
Total number of stable fractures		**283**	**13 (4.6%)**
Multiple fragments	125 (25.7%)	113 (25.6%)	9 (8.0%)
Zone of comminution	48 (9.9%)	46 (10.4%)	6 (13%)
Total number of unstable fractures		**159**	**15 (9.4%)**

* One of the 29 patients occurred in the group of the non-assessed patients

Table 17. Frequency distribution of followed up Garden-III and -IV fractures in respect of decades of age and loss of reduction. The difference between the patients < 70 years and that > 70 years is significant (Fisher's exact test $p < 0.05$)

Age	< 40	41–50	51–60	61–70	71–80	81–90	> 90	N
Total	4	24	41	90	139	168	23	489
Garden-I- and -II	3	6	9	18	24	21	1	82
Garden-I- and -II (%)	75	25	22	20	17.3	12.5	4.4	16.7
Followed up Garden-III and -IV	1	17	30	64	106	131	21	370
Loss of reduction (n)	1	0	0	3	9	13	1	27*
Incidence of dislocation of followed up Garden-III and -IV (%)	–	0	0	4.7	8.5	9.9	4.8	7.3

* In one of the 28 patients one had a loss of reduction after the already described overlooked Garden-II fracture, one other patient did not form part of the followed up group.

of age were 191/489 (39%) patients. Among the loss of reduction observed in a total of 27 this complication was observed in 14 (51.9%) of elderly patients. For this reason we examined the frequency of distribution of loss of reduction in respect to age (Table 17).

If one disregards the number of patients, < 40 years of age and > 90 years on account of their small number, the **increase in the incidence of loss of reduction after 60 years and the sudden increase in the 70 to 90 year age groups is obvious. The percentage of Garden-I and -II fractures decreases with increasing age.**

Assessment

The incidence of loss of reduction increases with increasing age, the cause of the phenomenon must be sought in the progression of osteoporosis.

The increasing osteoporosis leads foremost to problems in stability in the femoral head, the first buttressing point: the screw threads find less purchase in the atrophic cancellous bone. For this reason it seems advisable to proceed with a preventive modification of the standard technique to increase the stability in patients over 70 years (9.5 mm screw, flanged screw or use of three screws). Their use leads to an improved purchase in the femoral head.

11.4.4 Experiences with the lateral reinforcement

We analyzed not only the stability of the first and second buttressing points but also the advantages and disadvantages of the 2 mm plate for reinforcement of the lateral cortex (third buttressing point). To reach this goal we divided our patients into the following groups: internal fixation with **only two screws, two screws with a 2 mm plate and two screws with a 4.5 mm DC plate** that was in these years used in greater numbers. We compared the results of the **followed up Garden-III and -IV fractures** for each of the three groups (Table 18).

Internal fixation with two screws was mainly done for Garden-I and -II fractures. If one excludes these patients, a **comparison is possible** (the percentage of followed up patients respectively the frequency distribution of multifragmentary and comminuted fractures did not show a marked difference). The use of the 2 mm plate led only to a negligible increase in surgical time at a slight increase in need for transfusions.

Contrary to our expectations **the local wound complications were not lower in the group where only two screws without plate were used.** The possible explanation is that in these days we did not routinely insert a suction drain.

Backing-out of screws and loss of reduction were less frequent in the group where **2 mm plates and particularly DC plates** were used.

Table 18. Efficacy of the various small plates in Garden-III and -IV fractures. The incidence of loss of reduction shows marked differences. They are, however, not significant when comparing internal fixation with only two screws with that of an additional use of a 2 mm plate or of a DC plate (Fisher's exact test p = 0.384 respectively 0.176)

	Total	Only 2 screws	Screws and 2 mm plate	Screws and 4.5 mm DC plate	Significance (χ^2-test)
Total	488*	130	295	63	
Followed up Garden-III and -IV	369	70 (100%)	247 (100%)	52 (100%)	
Multifragmentary, comminuted fractures	159	30 (42.3%)	106 (42.9%)	23 (44.2%)	p = 0.993
Mean duration of surgery (min)		37.7	42.3	48	
Transfusion	144	24 (34.3%)	99 (40.1%)	21 (40.4%)	p = 0.380
Hematoma	8	2 (2.9%)	4 (1.6%)	2 (3.8%)	
Infections	10	2 (2.9%)	6 (2.4%)	2 (3.8%)	
Hematomas and infections	18	4 (5.7%)	10 (4%)	4 (7.7%)	p = 0.516
Backing-out of screws	5	3 (4.3%)	2 (0.8%)	0	
Femoral head perforation	12	1 (1.4%)	6 (2.4%)	5 (9.6%)	
Loss of reduction	27**	7 (10%)	18 (7.3%)	2 (3.8%)	
Mechanical complications, total	44	11 (15.7%)	26 (10.5%)	7 (13.5%)	p = 0.355
Adaptation	49	13 (18.6%)	33 (13.4%)	3 (5.8%)	p = 0.275

* In one of the 489 patients both screws were attached to two 2 mm plates

** In one of the 29 patients one had a loss of reduction after the already described overlooked Garden-II fracture, one other patient did not form part of the followed up group.

The difference, however, is not significant. The changed conditions of stability are also reflected by the inverse distribution of adaptation. **The insertion of a DC plate** for which no seating instrument was available led to a **marked increase** in local complications, particularly in respect to **femoral head perforation.** The flattened screw end jammed in the sharp-edged hole of the massive implant after tightening of the cortical screw in the compression hole.

Assessment

The addition of small plates diminishes the number of screws displaced laterally and the incidence of loss of reduction. In spite of the fact that the stability of a DC plate proved to be more favorable, the incidence of other complications, particularly that of head perforation, was higher. The use of DC plates was therefore improved by other developments (see Sect. 5.7, Fig. 166).

In summary, our experiences based on analysis of patients operated in 1993 and 1994 are as a follows:

For the prevention of *hematomas and infections* the following points are important:
- **Properly placed suction drains;**
- **Use of soft tissue sleeves.**

The causes of loss of reduction are:
- **Degree of osteoporosis;**
- **Fracture morphology, multifragmentary or comminuted fractures;**
- **Quality of reduction and internal fixation.**

The use of a small plate reduces the incidence of loss of reduction, its proper application demanded further developments.

11.5 Cannulated screw fixation 1993–94 in comparison with 1997–98

We felt compelled to investigate how the above described experiences affected our later results. This seemed to be of particular importance in view of the fact that the developments aimed to solve the problems encountered and to increase the stability had already been done and incorporated into our daily practice.

With this in mind, we compared the results of **489 cannulated screw fixations** performed **between January 1, 1993 and December 31, 1994** with those of **240 cannulated screw fixations performed between October 1, 1997 and September 30, 1998.** The latter results were documented within the **SAHFE** projects (Standardized Audit of Hip Fracture in Europe) (Fekete et al, 2000a; Fekete et al, 2000b; Fekete et al, 2000c; Cserháti et al, 2002b; Szita et al, 2002) (Table 19).

After four years the percentage of femoral neck fractures that were not treated with cannulated screws but with a primary hip replacement or other techniques of internal fixation had decreased further. Among the six conservatively treated patients three had suffered a Garden-I fracture, two other patients were in extremely poor general health and passed away after four to five days in our institute and one patient died after one week following the transfer to another hospital without having undergone surgery.

Neither fracture type nor sex differed between the two periods (Table 20). Thereafter, we present only data in respect to the treatment of Garden-III and -IV fractures (Table 21).

It became evident that access to the operating room for emergencies at our institute had not improved, but had gotten worse. After four years **the percentage of patients operated within 24 hours increased, but the incidence of surgeries done within six hours decreased** (see also Table 4). **The length of hospital stay and the initial mor-**

Table 19. Data of patients admitted for femoral neck fractures in 1993 and 1994 respectively 1997 and 1998

	01.01.1993 – 31.12.1994	01.10.1997 – 30.09.1998
n	596 (100%)	261 (100%)
Conservatively treated	9 (1.5%)	6 (2.3%)
Primary hip replacement	64 (10.7%)	13 (5%)
Cannulated screw fixation	**489 (82%)**	**240 (91.9%)**
Other techniques of internal fixation	34 (5.7%)	2 (0.8%)

Table 20. Data of all patients treated with cannulated screws in 1993–94 respectively 1997–98

	01.01.1993 – 31.12.1994	01.10.1997 – 30.09.1998	Significance T (*t*-test) C (χ^2-test)
n	489 (100%)	240 (100%)	
Garden-I and -II	82 (16.8%)	42 (17.5%)	p = 0.805 C
Garden-III and -IV	**407 (83.2%)**	**198 (82.5%)**	
Average age (years)	76 ± SD 10.38	77.9 ± SD 10.37	p = 0.254 T
Number of women	363 (74.2%)	179 (74.6%)	p = 0.919 C

Table 21. Data of cannulated screw fixation for Garden-III and -IV fractures for the years 1993–94 respectively 1997–98

	01.01.1993 – 31.12.1994	01.10.1997 – 30.09.1998	Significance T (*t*-test) C (χ^2-test)
Garden-III and -IV	407 (100%)	198 (100%)	
Surgery within 6 h	**84 (20.6%)**	**29 (14.6%)**	$p = 0.076$ C
Surgery between 6 and 12 h	116 (28.5%)	76 (38.4%)	
Surgery between 12 and 24 h	65 (16%)	44 (22.2%)	
Surgery within 24 h, total	**265 (65.1%)**	**149 (75.2%)**	**$p < 0.05$ C**
Surgery after 24 h	142 (34.9%)	49 (24.8%)	
Mean duration of surgery (min)	42.6 ± SD 16.3	36.0 ± SD 7.0	**$p < 0.001$ T**
Length of initial hospital stay (days)	12.3 ± SD 9.0	10.9 ± SD 7.2	$p = 0.055$ T
Early mortality	26 (6.4%)	10 (5%)	$p = 0.514$ C
Mortality at 4 months	80 (19.7%)	34 (17.2%)*	
Fate unknown	37 (9.1%)	18 (9.1%)	
Two screws only	75 (18.4%)	7 (3.5%)	**$p < 0.001$ C**
Two screws + 2 mm plate	274 (67.4%)	185 (93.5%)	**$p < 0.001$ C**
Two screws + 4.5 mm DC plate	57 (14%)	0	
Two screws + two 2 mm plates	1 (0.2%)	0	
DCD plate	0	4 (2%)**	
DCD + satellite plate	0	2 (1%)**	

* The follow-up of the SAHFE project was limited to four months
** During the same period 11 single DCD plates and two DCD plates + satellite plate were used for base of neck and trochanteric fractures.

tality diminished. On the other hand, no appreciable improvement of the mortality after four months was noted indicating that rehabilitation following the initial care continued to be inadequate (Cserháti et al, 1992).

Our early experiences were reflected in the choice of methods of internal fixation: in 1997–98 we did not use anymore the 4.5 mm DC plate. Two **screws without the 2 mm plate** rarely were chosen in the treatment of Garden-III and -IV fractures. **In 21 patients we inserted one or two 9.5 mm screws** and in a certain number **DCD plates were applied.** This signified that we had introduced in our daily practice techniques to increase the stability but not to a desirable extent (see incidence of multifragmentary and comminuted fractures and of osteoporosis in Sect. 11.4.2.3 and 11.4.3).

The incidence of early complications had decreased significantly (Table 22). The frequency of loss of reduction approached the low values seen after Smith-Petersen nailings (see Table 10).

Table 22. Revision surgery for early complications (within four months) after cannulated screw fixation for Garden-III and -IV fractures in the years 1993–94 and 1997–98

	01.01.1993 – 31.12.1994	01.10.1997 – 30.09.1998	Significance (χ^2-test)
Garden-III and -IV	407 (100%)	198 (100%)	
Hematoma	8 (2%)	1 (0.5%)	
Infection	9 (2.2%)	3 (1.5%)	
Hematomas and infections	17 (4.2%)	4 (2%)	$p = 0.114$
Femoral head perforation, implant migration	9 (2.2%)	0	
Loss of reduction	20 (4.9%)	7 (3.5%)	
New fracture	1 (0.2%)	0	
Mechanical complications, total	30 (7.3%)	7 (3.5%)	$p = 0.121$
Total	47 (11.5%)	11 (5.5%)	**$p < 0.05$**

Conclusion

(1) Percutaneous cannulated double screw fixation is superior in respect to mortality, length of hospital stay and the majority of complications compared with fixation of two Smith-Petersen nails necessitating an exposure of the femur.

(2) The biomechanical disadvantage of screw fixation (low rotational stability) caused initially an increased frequency of loss of reduction. We achieved an incidence of loss of reduction barely exceeding the frequency of loss of reduction observed after nailing thanks to following measures: application of experimental developments, selective indications based on the analysis of fracture morphology and osteoporosis, and, if necessary, intraoperative changes of procedure.

(3) Beside the advantages of percutaneous screw fixation this development also led to an incidence of early complications similar to those published by advocates of primary joint replacement.

(4) The frequency of late complications can be decreased foremost by an improved organization: operating patients within six hours if at all possible. In this respect the minimally invasive, percutaneous procedure is more advantageous as usually less preparation is sufficient (possibility of local anesthesia). For the same reason the number of non-operated patients dropped.

(5) One should not consider the percutaneous cannulated screw fixation a “closed technique” of fracture fixation. Its use requires an atraumatic technique (soft tissue protection, drainage) similar to open internal fixations.

11.6 Treatment of femoral neck fractures – internal fixation versus joint replacement

During the first half of the twentieth century the exclusive treatment of displaced neck fractures consisted of internal fixation. Since the introduction of total joint replacement, this approach became an alternative.

In the nineties, in most of the industrialized countries, **total joint replacement** for femoral neck fractures was the treatment of choice for patients between 60 and 75 years of age (in USA recently over 75 years) and for older patients **hemiarthroplasty.** To the contrary, in Sweden and Hungary, in some part of Austria and Great Britain, the **internal fixation** was the preferred approach. The influence in Sweden of **S. Johansson** and in Austria of **L. Böhler** played a major role. In Hungary, this trend was reinforced by the initial difficulties of importing total joint components and their high costs. In addition, these countries emphasized the improvement of **internal fixation** whereas in other countries it took a second place to total joint replacement developments. It should be pointed out that some techniques such as the 130° blade-plate and the DHS were not successful in the treatment of elderly patients with femoral neck fractures, in spite of the recommendations of the AO/ASIF known for their success in many areas (Krebs, 1970; Levi and Retpen, 1997; Ovesen et al, 1997). The opinion that "nothing has changed in the field of internal fixation since 1976" reflects a lack of practical experience (Raaymakers and Marti, 1991; Raaymakers, 1993).

It is common knowledge that a surgical technique well known to and mastered by a surgeon yields better results. For this reason, it is difficult to compare different techniques practiced in various hospitals or countries. Comparative randomized studies of two identical techniques are rare (Parker, 1998; Parker and Blundell, 1998; Johansson et al, 2000; Parker and Pryor, 2000). Studies of comparing techniques – internal fixation and joint replacement – are open to criticism given their different levels of technical difficulties. The selection should not be hazardous. For these reasons the results and the conclusions of analyses show marked deviations. During the first part of the nineties, studies comparing the two procedures were performed within the framework of the Multicenter Hip Fracture Study: internal fixation in Sweden and joint replacement in Holland and Finland. The results spoke rather in favor of internal fixation (Jalovaara et al, 1992; Swiestra et al, 1993; Berglund-Rödén et al, 1994).

In 1994, a meta-analysis appeared in the USA based on 106 publications documenting the advantages of joint replacement (Lu Yao et al, 1994). The value of the results is open to question as only five publications were found to be relevant based on statistical considerations (prospective, double blind, randomized) and could be used for conclusions. We believe that such a study cannot exclude systemic errors, as various forms of internal fixation cannot be considered as being equal.

Starting in 1993 the production of total joint components in Hungary has seen a boost and consequently the treatment of femoral neck fractures was discussed. One of us analyzed the advantages and disadvantages based on 100 world-wide publications that appeared during the 14 preceding years. He compared internal fixation with joint replacement using the following criteria (Kazár, 1995):

(1) Surgical time, circumstances;
(2) Surgical trauma, need for transfusion;
(3) Intraoperative complications;
(4) Contraindications for surgery (threat of early mortality);
(5) Stability of coxofemoral joint, early mobilization, weight bearing;
(6) Postoperative complications;
(7) Incidence of revision surgery;
(8) Late results;
(9) Economic considerations.

(ad 1) Internal fixation can usually be achieved in a **much shorter time** than a total hip replacement (THR). But even hemiarthroplasty (HAP) is a procedure that takes longer. The difference is particularly pronounced in favor of percutaneous, head preserving procedures such as hook pin or the cannulated, subchondral screw fixation developed and practiced by us.

(ad 2) The surgical trauma and soft tissue damage are markedly **reduced** during percutaneous techniques compared to implantation of THR or HAP. The stabilization of the femoral head is achieved without exposure of the fracture with minimal blood loss. A postoperative blood transfusion is rarely required. Contrary to internal fixation, large cancellous bone surfaces are exposed during femoral head resection, necessitating transfusions, particularly during THR. Transfusions are well known for their problems (transmission of infection, refusal for matters of faith, economic factors). An autotransfusion is only possible in instances of elective THR procedures but is not feasible in femoral neck fractures. For the majority of femoral neck fractures surgery is performed today after one to two days.

The **preparation** for joint replacement is considerably **more extensive:** medical assessment and treatment, exclusion of focus of infection, request for transfusions, central venous line, antibiotic prophylaxis, operating rooms providing higher sterility (laminar air flow), considerably more sophisticated and expensive implants and instruments, one or two surgical assistants (Miles et al, 1990). However, the disadvantage of internal fixation is the **personnel's exposure to radiation,** nowadays much reduced by the possibility to store the images.

(ad 3) The **incidence of intraoperative complications** after arthroplasty (dislocation, shaft perforation, femoral fractures, injury to vessels and nerves) used to be higher than after internal fixation. The incidence of intraoperative complications of total joint replacement, however, is negligible when compared to their postoperative complications. In the past years more attention was directed to the danger of fat embolism during the preparation of the acetabulum or during the impaction of cement into the medullary canal. This complication is only seen in THR or HAP.

(ad 4) An arthroplasty presents a more radical procedure than internal fixation, therefore its incidence of early mortality is higher (Cserháti et al, 1992; Laczkó et al, 1992; Laczkó et al, 1993; Swiestra et al, 1993; Berglung-Rödén et al, 1994; Cserháti et al, 1997; Kazár et al, 1997; Palmer et al, 2000; Cserháti et al, 2002a; Partanen et al, 2002). Frequency of mortality and complications after THR for neck fractures is definitely greater than after elective procedure in patients with osteoarthritis. In high-risk patients joint replacement can be contraindicated whereas internal fixation, possibly under local anesthesia, is still feasible (Kasparsen and Nörgaard, 1996). Publications of results of arthroplasties after fractures usually **do not mention the fate of the conservatively managed patients.** Data of some publications indicate that in 15 to 20% of admitted patients joint replacement cannot be performed on account of their poor general health.

(ad 5) Rehabilitation and also the survival of elderly patients depend on the success of mobilization and ambulation with weight bearing. In this respect, in previous years an arthroplasty, particularly when cemented, was much superior to the internal fixation that required non-weight bearing for two to three months. This point is still raised today by advocates of joint replacements. The modern **internal fixation with two or three implants,** the subchondral anchorage in the femoral head, the support on Adam's arch and lateral cortex, known also as three-point-buttressing, has **eliminated this advantage** (Bout et al, 1997). The percutaneous approach causes only minimal wound pain allowing the majority of patients to ambulate with a walker and not with crutches the day after surgery. For unstable fractures such as seen in porotic bone stock, Pauwels-III fractures, base of neck fracture and multifragmentary and comminuted fractures, the stability needed for weight bearing can be achieved with 9.5 mm screws, flanged screws and DCD plates.

(ad 6) The strongest argument for an initial arthroplasty is the lower incidence of postoperative complications, a fact that cannot be denied by proponents of internal fixation. The early and late complications after internal fixation that are due to mechanical causes or disturbances of blood supply to the femoral head (loss of reduction, femoral head perforation, backing-out of the implant, non-union, femoral head necrosis) constitute in their totality a greater percentage than the frequent intraoperative and early postoperative complications (femur fracture, hematoma, infection) and the rare late complications (dislocation, loosening, protrusion) after joint replacement. The incidence of complications is slightly higher after HAP than after THR.

We believe that the cause for an average of 30% of complications after internal fixation reported in the literature is due in part to an inadequate stabilization of the fracture. Undisplaced, stable and unstable displaced neck fractures, multifragmentary and osteoporotic fractures are all treated **with the same implant without any distinction.** Possible errors during reduction and internal fixation can increase the number of mechanical complications to a point of doubling them.

In addition most hospitals **do not have the facilities to perform surgery within six hours.** The majority of internal fixation is done one to two days post-trauma (Parker and Pryor, 2000). This leads to **an additional damage of the blood supply to the femoral head** caused by movements during care and positional changes as long as the fractured limb has not been immobilized for many hours. Most probably this leads to a marked increase in late complications.

Four facts need our attention:

– **The incidence of complications after immediate internal fixation is halved when compared to delayed surgery;**
– **The incidence** of the most serious complication, **the infection, is higher after arthroplasty;**
– **The incidence of complications of THR done for femoral neck fractures in the presence of osteoporosis is many times higher** than after arthroplasty for osteoarthritis with good bone stock;
– **The incidence of complications after internal fixation can be markedly reduced** when problems and errors are analyzed and instruments and techniques are continuously improved.

(ad 7) In respect to the frequency of revision, particularly within one year, the postoperative complications show a pronounced difference in favor of arthroplasty. One has to consider, however, that **revision surgery after internal fixation is usually a smaller intervention.** After a percutaneous approach the tissues are less damaged than after an arthroplasty.

(ad 8) Late complications can occur after both procedures: following internal fixation a femoral head necrosis may occur after consolidation of the fracture; after arthroplasty an aseptic or septic loosening of the femoral stem or the acetabular component is possible. In addition, after HAP a protrusion may develop. A difference also exists in the frequency in these complications. After internal fixation, not performed as an emergency procedure, the incidence of head necrosis amounts to 20 to 30%; it occurs usually **three to five years after the accident.** Complications after arthroplasty are observed **any time** after surgery. With increasing time the **frequency and possibility** of revision surgery after arthroplasty reaches relatively **higher levels** when done for femoral neck fractures than for osteoarthritis (Broos, 2002). Absolute numbers are low because complications after arthroplasty occur at a time when only a few of the elderly patients with femoral neck fractures are still alive.

(ad 9) The **internal fixation** as an initial treatment is a considerably **less expensive intervention** than a primary joint replacement when taken into consideration the total cost of an arthroplasty, including preparation for surgery, implants, cement and antibiotics, the longer operating time, the need for assistants and for transfusions as well as the longer stay in hospital. On the other hand, the more **frequent revision surgery** and the need for readmission **increase the costs** of internal fixation. If one takes, however, the incidence of revision surgery after arthroplasty into account amounting to 12 to 18% according to Swedish and English studies, the expenses for initial treatment and revisions after internal fixation are lower.

This opinion has been voiced before by other authors (Nilsson et al, 1991; Parker et al, 1992; Strömqvist et al, 1992). In 2000 in a 12-year study **Palmer and collaborators** analyzed the cost of 3000 interventions for hip fractures in two British hospitals with particular emphasis on the effects of revision surgery. Of 1688 femoral neck fractures 908 were treated with a hemiarthroplasty (HAP) and 780 with internal fixation (IF). In respect to the mean age of the patients both groups were comparable (HAP: 77 years, IF: 75 years). The incidence of complications after IF was four times greater than after HAP (HAP: 4.8%, IF: 18.7%). On the other hand, the incidence of septic complications was reversed (HAP: 1.2%. IF: 0.4%). Also the one-year mortality was lower after internal fixation (HAP: 11.5%. IF: 7.3%).

The treatment costs for one year for an **uncom-**

plicated course after internal fixation was considerably lower (HAP: £ 5259, IF: £ 3746). The author also established the average cost for each separate complication and could show that the **complications after IF create a lesser expense** than complications after HAP. If one considers all calculations, it turns out that internal fixation in spite of its higher incidence of complications **is on the whole the less expensive procedure** (HAP: £ 5598, IF: £ 4486). An internal fixation resulted in a saving for the health system of £ 1112 per patient.

This valuable comparative analysis of both procedures done under identical conditions reinforces our opinion: **if a femoral neck fracture is immediately operated and provided that the indication is correct (stability), the incidence of complications can be reduced. Consequently, internal fixation is a viable alternative to arthroplasty particularly for economic reasons.**

Timing and choice of surgical procedure

Finding out which of two drugs or two treatment regimens is the better one should be simple at the age of evidence based medicine. Properly set up **prospective** and well organized **randomized (double-blind) studies** always give a reliable answer to this question. Therefore, one is wondering why a search of the international literature results only in an unsatisfactory answer when looking for the optimal surgical procedure.

On one hand, the surgeon is **neither a drug nor an instrument but a human being.** The success of surgery depends predominantly on the technical skills of the surgeon, on his physical and mental state at that moment, his belief in the procedure, only to mention a few factors. To exclude them, trials were set up where surgeons or similar teams well versed in a given procedure were randomized instead of patients. Both set-ups, however, were subject to a new source of systematic errors.

On the other hand, individual analyses are **only valid for a given time and place** (such as the influence of economic factors). One has also to consider that medicine is in a constant flux of evolution. Based on recent results, the use of the “Duokopfprothese®” (double cup prosthesis), a hemiarthroplasty, seems to be a viable alternative to a total hip replacement in 70- to 80-year-old patients. In Sweden, internal fixation techniques have been further improved (Olerud et al, 1995; Olerud, 1999). In spite of this development, an increasing number of arthroplasties are now performed in Sweden (a frequency of 10% based on some publications) (Rogmark et al, 2002; Roden et al, 2003; Tidermark et al, 2003).

We want to endorse this development with our current study. Our goal has been to obtain a stable internal fixation by designing a relevant series of implants based on anatomy and pathology and by regular follow-ups of our results.

We are in full agreement with **Pannike** (1996) who wondered why in traumatology **procedures stabilizing a fracture are superseded by joint replacement, a technique that substitutes the broken bone.** In instances of all other injuries to the human body the goal of researchers and progressively thinking surgeons is the **functional rehabilitation based on an anatomic restitution and healing of tissues.** Indeed, the femoral neck fracture of elderly high-risk persons is a problematic osseous injury on account of the particular biomechanic and circulatory conditions. The solution to these problems must be found in the advancement of internal fixation, similar to the solution of problems relating to other regions of the body. When choosing an arthroplasty, one ignores the solution of these problems (Dickson, 1953; Nicoll, 1963; Manninger et al, 1979).

The more recent percutaneous techniques are certainly more favorable in respect to the **surgical trauma** than the joint replacement. In regard to the ability of postoperative weight-bearing internal fixation has caught up with arthroplasty. Based on our own investigations we are of the opinion that the incidence of **early complications** after internal fixation **can be noticeably reduced** when taking into consideration the proper need for stability and when choosing the appropriate surgical technique (Asnis and Wanek-Scaglione, 1994; Robinson et al, 1994).

The only remaining, definite disadvantage of internal fixation is the **femoral head necrosis.** When assessing the effect of this complication, the functional status should be foremost considered and not the anatomic result: in the majority of patients the necrosis is only partial but even total necroses are not always causing severe symptoms (the so-called silent necrosis) (Manninger et al, 1967; Barnes et al, 1976).

Based on our results and on the opinion of other authors we believe that the **incidence of this complication can be further reduced.** Foremost in this respect is an **organization that allows to bring the patients to the hospital and operate them within six hours** (Zuckerman et al, 1995).

In our opinion, the **increased costs** that result from an assured access to the operating room, an increased need for surgical personnel (leisure time) and the financial compensation for overtime can be offset by a reasonable financial plan. This saving can be achieved by selecting a more recent percutaneous technique instead of a joint replacement.

It is a typical sign of our times that the development and dissemination of orthopedic and traumatologic techniques is **influenced by various interests** (Sarmiento, 2000a; Sarmiento, 2000b). It becomes more and more evident that health care providers are **interested in a more favorable cost-benefit-ratio.** This pressure on the health system is a world-wide phenomenon.

Thanks to adequate rehabilitation in industrialized countries, chances of survival and of having better function are greater there even after major surgery. In the course of the Multicenter Hip Fracture Study we could show that under equal conditions of (often inadequate) rehabilitation the 4-months mortality after hemiarthroplasty was 50% higher (35.7%) than after internal fixation (20.4%). The stay of patient in a trauma ward after internal fixation was markedly shorter (15 vs. 27 days). The incidence of complications during the first four months after internal fixation was not appreciably higher than after hemiarthroplasty (8.8% vs. 7.1%) (Cserháti et al, 1992; Laczkó et al, 1992; Laczkó et al, 1993; Cserháti et al, 1997; Kazár et al, 1997; Cserháti et al, 2002a).

We want to emphasize that for us the internal fixation of femoral neck fractures is the procedure of choice although not the only one.

Imaging techniques have made a tremendous progress during the recent years. They offer us new, as yet incompletely realized possibilities, not only to measure the extent of circulatory disturbances – **particularly in younger patients** – but also to identify borderline cases which will help us in the decision whether to preserve or to replace the femoral head.

In selected cases we feel that a primary **implantation of a prosthesis is indicated:**

- Remote fracture (pay attention to radiologic signs!);
- Other concomitant coxofemoral conditions (progressing femoral head necrosis, osteoarthritis, rheumatoid arthritis);
- Very pronounced, initial rotational displacement, multifragmentary or comminuted fractures or very cranial running Garden-IV fractures. In these instances the reduction and adaptation of the fracture surfaces is often unsuccessful.

There is no absolute need to **limit** the treatment of femoral neck fractures **to one sitting.** Particularly in **elderly, high-risk patients** with a remote fracture and weakened by a prolonged confinement to bed a **minimally invasive fixation (possibly under local anesthesia)** may be considered. The surgical stabilization decreases or eliminates the pain and allows proper **care.** After improvement of the general condition an **arthroplasty can be performed in selected patients, an operation that had been initially contraindicated.**

We believe that only future research endeavors can define the exact place in the treatment of either procedure; such an undertaking is in the interest of patients, specialists and society.

Chapter 12

APPENDIX

12.1 Definition of terms particular to the subject of internal fixation of femoral neck fractures

Classification of hip fractures

1. Intracapsular (medial)
   (a) **Subcapital neck fractures**
   (b) **Transcervical neck fractures** (the distinction is of little clinical significance)
2. Extracapsular
   (a) **Lateral neck fracture** (part of the neck remains attached to the caudal fragment. If this part lies in the region of Adam's arch, the screw can still find support on the 2nd buttressing point. An angle-stable implant is therefore not necessary. Exceptionally, this fracture can run partly intracapsular (due to a variation of the course of the capsule); consequently, immediate surgery is recommended).
   (b) **Base of neck fracture** (part of the neck does not remain attached to the caudal fragment. The trochanteric area, however, remains intact. Use of an angle-stable DCD plate is always recommended)
   (c) **Trochanteric (per-intertrochanteric) fracture**
   (d) **Subtrochanteric fracture**

Undisplaced femoral neck fractures
Overall term for Garden-I and -II fractures. Previously, the Garden-I fracture was known as impacted valgus or abduction fracture of the femoral neck.

Displaced femoral neck fracture
Overall terms for Garden-III and -IV fractures. Previously, they were known as varus or adduction fractures.

Garden alignment angle, measured in the a.-p. projection
Normally, a line along the medial cortex of the femoral shaft and a line going through the center of the compression trabeculae of the femoral head form an angle of 160° (see Fig. 69a).

If the angle is greater than 160°, we speak of valgus position. If it exceeds 190°, the term hypervalgus is used and if it is below 160°, it is termed varus position.

A valgus position between 160 and 180° is acceptable. In respect to stability it is even desirable. An increased risk of avascular necrosis exists in instances of hypervalgus. If the angle is less than 150°, the danger of loss of reduction is higher. In both cases a reduction is mandatory.

Garden alignment angle, as measured in the lateral projection
This is defined as an angle formed by a line going through the center of the femoral neck and by a line going through the center of the compression trabeculae of the femoral head; it amounts normally to 180° (see Fig. 69b). If the Garden alignment angle is smaller than 180° in the lateral projection (open posteriorly, the apex pointing anteriorly), we speak of antecurvature. If the angle exceeds 180°, (open anteriorly, the apex pointing posteriorly) we are dealing with a recurvatum.

Still acceptable is an angle between 180 and 160°. A fracture having an antecurvature of < 160° has a tendency for loss of reduction. A recurvatum > 190° carries the increased risk of avascular necrosis. In both instances a reduction is mandatory.

Garden alignment index
Anatomically, the ratio of the a.-p. Garden angle over the lateral Garden angle amounts to 160/180°. Acknowledging an acceptable margin of error of 5° this index is the most precise parameter of displacement of a femoral neck fracture or of the quality of reduction in both planes.

Adam's arch
In the a.-p. projection this bony structure is seen as a cortical thickening at the medial side of the femoral neck.

Calcar femorale
A cortical thickening in the posterior half of the proximal femur extending through the cancellous bone. The calcar femorale together with Adam's arch forms a U-shaped gutter in the caudal part of the neck extending to the femoral head. The calcar femorale is a continuation of the posterior cortex of the femoral diaphysis. Appositional growth of the lesser trochanter during organogenesis leads to its migration to the center of the neck.

A reduction is needed when on a.-p. radiograph the following signs are seen (see Sect. 7.6)
Varus: <150°
Valgus: >190°
Too strong (causing a caudal translational – ad latus – displacement) or **inadequate traction** on the limb (causing a cranial translational displacement) is defined

– by the translational displacement exceeding one cortical width;
– by the width of a fracture gap inferiorly – rarely superiorly – exceeding 3 mm (in general, a smaller gapping corrects itself spontaneously during the postoperative phase. To obtain, however, a good early metaphyseal drainage it is advisable to use the adapter during the operation to reduce or eliminate any gapping).

Diastasis involving the entire fracture line: an immediate correction using the adapter is absolutely necessary.

A reduction is needed when on a lateral radiograph the following signs are seen (see Sect. 7.6)
Antecurvature: <160°
Recurvatum: >190°
Too strong or inadequate rotation (exaggerated or insufficient internal rotation of the limb around the longitudinal axis of the femur) is defined by a posterior step (too strong) or by an anterior step (insufficient rotation) exceeding a quarter of the width of the femoral neck.

Anterior positioning of insertion of the first cannulated screw
An optimal position for the start of drilling should produce a placement of the first caudal screw 3 mm anterior to the midline of the neck. At this site the gutter formed by Adam's arch and calcar femorale is situated, it forms the site of the second buttressing point. Its course is well seen in bony, cross sections of human specimens and in sagittal serial CT cuts. In this way the caudal, more important first screw is optimally secured in the gutter. If we start drilling in the midline of the neck, we injure the calcar femorale, the posterior wall of the gutter.

As described in Sect. 5.7 the first step of drill bit placement is the insertion of the two-hole drill guide with its attached handle into the soft tissue sleeve also having a handle. A short Kirschner wire is driven through the center hole of the drill guide to prevent its slipping from the midline. Imaging in the lateral projection must confirm the wire's placement in the center of the neck. 3 mm anterior to the guide wire hole is the hole for the 3.2 mm spiral drill bit. If the handle of the two-hole drill guide points strictly posterior, a drilling 3 mm anterior to the midline of the neck is assured and the 3.2 mm drill bit cannot slip on the convex cortex. Thanks to the use of the two-hole drill guide the position of the caudal screw in the center of the gutter is guaranteed (anterior positioning) (see Fig. 164).

Assessment of internal fixation (see Sect. 8.4)

Adaptation and settling (sliding)
Even after a perfect reduction the surfaces of a displaced fracture do not fit exactly. In the majority of patients a spontaneous fitting of the surfaces is taking place already during the postoperative return of the muscle tone and also later at the beginning of mobilization and during consolidation. We term this fitting **adaptation.** In the course of this process the femoral neck shortens usually due to an impaction. A slight varus displacement is also possible. A lateral measurable protrusion of the screw end accompanies this process **(settling, sliding).** The position of the screw's tip in the femoral head is not affected by this process.

We attempt already intraoperatively to reduce or eliminate a possible gapping (diastasis) as seen on the monitor. Careful use of the adapter helps to achieve an adaptation of the fracture surfaces. Its use is always recommended, when a gap is seen during surgery; it is obligatory, when the gap is wide.

A certain degree of settling is already discernible on radiographs taken after postoperative mobilization. Small gaps, usually associated with intraoperative exaggerated distraction or defects at the fracture surfaces, have disappeared and the slight rotation is corrected.

In the majority of patients a further backing-out of the screw end is evident on radiographs taken after four months. The cause of this settling during consolidation is a further impaction and also a resorption of small fragments and the fracture surfaces, all explaining the shortening of the femoral neck.

Degree of settling

Small degree of settling (< 1 cm), usually favorable as it increases the stability.

Moderate settling (1–1.5 cm), the fracture most often consolidates

Considerable settling (> 1.5 cm), in the absence of an axial malalignment indicates a serious circulatory disturbance. If accompanied by a varus alignment, it is usually a sign of an imminent loss of reduction. Only in exceptional cases the fracture may consolidate.

In instances of a marked settling, radiographic controls at shorter intervals are recommended and a prolongation of partial weight bearing may be necessary.

Summary of methods for enhanced fixation of the femoral neck fracture
(Figs. 241 and 242)

The phases of uneventful consolidation of femoral neck fractures

Consolidation – end of the 4th month: the patient is symptom-free, radiographs show the beginning of healing and remodeling and no signs of imminent complications are present such as loss of reduction, femoral head perforation and gaping.

Remodeling – end of year 1: the patient is symptom-free, in general the fracture gap has disappeared, no radiographic evidence of complications such as non-union, necrosis etc.

Healed fracture – end of year 3: the patient is symptom-free, the fracture cannot be recognized anymore, contour and cancellous bone structure of the femoral head are normal, no evidence of necrosis (uncomplicated healing).

Disturbances of healing in femoral neck fractures

Loss of reduction: occurring up to the end of the 3rd month (sometimes 6th month), displaced fracture, need for revision surgery. No necrosis!

Delayed union: three to six month after injury: no or inadequate callus formation on radiographs. No signs of complications such as loss of reduction, femoral head perforation, gaping are present. If the patient complains about pain, follow-up examinations at shorter intervals are recommended.

Non-union: even after six months no evidence of consolidation of the fracture visible. It may happen that an apparently consolidated fracture displaces without adequate trauma. A cortication of the cranial fracture surface is present. It is an evidence of femoral head vitality (L. Böhler, 1996) (see Fig. 120).

Migrating non-union: Simultaneous occurrence of total head necrosis and non-union. Remodeling of the fracture only from the caudal fragment. Cranially, the necrotic trabeculae undergo a gradual fragmentation. Consequently the fracture line "migrates" cranially by 0.5 to 1 cm. Radiographs show the characteristic, homogenous radiodensity (Böhler, 1996).

Femoral head necrosis: occurring more than one year after injury: usually progressive changes of the femoral head taking place after remodeling of the fracture. In displaced femoral neck fractures certain vascular disturbances occur almost always; their prognosis depends on many factors such as anatomic vessel variants, degree of initial displacement, length of interval between injury and reduction, quality of reduction and/or internal fixation.

Assessment of femoral head necrosis, stages
The first classification of femoral head necrosis was published by Arlet and Ficat (1968). Today, the following modified and internationally recognized classification is used (Arnoldi, 1994; Mont and Hungerford, 1995). Both classifications are based on the aseptic, atraumatic avascular necrosis, they can, however, also be applied to the posttraumatic femoral neck necrosis.

Stage 0: absence of clinical symptoms, no pathologic changes on standard radiographs taken in two planes. Earliest evidence of vascular disturbances

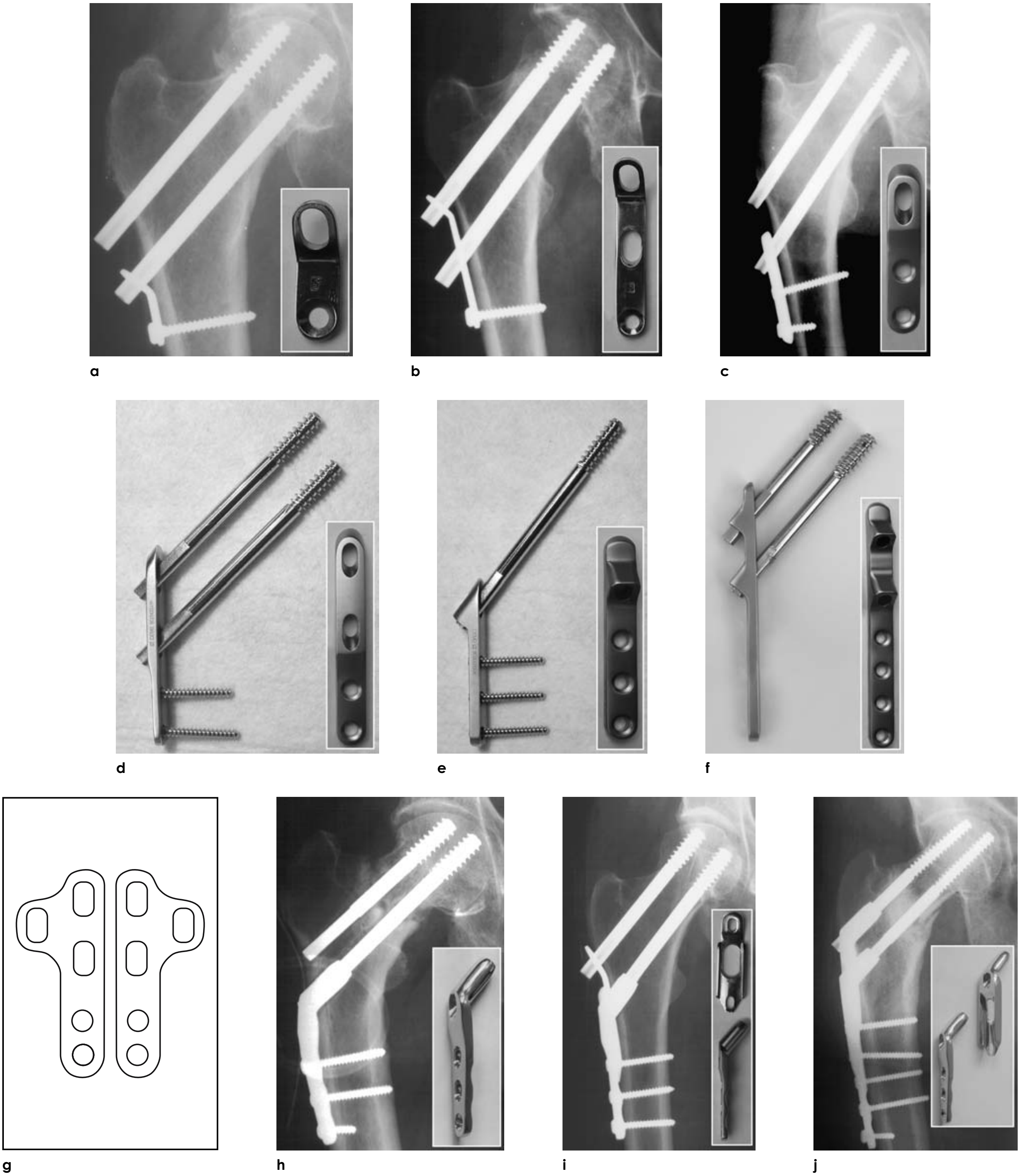
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Fig. 241. Series of methods for enhanced fixation of the femoral neck fractures.
a. 2 mm two-hole plate, standard, for the fixation of the caudal cannulated screw;
b. 2 mm three-hole plate, for the fixation of both cannulated screws;
c. 4.5 mm three-hole plate, for enhanced fixation of the caudal cannulated screw;
d. 4.5 mm four-hole plate, for enhanced fixation of both cannulated screws;
e. Four-hole cam-plate, for limited angle-stable fixation of the caudal cannulated screw;
f. Six-hole cam-plate, for limited angle-stable fixation of both cannulated screws;
g. 2 mm five-hole plate (left and right side) for the fixation of three cannulated screws (with the new parallel guide, see Fig. 163);
h. Simple DCD (Dynamic Collo-Diaphyseal) plate, angle-retaining fixation of the caudal cannulated screw (missing Adam's arch);
i. DCD plate and satellite plate, angle-retaining fixation of the caudal cannulated screw (missing Adam's arch) and fixation of the cranial cannulated screw (against rotational instability);
j. Double angle-stable DCD plate, angle-retaining fixation of both cannulated screws (comminuted fracture);
k. Flanged screw, plate inserted in the caudal cannulated (longitudinal splitted) screw (against rotational instability);
l. Flange and the same inserted in the screw;
m. Two cannulated screws connected by one flange, increases the stability of the cranial screw (see also Fig. 168)

can be detected by MRI and later by SPECT or DS-intraosseous venography. Vascular disturbances diagnosed by special imaging techniques do not always lead to demonstrable structural signs of necrosis.

Stage 1: Slight symptoms may be present, but the contour of the femoral head is preserved. Plain radiographs taken in two planes show an early, subchondral diminished transparency, a zone of "sclerosis" at the zone of weight bearing of the femoral head. Later on, in the presence of partial necrosis radiodense and atrophic spots may appear and occasionally cystic changes.

Stage 2: Increasing symptoms. The sphericity of the femoral head is lost due to a flattening at the weight bearing surface. The continuity of the bony structure is however preserved. During stage 1 and 2 a core decompression procedure is indicated.

Stage 3: Collapse of the weight bearing surface. In older patient (> 60 years) a symptomatic femoral head necrosis after neck fractures necessitates an arthroplasty. In younger patients result of the CT is decisive: If the sum of the a.-p. and lateral angles of necrosis does not exceed 200°, a rotational osteotomy may be attempted to transfer the collapsed segment out of the weight bearing area (Salacz et al, 1993). The type of osteotomy is determined with the help of radiographic films. After consolidation of the osteotomy a revascularization of the femoral head with a pedicled bone transplant can be attempted. In selective, early diagnosed cases we may obtain a remodeling of the femoral head on the condition that we support carefully the collapsed segment with autogenous cancellous bone during the revascularization procedure.

Stage 4: Pronounced deformation of the femoral head followed by subluxation and coxofemoral osteoarthritis. In the presence of symptoms an arthroplasty is indicated (in younger patients perhaps an arthrodesis).

Core decompression
Decompression of the femoral head: with a 5 mm hollow drill bit we remove a bony cylinder from femoral neck and head. We perforate the sclerotic border around the zone of necrosis where the intraosseous pressure is elevated due to congestion. The congested blood in the endangered zone can drain through the drill channel. Thus the intraosseous pressure in this zone can be reduced or eliminated decreasing the risk of progression of necrosis. Under favorable circumstances a necrosis of limited extent can heal and the patient becomes symptom-free (Hungerford and Lennox, 1985).

Revascularization procedure
If an extensive necrosis in patient under 50 years causes pronounced symptoms, a pedicled bone graft can be transplanted under the weight bearing surface.

Optimal treatment
A proper reduction, a stable internal fixation and a state of art rehabilitation are defined as an optimal treatment (Thorngren, 1991a).

12.2 Members in charge of the research team "Femoral Neck Fractures" at the National Institute of Traumatology (Budapest)

Manninger Jenő	1953–
Szabó László†	1953–1964
Borók László†	1953–1958
Kazár György†	1957–2002
Nagy Ernő†	1962–1985
Zolczer László†	1964–1985
Salacz Tamás	1968–
Fekete Károly	1988–2003
Cserháti Péter	1990–
Szita János	2003–
Laszkó Tibor	1991–
Melly András	1986–
Kádas István	1987–
Flóris István	1995–
Baktai József	1995–

12.3 Foreign teachers, councilors and supporters

Aichner H.	A
Allgöwer M.	Ch
Beck E.	A
Bonnaire F.	D
Boyd H. L.	USA
Böhler J.†	A
Böhler L.†	A
Ehalt W.	A
Hungerford D. S.	USA
Kaplan M.	RUS
Kinzl L.	D
Kuderna H.	A
Kuner E. H.	D
Müller M. E.	CH
Olerud S.	S
Pannike A.	D
Parker M. J.	GB
Poigenfürst H.	A
Povacz F.	A
Rehnberg L.	S
Rommens P. M.	D
Schneider R.†	CH
Schweiberer L.	D
Sevitt S.	GB
Stock W.	D
Thorngren K-G.	S
Tscherne H.	D
Vécsei V.	A
Willenegger H.†	CH
Wingstrand H.	S

In the early stages of our research team we received the most encouraging support from Lorenz and Jörg Böhler and from Hans Willenegger.

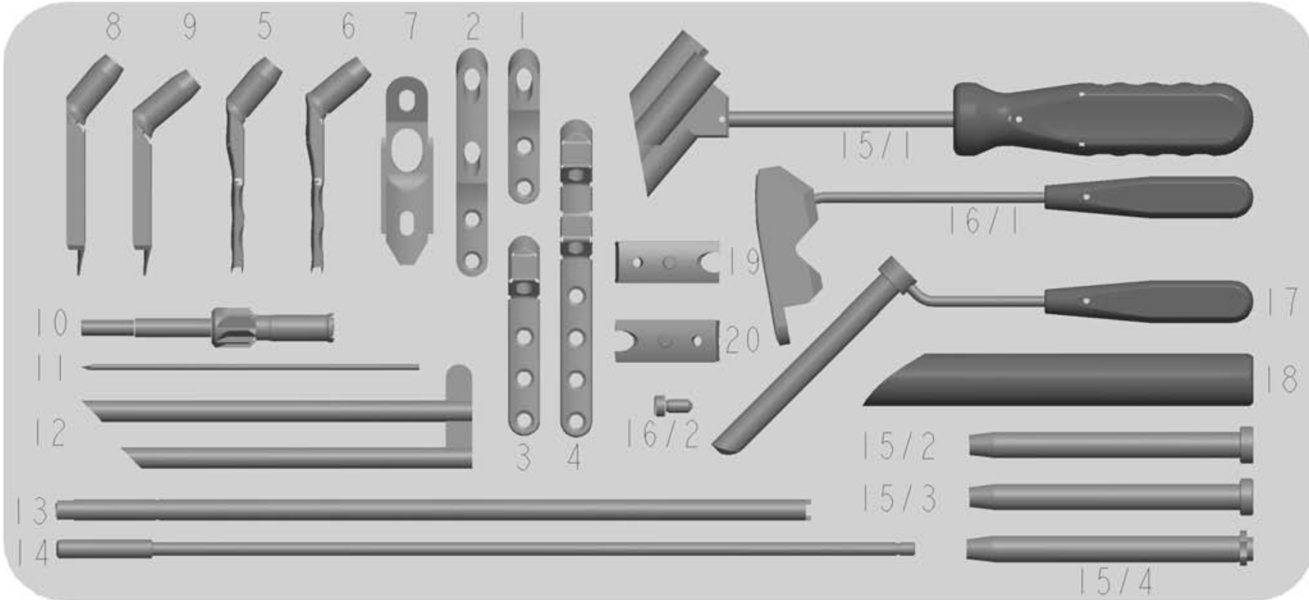

Fig. 242. Implants and instruments for enhanced fixation of the femoral neck fractures.

Implants

1. Three-hole 4.5 mm plate (Fig. 241. d)
2. Four-hole 4.5 mm plate (Fig. 241. c)
3. Four-hole cam-plate (Fig. 241. e)
4. Six-hole cam-plate (Fig. 241. f)

5–6. DCD plate for the fixation of the caudal cannulated screw, 140° and 130° (Fig. 192. a)

7. DCD satellite plate (Fig. 241. i)

8–9. DCD (Dynamic-Collo-Diaphyseal) cranial supplementary plate allows to double the angular stability, 140° and 130° (Fig. 192. c)

Instruments

10. Crown drill bit for preparation of the barrel of DCD plate (Fig. 196. b)
11. Kirschner wire for fixation of the two-hole parallel drill guide (Fig. 164)
12. The two sleeves for the parallel alignment of the flattened end of the cannulated screws (Fig. 167)
13. 290 mm long 8 mm extension rod for slotted screw (Fig. 161. b/2)
14. Long screw holder (Fig. 161. b/4)

15/1. The new parallel guide for insertion of two or three cannulated screws (Fig. 163. a, b)

15/2, 3, 4. Three special sleeves for the new parallel guide

16/1. DCD parallel guide for 140° plates (Fig. 196. a)

16/2. Screw for fixation the wedges 19 and 20 to the DCD parallel guide for 140° plates

17. Two hole drill guide with handle for anterior translation of the caudal cannulated screw (Fig. 164)
18. The adapter used for the intraoperative elimination of diastasis in the fracture gap (Fig. 159)

19–20. Wedges to the DCD parallel guide for 120 and 130° plates

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