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FEMORAL SHAFT FRACTURES IN ADULTS: EPIDEMIOLOGY, FRACTURE PATTERNS, NONUNIONS, AND FATIGUE FRACTURES

A clinical study

Sari Salminen

Academic dissertation

To be presented with the permission of
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for public discussion in the Auditorium of the Töölö Hospital,
Helsinki University Central Hospital, on June 29th, 2005, at 12 o'clock noon.

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To my family

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ABSTRACT

The femur (thigh bone) is the longest, strongest, largest and heaviest tubular bone in the human body, and one of the principal load-bearing bones in the lower extremity. Femoral shaft fractures are among the most common major injuries that an orthopaedic surgeon will be required to treat. Although demographic data of the patients have been analyzed in some epidemiologic studies, little attention has been paid to the characterization of the fracture patterns of femoral shaft fractures using morphologic classification systems.

Femoral shaft fractures are commonly thought to be primarily associated with severe trauma in young persons. Low energy violence as a cause of these fractures, especially among the elderly, has been mentioned only sporadically in epidemiologic studies. Another subgroup of operatively treated femoral shaft fractures are displaced fatigue fractures of the femoral diaphysis, which mainly occur among military trainees.

The concept of intramedullary fixation in the treatment of femoral shaft fractures has gained wide acceptance. Delayed union or nonunion following intramedullary nailing of the femur has been considered an infrequent clinical problem. As a consequence of the more frequent use of intramedullary nailing for the treatment of femoral shaft fractures, an increasing number of orthopaedic surgeons will be confronted with this complication.

The present study shows that femoral shaft fractures in adults are not exclusively the result of high energy trauma. Low energy trauma can cause 25% of the fractures. Femoral shaft fractures caused by low energy violence mainly occur in patients suffering from a chronic disease or a condition causing osteopenia of the femur. In displaced femoral shaft fatigue fractures, regardless of the symptoms, the diagnosis can be delayed until displacement. The incidences of femoral shaft fractures caused by different injuries vary from 1.5:100 000 person-years to 9.9:100 000 person-years. Most traumatic femoral shaft fractures are isolated without concomitant injuries. The most common fracture type of the femoral shaft is a non-comminuted simple AO Type A, most of which, in traumatic fractures, are purely transverse and located in the middle third of the femur. Spiral fractures that are related to low energy trauma situate in the middle third of the femur. Displaced fatigue fractures are oblique or oblique-transverse, and located in the distal third of the femoral shaft. Femoral shaft fractures caused by low energy trauma are morphologically different from displaced fatigue fractures, which can also be primarily comminuted.

Factors that predispose traumatic fresh femoral shaft fractures to nonunion after intramedullary nailing are related to severe fracture comminution and concomitant injuries. Reoperation of traumatic femoral shaft fractures treated with intramedullary nailing should be performed within six months of the primary nailing to minimize the risk of nail breakage, if convincing signs of consolidation in progress are lacking. Exchange nailing seems to be the method of choice for the treatment of a disturbed union. In some selected cases with primary static interlocking nailing, dynamization alone can be considered. Bone grafting alone as a treatment of a failed union of a femoral shaft fracture cannot be recommended.

LIST OF ORIGINAL PUBLICATIONS

The present study is based on the following articles, referred to in the text by their Roman numerals:

I Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM. Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000

II Salminen S, Pihlajamäki H, Avikainen V, Kyrö A, Böstman O. Specific features associated with femoral shaft fractures caused by low energy trauma. J Trauma 43:117-122, 1997

III Salminen ST, Pihlajamäki HK, Visuri TI, Böstman OM. Displaced fatigue fractures of the femoral shaft. Clin Orthop Relat Res 409:250-259, 2003

IV Pihlajamäki HK, Salminen ST, Böstman OM. The treatment of nonunions following intramedullary nailing of femoral shaft fractures. J Orthop Trauma 16:394-402, 2002

ABBREVIATIONS

ACL	anterior cruciate ligament
AO	Arbeitsgemeinschaft für Osteosynthesefragen
AP	anteroposterior
ARDS	adult respiratory distress syndrome
ASIF	Association for the Study of Internal Fixation
BMI	body mass index
C	closed (intramedullary nailing)
CAB	chronic alcohol abuse
cm	centimeter (SI)
COPD	chronic obstructive pulmonary disease
CT	computerized tomography
DCP	dynamic compression plate
DCS	dynamic condylar screw
DM	diabetes mellitus
F	female
G-K	Grosse-Kempf
IAC	intraoperative additional comminution
ICD	International Classification of Diseases
IM	intramedullary
ISS	Injury Severity Score
kg	kilogram (SI)
KLR	knee ligament rupture
K-S	Klemm-Schellmann
L	left
LCL	lateral collaterale ligament
LISS	Less Invasive Stabilization System
M	male
m	meter (SI)
m.	musculus (muscle)
m^2	square meter (SI)
MCL	medial collaterale ligament
mm	millimeter (SI)
mm^3	cubic millimeter (SI)
mmHg	millimeter of mercury
MRI	magnetic resonance imaging
N	number
ND	neuromuscular disorders
Nm	Newtonmeter
O	open (intramedullary nailing)
OA	osteoarthritis
OTA	Orthopaedic Trauma Association
p	probability
PCL	posterior cruciate ligament

PF	previous major fracture
R	right
STIR	short tau inversion recovery
T2	transverse relaxation
TP	total prosthesis replacement
V-W	Vari-Wall
W-H	Winquist and Hansen
WHO	World Health Organization

1. INTRODUCTION

The femur (thigh bone) is the longest, strongest, largest and heaviest tubular bone in the human body (Moore 1992; Bucholz and Brumback 1996; Schatzker 1996; Platzer 2003; Whittle and Wood 2003), and one of the principal load-bearing bones in the lower extremity (Whittle and Wood 2003). Femoral shaft fractures are among the most common major injuries that an orthopaedic surgeon will be required to treat (Gozna 1982; Whittle and Wood 2003).

Femoral shaft fractures often result from high energy forces associated with possible multiple system injuries (Bucholz and Jones 1991; Bucholz and Brumback 1996; Whittle and Wood 2003). Fractures of the femoral diaphysis can be life-threatening on account of an open wound, fat embolism, adult respiratory distress syndrome (ARDS) (Zalavras et al. 2005), or resultant multiple organ failure (Bucholz and Jones 1991; Bucholz and Brumback 1996; Keel and Trentz 2005). Femoral shaft fractures can lead to a major physical impairment, not because of disturbed fracture healing, but rather due to fracture shortening, fracture malalignment, or prolonged immobilization of the extremity by traction or casting in an attempt to maintain the fracture length and alignment during the early phases of healing (Bucholz and Brumback 1996). Even minor degrees of shortening and malalignment can eventuate in a limp and posttraumatic arthritis (Bucholz and Jones 1991; Bucholz and Brumback 1996). The art of femoral fracture care is a constant balancing of the often conflicting goals of anatomic alignment and early functional rehabilitation of the limb (Bucholz and Brumback 1996).

Although most musculoskeletal injuries occur in a predictable manner, as dictated by the forces involved and the structure of the region, there are always certain fractures that are unique to each injury (Gozna 1982). Few epidemiologic studies have been published on femoral shaft fractures. Although demographic data of the patients have been analyzed (Knowelden, Buhr, Dunbar 1964; Wong 1966; Hedlund and Lindgren 1986; Arneson et al. 1988; Bengnér et al. 1990), little attention has been paid to the characterization of the fracture patterns using morphologic classification systems. Epidemiologic studies offer important data contributing to improved fracture treatment or better patient care. Surgeons should have knowledge of the spectrum of fractures they treat, not only for an intrinsic educational value, but also to allow resources to be allocated on the basis of projected numbers of patients. The ability to predict the level of admissions to a trauma unit is useful for administrative and training purposes.

Femoral shaft fractures are commonly thought to be primarily associated with severe trauma in young persons. Low energy violence as a cause of these fractures, especially among the elderly, has been mentioned only sporadically in epidemiologic studies of fractures of the femoral shaft (Wong 1966; Hedlund and Lindgren 1986; Arneson et al. 1988; Bengnér et al. 1990). The outcome of tibial shaft fractures caused by low energy mechanism has been recently studied (Toivanen 2001). Another subgroup of operatively treated femoral shaft fractures are displaced fatigue fractures of the femoral diaphysis. Military trainees form a relatively homogenous population to be investigated of the epidemiologic features of fatigue fractures. The trainees are usually affected by undisplaced fatigue (stress) fractures of the lower extremities. Displacement of a fatigue fracture in a long bone is a rare but serious injury.

The treatment of femoral shaft fractures has always been a focus of interest, but may still remain a clinical problem, and a subject of controversy. Several techniques have been developed for the treatment. With the awareness of the advantages, disadvantages, and limitations of these techniques, an orthopaedic surgeon has the opportunity to avoid prolonged morbidity and extensive disability owing to lower extremity injuries (Bucholz and Brumback 1996; Whittle and Wood 2003). In 1963, Dencker published his thesis of 1003 recent fractures of the femoral shaft in 992 patients treated at the public hospitals of Sweden during a three-year period from 1952 to 1954 with a follow-up of 4 to 8 years to analyze the results obtained with different methods of fracture treatment (Dencker 1963). He concluded that conservative treatment with traction is the method of choice in the routine management of femoral shaft fractures. Ten years later, as the Küntscher nailing with reaming and a compression plate osteosynthesis had gained more popularity in fracture management, Kootstra introduced in the Netherlands a study of 335 consecutive femoral shaft fractures in 329 patients with a statistical analysis of the different methods of treatment during 1958-1969 (Kootstra 1973). Since the studies of Dencker and Kootstra, the changes over the 30-40 years have introduced a new preferential fracture treatment in intramedullary nailing with extended indications, nailing types (unreamed nailing or retrograde nailing), and diverse nail materials. The concept of intramedullary fixation in the treatment of femoral shaft fractures has gained wide acceptance, yet the the literature, though abundant and comprising a lot of clinical series, shows limitations in reporting of more or less unspecified fractures managed by one certain intramedullary nail type. In fact, the discussed issues seem seldom to have focused on the type of fracture itself, leaving the specific problematics of fractures caused by infrequent mechanisms nearly unobserved.

Delayed union or nonunion following intramedullary nailing of the femur has been supposed to be an infrequent clinical problem compared with the treatment results of the lower leg (Winquist, Hansen, Clawson 1984; Thoresen et al. 1985; Brumback et al. 1988b; Christie et al. 1988; Søjberg, Eiskjaer, Møller-Larsen 1990; Brumback 1996; Bhandari et al. 2000; Herscovici et al. 2000; Tornetta and Tiburzi 2000). As a consequence of the more frequent use of intramedullary nailing for the treatment of femoral shaft fractures, an increasing number of orthopaedic surgeons will, however, be confronted with this complication. Failed union of a femoral shaft fracture is a serious complication, prolonging patient morbidity and possibly influencing the ultimate functional recovery. Nevertheless, the studies on the outcome of femoral shaft fractures have seldom focused on proper identification and treatment of a disturbed process of consolidation after intramedullary nailing of a shaft fracture of the femur. Many of the previous reports have heterogenous patient material because the type of primary treatment before the development of the disturbed consolidation has varied considerably (Christensen 1973; Harper 1984; Heiple et al. 1985; Kempf, Grosse, Rigaut 1986, Klemm and Börner 1986; Curylo and Lindsey 1994; Canadian Orthopaedic Trauma Society 2003). Hence, it has been difficult to characterize the typical features and problems of nonunion after intramedullary nailing.

2. REVIEW OF THE LITERATURE

2.1. Definition of the femoral shaft

The length of a tubular human femur is about one fourth of the height of a person (Thorek 1962; Healey and Seybold 1969; Moore 1992). The skeletal maturity of the adult type of femoral diaphysis can be judged by the age of the patient, which usually has been 17 years or older in studies concerning femoral shaft fractures in adults (Dencker 1963; Kootstra 1973), but more definitely by the closed (mature) growth plates (Platzer 2003).

The proximal end of the femur consists of the head, the neck, the greater trochanter, and the lesser trochanter. The distal end of the femur has medial and lateral condyles. The proximal and distal parts widen into metaphyseal subtrochanteric and supracondylar regions (Thorek 1962; Healey and Seybold 1969; Moore 1992; Bucholz and Brumback 1996; Platzer 2003). The designation femoral shaft fracture denotes that the fracture situates entirely on the femoral diaphysis. The definition of the diaphysis measured from the anteroposterior (AP) radiographs has varied (Carr and Miller 1958; Dencker 1963; Kootstra 1973; Hedlund and Lindgren 1986; Böstman et al. 1989; Canadian Orthopaedic Trauma Society 2003). The femoral shaft is 1) the portion of the bone between the proximal boundary of 4 inches (10.16 cm) from the tip of the trochanter major and the distal boundary of 4 inches (10.16 cm) from the end of the femoral medial condyle (Carr and Miller 1958), or 2) the distance between 5 cm distal to the lesser trochanter and 6 cm proximal to the most distal point of the medial femoral condyle (Dencker 1963), or 3) the diaphyseal section between the boundaries of the lower edge of the lesser trochanter and of a line which parallels the joint space of the knee at a distance equal to the width of the condyles (Kootstra 1973), or 4) the part of the femur between 10 cm distal to the lesser trochanter and 15 cm proximal to the knee joint line (Hedlund and Lindgren 1986), or 5) the portion of bone between a point 5 cm distal to the lesser trochanter and 8 cm proximal to the adductor tubercle (Böstman et al. 1989), or 6) the bone section between the boundaries of at least 1 cm distal to the lesser trochanter and 6 cm or more proximal to the distal femoral physeal scar (Canadian Orthopaedic Trauma Society 2003).

2.2. Anatomy of the femoral shaft

The femoral shaft has a physiologic anterior curve (Thorek 1962; Dencker 1963; Kootstra 1973), which can increase in certain pathologic conditions, such as fibrous dysplasia or Paget's disease (Grundy 1970; Bucholz and Brumback 1996; Whittle and Wood 2003). The external circumference of the femur is triangular exhibiting three surfaces: anterior, lateral, and medial (Thorek 1962; Healey and Seybold 1969; Kootstra 1973; Platzer 2003). The greatest cortical thickness is posteriorly, where the fascia inserts to the linea aspera, a two-lipped roughened line (Thorek 1962; Healey and Seybold 1969; Bucholz and Brumback 1996; Platzer 2003). The medial and lateral lips of the linea aspera diverge proximally and distally, the lateral lip becoming continuous proximally with the gluteal tuberosity (Thorek 1962; Platzer 2003). The medial lip extends up to the undersurface of the femoral neck (Platzer 2003). Lateral to this lip is a ridge, the pectineal line, descending from the lesser trochanter. Both proximally and distally the femoral shaft loses its triangular form and becomes four-sided (Platzer 2003). The medullary cavity varies in diameter and shape (Thorek 1962; Healey and Seybold 1969; Kootstra 1973; Moore 1992). Slightly proximal to the midshaft is the isthmus, where the circular medullary cavity is its narrowest with a diameter of 8 mm to 16 mm compared with the otherwise more oval medullary canal (Dencker 1963).

The thigh extends superficially from the inguinal ligament anteriorly and the gluteal skin fold posteriorly to the knee level (Thorek 1962; Healey and Seybold 1969). Superficial fascia contains cutaneous nerve branches from the lumbar plexus (the lateral femoral cutaneous nerve), the femoral nerve (the anterior and medial femoral cutaneous nerves), the obturator nerve (medial aspect of the thigh), and the genitofemoral nerve (the lumboinguinal branch). The included arteries are the superficial circumflex iliac, the superficial inferior epigastric, and the superficial external pudendal arteries branching from the common femoral artery. The great saphenous vein has the ramifications of the superficial circumflex iliac, the superficial inferior epigastric, and the superficial external pudendal veins at the region (Thorek 1962; Healey and Seybold 1969).

On the posterior side of the femoral diaphysis attach the pectineus, adductor brevis, adductor magnus, adductor longus, and gluteus maximus muscles. From the femoral shaft originate m. vastus lateralis (upper half of the intertrochanteric line), m. vastus medialis (medial lip of linea aspera and spiral line of femur), m. vastus intermedius (anterior and lateral aspect of upper two thirds of femoral shaft), the short head of m. biceps femoris (linea aspera and lateral supracondylar line of femur), and m. articularis genus (Thorek 1962; Healey and Seybold 1969; Kootstra 1973). The muscles of the thigh are encased by dense fibrous tissue (Healey and Seybold 1969; Kootstra 1973; Moore 1992; Bucholz and Brumback 1996). The fascia lata reinforces the lateral aspect to form distally the iliotibial tract (Thorek 1962; Kootstra 1973; Platzer 2003), which on the lateral side extends to the Gerdy's tubercle of the tibia (Platzer 2003).

The thigh contains three distinct fascial compartments. The anterior compartment encases the knee extensor muscles (quadriceps femoris including rectus femoris, vastus intermedius, vastus medialis, and vastus lateralis; and sartorius) innervated by the femoral nerve from the lumbar plexus L 2-4 for the quadriceps femoris and L 2-3 for the sartorius (Thorek 1962; Healey and Seybold 1969; Kootstra 1973; Hoppenfeld and deBoer 1984; Moore 1992; Platzer 2003). The rectus femoris muscle is also a weak flexor of the hip (Healey and Seybold 1969; Platzer 2003). The sartorius flexes, abducts, and medially rotates the thigh (Thorek 1962; Healey and Seybold 1969; Kootstra 1973; Moore 1992). The anterior compartment also includes the tensor fasciae latae, the iliacus and psoas major muscles, and the femoral artery and vein, femoral nerve, and lateral femoral cutaneous nerve (Moore 1992).

The medial compartment contains the adductor muscles (gracilis, adductor longus, adductor brevis, adductor magnus, pectineus) and the obturator externus muscle, which are supplied by the obturator nerve (Thorek 1962; Healey and Seybold 1969; Kootstra 1973; Hoppenfeld and deBoer 1984; Moore 1992; Platzer 2003). The pectineus and the adductor magnus muscle receive dual innervation: the former from the femoral nerve and the latter from the sciatic nerve (Kootstra 1973; Platzer 2003). The medial compartment also includes the deep femoral artery, obturator artery and vein, and obturator nerve.

The posterior compartment includes the flexor muscles (biceps femoris, semitendinosus, and semimembranosus), which extend the hip, and a portion of the adductor magnus muscles, as well as branches of the deep femoral artery, sciatic nerve, and posterior femoral cutaneous nerve. The posterior knee flexor group is innervated by the sciatic nerve (Thorek 1962; Healey and Seybold 1969; Hoppenfeld and deBoer 1984). The biceps femoris extends, adducts and laterally rotates the thigh, as well as flexes the lower leg (Thorek 1962; Healey and Seybold 1969; Platzer 2003). The long head of the biceps femoris is innervated by the tibial nerve (L5-S2), and the short head receives innervation from the common peroneal division (S1-2) (Platzer 2003). The semimembranosus and semitendinosus muscles also act as medial rotators of the thigh (Thorek 1962; Healey and Seybold 1969), and are innervated from the tibial nerve (L5-S2) (Platzer 2003). The intermuscular septum between the anterior and posterior compartments is thicker than the septa between the medial and anterior compartments (Hoppenfeld and deBoer 1984; Bucholz and Brumback 1996; Platzer 2003). Because of the high volume of these three compartments, compartment syndrome of the thigh is much less common than that of the lower leg (Bucholz and Brumback 1996).

The arterial supply of the femur is mainly derived from the deep femoral artery (a. profunda femoris) (Thorek 1962; Healey and Seybold 1969; Bucholz and Brumback 1996). From its branches, the lateral circumflex femoral artery, among others, supplies blood to the extensor muscles, while other proximal branches provide vascular supply to the adductor muscles, and, more distally, three perforating arteries supply the flexor muscles (Kootstra 1973). The muscular branch of the superficial femoral artery supplies blood to the vastus medialis muscle (Kootstra 1973).

The femoral shaft has periosteal and endosteal blood supply (Laing 1953). The endosteal circulation of the femoral diaphysis is predominatly derived from a nutrient artery that branches from the first perforating branch of the deep femoral artery (Laing 1953; Brookes 1971), enters the bone proximally and posteriorly through a nutrient foramen in the middle of the diaphysis near the linea aspera, and arborizes proximally and distally (Laing 1953; Bucholz and Brumback 1996). Very seldom, a second nutrient artery exists distally (Laing 1953), but no major artery enters the lower third of the shaft (Anseroff 1934; Laing 1953). Under normal physiologic conditions, the circulation is endosteal to the inner two thirds to three quarters of the cortex (Rhinelander 1968, Rhinelander et al. 1968), and periosteal to the outer one quarter of the cortex (Bucholz and Brumback 1996). Endosteal circulation anastomoses with the numerous small periosteal vessels that are derived from the adjacent soft-tissues (Kootstra 1973). The periosteum is protected from complete vascular disruption by an extensive collateral circulation and perpendicularly orientated vessels, which seldom undergo major stripping with the exception of severe open injuries or perioperative injuries that can possibly result in delayed fracture healing (Kootstra 1973; Bucholz and Brumback 1996).

The normal blood flow is centrifugal (Brookes 1971), although some blood returns to the large venous sinusoids of the medullary canal. After diaphyseal fractures, the circulatory pattern is altered (Trueta and Cavadias 1955; Cavadias and Trueta 1965). In a nondisplaced fracture of the shaft, the endosteal supply can be relatively undisturbed and remains dominant, whereas displacement results in a complete disruption of the medullary vessels. Proliferation of the periosteal vessels is the paramount vascular response to a fracture, and the rapidly enhanced periosteal circulation is the primary source of cells and growth factors for healing. The medullary blood supply is eventually restored during the healing process (Trueta and Cavadias 1955; Cavadias and Trueta 1965; Bucholz and Brumback 1996). Preservation of the muscle envelope around the fracture enhances revascularization of the injured bone and promotes periosteal callus formation.

Earlier studies on the blood circulation of long bone fractures treated with intramedullary nailing suggested that an intramedullary nail, when introduced into the medullary cavity, affects the intramedullary vascular system (Trueta and Cavadias 1955; Rhinelander 1974) and causes ischemia of the inner 2/3 of the cortical bone (Trueta and Cavadias 1955), which has been concerned in several studies on different nail designs (Eriksson and Hovelius 1979; McMaster et al. 1980; Murti and Ring 1983; Johnson and Tencer 1990). Intramedullary reaming causes additional destruction of the endosteal circulation of a long bone (Danckwardt-Lillieström 1969; Kessler et al. 1986; Klein et al. 1990; Schemitsch et al. 1994; Schemitsch et al. 1995). Unreamed nailing diminishes the circulation of the inner cortex by 30% (Klein et al. 1990; Schemitsch et al. 1994). Extensive reaming may reduce the cortical blood flow by 30-70% and the total bone blood flow by up to 50% (Klein et al. 1990; Grundnes and Reikerås 1993). A sixfold increase in periosteal blood flow has been measured after reaming (Reichert, McCarthy, Hughes 1995).

Dislocation in femoral shaft fractures is a resultant of three forces: impinging violence, muscle action, and gravity (Kootstra 1973). As an initial fracture deformity, the proximal fragment of a fracture of the proximal third of the femoral shaft is usually abducted by m. gluteus medius and m. gluteus minimus, which both insert in the greater trochanter (Dencker 1963; Bucholz and Brumback 1996), the gemelli, the obturator internus, and the quadriceps femoris (Healey and Seybold 1969). The proximal fragment is flexed and externally rotated due to m. iliopsoas that inserts in the lesser trochanter (Dencker 1963; Bucholz and Brumback 1996). The distal fragment is displaced upward and medially by the adductor and hamstring group of muscles (Healey and Seybold 1969). In the middle third, the proximal fragment is frequently adducted with a strong axial and varus load due to the adductor muscles (Dencker 1963; Bucholz and Brumback 1996), and flexed due to the iliopsoas muscle (Healey and Seybold 1969). The distal fragment is externally rotated by the weight of the foot (Dencker 1963; Kootstra 1973; Bucholz and Brumback 1996), and displaced upward and posterior due to the adductors and hamstring muscles (Healey and Seybold 1969). The distal fragment of the supracondylar fractures is usually flexed posteriorly secondary to the pull of the gastrocnemius muscle (Dencker 1963; Kootstra 1973; Bucholz and Brumback 1996), and can cause damage to the popliteal artery, the popliteal vein, the tibial nerve, and the common peroneal nerve (Healey and Seybold 1969). The proximal fragment is pulled in flexion and adduction by the iliopsoas and adductor muscles (Healey and Seybold 1969). The extensors, such as m. rectus femoris, m. sartorius, and m. gracilis, as well as the flexors, except the short head of m. biceps femoris and the tractus iliotibialis, can also cause longitudinal dislocation of the fracture fragments of the femoral shaft (Kootstra 1973; Bucholz and Brumback 1996). The medial angulating forces are resisted by the fascia lata (Bucholz and Brumback 1996).

2.3. Biomechanics of long bone fractures

Bone comprises organic material (mainly type I collagen) and minerals (mainly calcium hydroxyapatite), and is capable of adapting to repeated mechanical load by changing its microscopic and macroscopic architectural configuration, especially in fatigue fractures. Bone remodels in response to forces to which it is subject according to the Wolff's law (Wolff 1892). Every change in the form and function of bone or of their function alone is followed by certain definite changes in their internal architecture, and equally definite alteration in their external conformation, in accordance with mathematical laws (Frost 1998; Frost 2004).

The effect of a force sustained in an accident depends on its magnitude, direction, and nature of load; the nature of the bone including bone microarchitecture with mineral content, bone density (Bentzen, Hvid, Jørgensen 1987; Rosson et al. 1991) and geometrical shape; and the counteraction of soft-tissues (Kootstra 1973; Brukner, Bennell, Matheson 1999). The directions of the force are tension, compression, shear, as well as bending, and torque (torsion) (Kootstra 1973). The fracturing force can be direct or indirect (rotation, axial compression, and bending without a direct impact) (Alms 1961).

Because of brittleness attributed to the mineral content (Burstein, Reilly, Martens 1976), bone breaks when deformed before other musculoskeletal materials. A fracture is a failure of the bone as a material and as a structure (Paavolainen 1979). The stress-strain behavior of bone is strongly dependent on the orientation of the bone microstructure with reference to the direction of loading (anisotropy). Although a complex relationship exists between loading patterns and mechanical properties, cortical bone is generally two times stronger and stiffer in the longitudinal direction than in the transverse direction. Trabecular bone is strongest along the lamellae of the trabeculae (Bono et al. 2003).

Due to viscoelasticity of the bone and load rate (the rate at which the force is applied), approximately 43% more of torsional energy is needed to break diaphyseal bone in 50 msec than to break it in 150 msec. Bones that have a larger cross-sectional area and in which bone tissue is distributed further away from the neutral axis will be stronger when subject to load and, therefore, less likely to fracture. The moment of inertia (the degree to which the shape of the material influences its strength) describing rigidity to bending (bending resistance) is greater at a distance from the neutral axis, and the polar moment of inertia describing rigidity to torsion (torsional resistance) is likewise greater at a distance from the neutral axis (Gozna 1982; Brukner, Bennell, Matheson 1999). Under tension and compression loads, bone strength is proportional to the bone cross-sectional area, and to the square of the apparent density: small reductions in bone density may be associated with large reductions in bone strength (Gozna 1982). The strength of a tubular structure is proportional to the third power of the outer diameter minus the third power of the inner diameter, and with regard to stiffness, the same diameters are raised to the fourth power (Russell et al. 1991). An increase in both the external diameter and the cortical thickness of a tubular bone will exert a great impact on its mechanical behavior (Bråten, Nordby, Terjesen 1993). For their length (longitudinal dimension), long bones of the lower extremity are subject to high bending moments and hence to high tensile and compressive stresses. Any sudden change in the shape of the bone alters the distribution of stress within the structure, giving rise to stress concentration (or stress risers) that the bone attempts to compensate for by remodeling (Burstein, Reilly, Martens 1976; Gozna 1982). The proximal and distal metaphyseal widenings in the subtrochanteric and supracondylar regions of the bone result in stress concentration, which at these levels, especially in the elderly, causes pathologic fractures starting at the weak metaphyseal bone and propagating into the shaft (Bucholz and Brumback 1996).

Understanding both the direction in which and the force by which a fracture is formed provides information on lesions of the soft-tissues, and can be useful in fracture reduction (Kootstra 1973). Human cortical bone offers less resistance to tensile stress at the convex site than to compressive stress at the concave site (Kootstra 1973), even in bending (Alms 1961). In the femur, the femoral shaft fails first under tensile strain (Evans, Pedersen, Lissner 1951) that, according to cadaveric studies, is maximal on the anterolateral aspect of the femoral shaft (Evans, Pedersen, Lissner 1951).

A bending load applied to a diaphyseal bone results in *transverse fractures* (Alms 1961; Gozna 1982) where the location of soft-tissue hinge is on the concave side (Gozna 1982). A normal, adult femoral shaft fractures after 250 Nm of bending movement (Kyle 1985).

Torsion (torque or twisting) causes *spiral fractures* with long, sharp, pointed ends, and a soft-tissue hinge on the vertical segment (Gozna 1982). The course of spiral is determined by the shearing stress or tension. The spiral curves around the shaft at an angle of 40º to 45º, with the long axis of the bone in a direction that would allow the portion of the bone under tension to open up (Gozna 1982). Due to the moment of inertia, a spiral fracture is common, for example, through the junction of the middle and distal one-thirds of the tibia. In bones with pathologic lesions, minor torsional loads cause spiral fractures that are rarely comminuted or associated with severe soft-tissue damage (Bucholz and Brumback 1996).

Moderate axial compression combined with bending and torsion causes *oblique fractures* (Alms 1961; Gozna 1982) with short and blunt fracture ends without a vertical segment (Gozna 1982).

Moderate axial compression together with bending results in *oblique-transverse* (a transverse fracture with one fragment containing a protuberance or beak) or *butterfly fractures* (a bending wedge on a compression side) by simultaneous interruption of continuity in two directions. The soft-tissue hinge is on the concave side of the butterfly (Gozna 1982), where compressive stresses produce an oblique fracture line due to shearing stresses (Kootstra 1973). The fracture is transverse when the oblique segment of the oblique-transverse fracture is very short (Kootstra 1973). Oblique-transverse and butterfly fractures are commonly seen in the lower extremities when the thigh or calf receives a lateral blow during weightbearing for instance, among pedestrians injured by automobiles (Gozna 1982).

Combinations of tension, compression, shear and torque produce a very complex stress pattern. *Comminuted fractures* result from a combination of a large amount of energy and a direct impingement of an abrupt force on the shaft. Here, the stresses which occur in the bone are so great that the limit of elastic formation is exceeded several times (Kootstra 1973), while the additional force is dissipated on the soft-tissues.

Bone elasticity decreases with increasing age (Kootstra 1973). Breaking strength and elasticity are, however, not the same throughout the bone (Kootstra 1973). The density of the cortical bone diminishes with age, especially on the anterolateral aspect of the femoral shaft (Atkinson and Weatherell 1967).

The breaking torque moment is inversely proportional to age (Hubbard 1973). The spiral fracture pattern is more pronounced with increasing age and osteoporosis (Kootstra 1973). The strength of the iliotibial tract, which is important in absorbing a bending force in the frontal plane, diminishes with age (Pauwels 1948). Considering that the ligaments of the mobile hip joint absorb torque applied to the femur (Pauwels 1948), spiral fractures are likely to occur more frequently at a more advanced age, when hip joint mobility is reduced and cortical bone density is altered (Kootstra 1973).

During activities like walking and running, bone is subject to a combination of loading modes (Burr et al. 1996; Ekenman 1998; Milgrom et al. 1998): compressive stresses predominate at heel strike, followed by high tensile stresses at push-off (Carter 1978). During physical activity, forces from ground impact and muscle contraction result in bone stress, defined as the load or force per unit area that develops on a plane surface, and in bone strain, defined as deformation of or alteration in bone dimension (Brukner, Bennell, Matheson 1999). During running, the vertical ground-reaction force has been shown to vary from two to five times the body weight, and during jumping and landing activities, ground-reaction forces can reach 12 times the body weight (McNitt-Gray 1991). Transient impulse forces, associated with ground-reaction forces, are propagated upward from the foot and undergo attenuation as they pass toward the head (Light, McLellan, Klenerman 1980; Wosk and Voloshin 1981). Running speed, muscle fatigue, type of foot strike, body weight, surface, terrain, and footwear influence the magnitude, propagation and attenuation of the impact force (Nigg and Segesser 1988; Dufek and Bates 1991). When bone is loaded in vivo, contraction of muscles attached to the bone also influences the stress magnitude and distribution. In addition to muscle contraction, intact soft-tissues substantially increase the tibial structural capacity of a rat, and the effect is similar in normal and osteopenic bone (Nordsletten and Ekeland 1993; Nordsletten et al. 1994). The calculated total force is a summation of the ground-reaction forces and the muscular forces (Scott and Winter 1990). Muscle activity partially attenuates the large bending moment and reduces the tensile and compressive stresses. Muscle contraction can both decrease and increase the magnitude of stress applied to the bone (Brukner, Bennell, Matheson 1999).

Repetitive strains are essential for the maintenance of normal bone mass, but physical activity either increases the bone mass (Morris et al. 1997) or diminishes the bone strength depending on the formation of microscopic cracks within the bone (Chamay and Tschantz 1972; Burr et al. 1985; Burr et al. 1990; Mori and Burr 1993). Microdamage (Rutishauer and Majno 1951; Frost 1960) due to physiological strain (Schaffler, Radin, Burr 1989) can coalesce into macrocracks eventually developing into a stress fracture, if remodeling does not occur (Frost 1989a; Frost 1989b). A threshold level for accumulation of microdamage is approximately 2000 microstrain (Frost 1998), which represents the upper range of physiological values, and above that, the relationship between strain and microdamage becomes exponential at deformation (Frost 1989a; Frost 1989b).

Normal bone remodeling, responding to cyclic loading, is a sequential process of osteoclastic resorption and osteoblastic new bone formation, which occurs continuously on both periosteal and endosteal surfaces within the cortical bone and on the surface of the trabeculae (Buckwalter et al. 1995). The main functions of remodeling are to adapt bone to mechanical loading, to prevent accumulation of microfractures or fatigue damage, and to maintain constant blood calcium levels. Remodeling with its stages of quiescence, activation, resorption, reversal, and formation results in net bone resorption, and is responsible for the bone losses that accompany aging. In human bone, the metabolic turnover rate is 0.05 mm^3 of tissue every three or four months for each basic multicellular unit consisting of bone resorbing osteoclasts and bone, through matrix synthesis and mineralization, repairing osteoblasts (Frost 1989a; Frost 1989b; Frost 1991). Following remodeling, bone requires three more months for adequate mineralization (Frost 1998). Some human studies have suggested that microdamage occurs at pre-existing sites of accelerated remodeling, where osteoclastic resorption weakens an area of bone and subjects it to higher strains before new bone is added by osteoblasts (Johnson et al. 1963). Microdamage is repaired either by direct repair (the stimulus being either a cellular membrane response or an electrical response in the Haversian canal cells), or by simple random remodeling of the cortex at the rate designed to keep up with the damage accumulation. Continued mechanical loading during a one- to two-week interval between termination of the resorptive processes and commencement of bone formation (the reversal phase) can result in microdamage accumulation and the beginning of clinical symptomatology.

A fatigue fracture is a consequence of nonphysiologic cyclic loading of the bone. Incipient stress osteopathy is likely, when localized pain of insidious onset worsens with progressive training and is relieved by rest (Worthen and Yanklowitz 1978; Greaney et al. 1983; Markey 1987; Jones et al. 1989; Hershman and Mailly 1990; Knapp and Garrett 1997), especially if the pain is combined with a recent change in physical activity. In normal activities, skeletal loading of long bones is dominated by muscle mediated bending forces. Repetitive bending loads produce stresses that peak on subperiosteal surfaces (Beck 2001). The repeated loading can cause microscopic damage to bone tissue with accompanying resorption by osteoclasts. This weakens the bone and triggers a remodeling response by osteoblasts. Inadequate adaptation of the bone to a mechanical change leads to an imbalance between bone microdamage and remodeling (Stanitski, McMaster, Scranton 1978; Jones et al. 1989; Brukner, Bennell, Matheson 1999), and gradually to a fracture, which may finally result in a total displacement from repeated applications of a stress lower than the stress required to fracture the bone in a single loading.

2.4. Fracture healing, delayed union, and nonunion of diaphyseal bone

Fracture healing includes phases of impaction, induction, and inflammation, soft and hard callus formation, and remodeling (Heppenstall 1980). A fractured long bone normally heals by the formation of periosteal and endosteal callus. In diaphyseal fracture repair, the healing cascade attempts to bridge the fracture gap with appropriate tissue leading to restoration of the skeletal integrity and the mechnical properties of the bone. Primary bone healing is characterized by widening of the Haversian canals, formation of resorption cavities and subsequent formation of new bone across the fracture gap (Lane 1914; Danis 1947). In gap healing, bone gaps are initially filled by bone with the lamellae oriented parallel to the fracture, and then penetrated by the osteons in a longitudinal direction (Olerud and Dankward-Lillieström 1968). The limit for direct primary osseous bridging of the fracture gap is about 0.5 mm (Schenk and Willenegger 1977). New bone is formed both by direct membranous ossification and by endochondral ossification. Endochondral fracture repair includes inflammatory phase, reparative phase, and remodeling phase. External callus formation includes the primary callus response and the phase of bridging callus (McKibbin 1978). Resorptive and formative changes in cortical bone generally occur in endosteal, intracortical and periosteal surfaces. In a bridging stage of the fracture healing process, a junction between the fracture fragments is established. In a remodeling stage, the morphology of the fractured bone is restored (McKibbin 1978).

Fracture healing in a long bone with motion between fracture fragments after intramedullary nailing implies the formation of external callus tissue (Falkenberg 1961; McKibbin 1978; Aro 1985). By absolute stability of plate fixation, healing is accomplished by primary bone healing without external callus (Willenegger, Perren, Schenk 1971; Allgöwer and Spiegel 1979; Perren 1979) and a decrease of the torsional strength of the cortical bone later (Paavolainen 1979).The amount of external callus in fractures intramedullary nailing depends on the thickness of the intramedullary nail (Aro 1985). External callus ossifies without the intermediate cartilage stage in fractures stabilized with tight-fitting nails, whereas loose-fitting-nails result in formation of cartilage at the fracture site (Anderson, Gilmer, Tooms 1962). Persistent displacement of butterfly fragments has a deleterious effect on the function only when the fragment is buttonholed to the quadriceps muscle or through the iliotibial band. Fragments dislocated more than 2 cm from the medullary canal do not contribute to the healing of the fracture (Bucholz and Brumback 1996).

Disturbed bone healing can result from technical problems during operations, or a biological failure, or both (Frost 1989a; Frost 1989b; Robello and Aron 1992). A delayed union is a failure of fracture repair, and may lead to nonunion (Perren 1979) where bone repair ceases before a firm union has been established. Predisposing factors to nonunion have been 1) gap or bone loss, overdistraction (Küntscher 1965), or soft-tissue interposition at the fracture site, 2) inadequate fracture fixation, 3) repeated manipulations injuring the fracture callus and its blood supply, 4) infection, 5) innervation impairment (Hukkanen et al. 1993), or 6) periosteal stripping (Aro, Eerola, Aho 1985; Utvag, Grundnes, Reikerås 1998b; Utvag, Grundnes, Reikerås 1999). The traumatic rupture of immature uniting callus may be common in the pathogenesis of fracture nonunions (Urist, Mazet, McLean 1954). According to the theory of Roux, pressure forces create bone while traction or thrust create connective tissue (Küntscher 1967). In abundant nonunion, the callus formation continues to increase, but does not unite the fragments by bone (Küntscher 1967). The resistance of callus to traction forces leads into tearing and crushing of the callus on the side of traction (Küntscher 1967). In an experimental nonunion, the chondral phase was prolonged with an abundant cartilage-specific type II collagen production in the callus and in the interfragmentary area (Hietaniemi et al. 1998), and further, the regulation of collagen genes was altered in the early phase of the cascade (Hietaniemi 1999). The development of pseudarthrosis has been related to mechanical instability across the fracture site, which prevents replacement of the cartilaginous callus by bone (Reikerås and Reigstad 1985; Hulth 1989; Hietaniemi 1999).

In most nonunions, the bone ends are characterized by hypervascularization, hypertrophic bone formation, and high potential for union ("elephant foot") due to insufficient fixation or premature weightbearing (Weber and Cech 1976). Other pseudarthrosis that are viable and capable of biological reaction are the "horse hoof", slightly hypertrophic pseudarthrosis poor in callus, and the oligotrophic pseudarthrosis without callus (Weber and Cech 1976) and with avascular fragments that have a low healing power. Pseudarthrosis that are non-viable and incapable of biological reaction include torsion wedge- or dystrophic pseudarthrosis, necrotis pseudarthrosis from comminution, defect pseudarthrosis, and atrophic pseudarthrosis (Weber and Cech 1976). Periosteal innervation is important for the bridging callus of fracture healing (Miller and Kasahara 1963; Aro 1985). In immunopathologic and neuroimmunologic studies on nonunited diaphyseal bones, delayed union and nonunion tissue consisted of vascularized connective tissue, 5B5 fibroblasts, CD11b macrophages, and vascular endothelial cells. Total lack of periferal innervation was also detected (Santavirta et al. 1992).

2.5. Classifications of femoral shaft fractures in adults

No universally accepted classification scheme exists for fractures of the femoral shaft (Bucholz and Brumback 1996). Fractures caused by trauma, excluding periprosthetic fractures or pathological fractures due to malignancy or osteoporosis, are categorized by soft-tissue injury; fracture location, geometry, comminution and associated injuries (Bucholz and Brumback 1996).

The Tscherne and Oestern classification of closed fractures categorizes blunt soft-tissue injuries into Grade C0 = none or negligible soft-tissue damage from indirect violence, CI = superficial abrasion caused by a fragment from within, CII = deep, skin or muscle contusion from direct trauma including impending compartment syndrome, and CIII = extensively contused skin and potentially severe muscle damage (Tscherne and Oestern 1982; Oestern and Tscherne 1984).

The Gustilo and Anderson classification of open fractures subdivides open wounds into three main categories: Grade I = clean puncture wound 1 cm or less; Grade II = laceration less than 5 cm without contamination or extensive soft-tissue flaps, loss, avulsion, or crush; Grade III = extensive soft-tissue damage with contamination or crush including Grade IIIA = adequate soft-tissue coverage of bone; Grade IIIB = extensive soft-tissue loss with periosteal stripping and bone exposure; and Grade IIIC = major arterial injury present demanding vascular repair or reconstruction (Gustilo and Anderson 1976; Gustilo, Mendoza, Williams 1984; Gustilo, Merkow, Templeman 1990). Abundant soft-tissue coverage of the femoral shaft makes Grade III, especially Grade IIIC, open fractures relatively uncommon compared with lower leg fractures (Bucholz and Brumback 1996). Reliability and reproducibility in using this classification may be problematic for femoral fractures as well, although this has not been studied (Brumback and Jones 1994; Bucholz and Brumback 1996).

In relation to their *location,* femoral shaft fractures can be categorized as proximal third, midshaft, or distal third, the latter also referred to as infraisthmal fractures (Bucholz and Brumback 1996). More detailed divisions have been used as well (Kootstra 1973).

The morphologic description by Alms is similar to other long bone fractures and classified according to the geometry of the major fracture line. The line of breakage resulting from direct violence is usually transverse and caused by the most common injury mechanism, bending load (Alms 1961; Gozna 1982; Bucholz and Jones 1991; Bucholz and Brumback 1996). Fractures from indirect impact are usually oblique, and caused by axial compression with bending and torsion (Alms 1961; Gozna 1982; Bucholz and Jones 1991). Fractures due to muscular action are characterized as spiral (Healey and Seybold 1969), and caused by torsion load (Alms 1961; Gozna 1982; Bucholz and Jones 1991). Oblique and spiral fractures are frequently compound fractures (Healey and Seybold 1969). Axial compression with bending causes an additional, oblique–transverse fracture type with a nonfractured or fractured butterfly fragment (Alms 1961; Gozna 1982). Measured by the angle between a line perpendicular to the long axis of the femur and the main fracture line, fractures with an angle of less than 30 degrees are considered transverse (Müller et al. 1990).

The Arbeitsgemeinschaft für Osteosynthesefragen (AO), the Association for the Study of Internal Fixation (ASIF) and, later, the Orthopaedic Trauma Association (OTA) have classified femoral shaft fractures into three main types (simple, wedge, and complex) with three main groups, and three subgroups according to the fracture location, with additional two to five ramifications in the complex type of fractures (Müller et al. 1990; Orthopaedic Trauma Association 1996). The simple fractures are subdivided according to the obliquity of the single fracture line into spiral, oblique, or transverse fractures. Wedge fractures can have a spiral, bending, or fragmented configuration. Complex fractures include spiral and segmental fractures, and fractures with extensive comminution over a long segment of the diaphysis. The influence of the AO/ASIF scheme on the preferred treatment and its outcome of any given fracture is still unsolved (Bucholz and Brumback 1996). The reliability of the AO/OTA classification system in femoral fractures caused by gunshots compared with those caused by blunt trauma has recently been criticized due to a low interobserver agreement on fracture group (Shepherd et al. 2003).

The former OTA classification resembled the Gustilo classification of fracture morphology that divided femoral shaft fractures into linear, comminuted, segmental, or boneloss types (Gustilo 1991). Before the AO classification system was introduced, Dencker (1963) categorized a femoral shaft fracture transverse, if the angle between the fracture plane and femoral shaft was 65º-90º, and oblique, if this angle was smaller. A short oblique fracture had an angle of 45º-65º, and a long oblique fracture an angle < 45º. Double fractures had two unrelated planes. In moderately or greatly comminuted fractures, the shaft was crushed over a longer distance of its length and displayed several fragments of indeterminate shape (Dencker 1963).

The stability of diaphyseal fractures is based on *the Winquist-Hansen classification of the fracture comminution* (Winquist and Hansen 1980; Johnson, Johnston, Parker 1984; Winquist, Hansen, Clawson 1984): segmental fracture (double fracture of the femoral shaft), Grade I fracture (fracture with a small fragment 25% or less of the width of the femoral shaft and not affecting the fracture stability), Grade II fracture (fracture with a fragment 25% to 50% of the width of the femoral shaft), Grade III fracture (fracture with a fragment over 50% of the width of the femoral shaft), and Grade IV fracture (fracture with circumferential comminution over a segment of bone). The degree of fracture comminution has implications for the preferred form of medullary fixation and locking of the major fracture fragments (Bucholz and Brumback 1996).

A patient can be categorized as having either an isolated femoral fracture or multiple injuries that determine the preferred timing for fixation of fractures of the femoral shaft (Ostrum, Verghese, Santner 1993). The Injury Severity Score (ISS) is one of several scales used to grade the severity of the multiply injured patient (Baker et al. 1974).

Classification of fatigue fractures according to Provost and Morris in 1969 categorizes femoral shaft fractures into Group I (linear oblique radiolucency in the medial cortex of the proximal shaft of the femur with associated periosteal reaction), Group II (displaced spiral oblique fracture in the midshaft of the femur), and Group III (transverse fracture of the distal third of the shaft of the femur) (Provost and Morris 1969). *The definition described by Hallel, Amit and Segal* contains three categories: Grade I (periosteal reaction on one side of the cortex in one or both radiological projections, an incomplete fracture), Grade II (circumferential periosteal reaction), and Grade III (a displaced fracture) (Hallel, Amit, Segal 1976).

2.6. Fracture mechanisms and injuries causing traumatic femoral shaft fractures

The causative violence of diaphyseal fractures can be divided into high energy injuries: motor vehicle accidents, auto-pedestrian accidents, motorcycle accidents, falls from the height of more than three to four meters (Mosenthal et al. 1995; Demetriades et al. 2005), and gunshot wounds (Bucholz and Brumback 1996), as well as low energy injuries: slipping or stumbling at ground level, falls from the height of less than one meter, and most sports injuries. The femur, like other long bones of the body, fractures as a result of direct or indirect violence or muscular action.

Femoral shaft fractures in young persons are commonly thought to be primarily associated with high energy trauma (Kootstra 1973; Bucholz and Brumback 1996). Femoral shaft fracture caused by indirect low energy trauma is an entity different from that of the direct-impact fracture of the young, and especially among the elderly, has been mentioned only sporadically in epidemiologic studies of the fractures of the femoral shaft (Wong 1966; Hedlund and Lindgren 1986; Arneson et al.1988; Bengnér et al. 1990). Table 1. shows some previous studies of the epidemiology of the femoral shaft fracture.

Table 1. Prior studies on epidemiology of femoral shaft fractures in adults.

Study and Year	Study Period	Definition of Femoral Shaft	Minimum Age (Years)	Number of Fractures	Statistical Analysis	Pathological Fractures eliminated
Buck-Gramcko, Germany 1958*	1954-1956	No	15	103	No	Yes
Martyn and McGoey, Canada 1961* [a]	1950-1960	No	< 30	62	No	No
Dencker, Sweden 1963*	1952-1954	Yes	17	1003	Yes	Yes
Knowelden, Buhr, Dunbar, United Kingdom 1964	1954-1958	No	35	69	Yes	No
Wong, Singapore 1966	1962-1963	No	20	219	Yes	Yes
Blichert-Toft and Hammer, Denmark 1970*	1959-1968	Yes	15	82	No	Yes
Suiter and Bianco, U.S.A. 1971*	1956-1965	No	15	127	No	Yes
Kootstra, Netherlands 1973*	1958-1969	Yes	17	329	Yes	Yes
Hedlund and Lindgren, Sweden 1986	1972-1981	Yes	20	139	Yes	Yes
Arneson et al., U.S.A. 1988	1965-1984	Indirectly	15	122	Yes	No
Bengnér et al., Sweden 1994	1950-1983	No	20	161	Yes	No

* also compared in the Kootstra study (1973), [a] also included subtrochanteric fractures.

Traffic accidents are responsible for 57-74% of all femoral shaft fractures (Dencker 1963; Blichert-Toft and Hammer 1970; Kootstra 1973), while the remaining fractures consist of occupational injuries and domestic accidents (Table 2.). The latter have mostly involved elderly patients (Table 3.): 65% of patients aged 70 years or older were injured at home (Kootstra 1973). In Sweden, the difference in traffic accidents causing femoral shaft fractures could probably be explained by the lower traffic density during 1952 - 1954 (Dencker 1963).

Table 2. Distribution of injury types causing femoral shaft fractures in adults (Kootstra 1973) (N=329 patients).

Injury Type	Number of Fractures (Percentage)
Traffic	242 (73.6%)
On foot	28 (8.5%)
On two wheels	130 (39.5%)
In car	84 (25.6%)
Train or aircraft crash	0 (0.0%)
Occupational	32 (9.7%)
Direct injury (thigh being squeezed or crushed by a heavy weight)	16 (4.9%)
Indirect injury (fall or lower leg stuck and entire body rotated)	14 (4.2%)
Sports	2 (0.6%)
Domestic (stumbling, slipping)	46 (14.0%)
Unclassifiable or unknown	9 (2.7%)
All	329 (100 %)

Table 3. Distribution of accident types causing femoral shaft fractures according to patient's age group (Kootstra 1973) (N=320 patients*)

Age Group	Accident			
Years	*Traffic Number (Percentage)*	*Occupational Number (Percentage)*	*Domestic Number (Percentage)*	*All Number (Percentage)*
17 – 19	45 (94%)	3 (6%)	0 (0%)	48 (100%)
20 – 29	69 (91%)	7 (9%)	0 (0%)	76 (100%)
30 – 39	32 (82%)	6 (15%)	1 (3%)	39 (100%)
40 – 49	31 (86%)	5 (14%)	0 (0%)	36 (100%)
50 – 59	31 (81%)	3 (8%)	4 (11%)	38 (100%)
60 – 69	21 (56%)	5 (14%)	11 (30%)	37 (100%)
≥70	13 (28%)	3 (7%)	30 (65%)	46 (100%)

*The injury mechanism was unclassifiable in 9 patients.

The gender-specific distribution of femoral shaft fractures has also significantly varied according to the accident type: 82% of men sustained a femoral shaft fracture in a traffic accident, 13% at work, and only 5% at home, whereas, of women, none was injured at work, 53% in a traffic accident, and 47% at home (Kootstra 1973).

2.7. Etiology of fatigue fractures of the femoral shaft

Stress fractures from prolonged, excessive, or repetitive physical activity were first described in a metatarsal by Breithaupt in 1855. Fatigue fractures differ from typical osteoporotic fractures that are due to low bone density (Cummings and Melton 2002). *Stress fractures* of the bones are divided into two general types: a) fractures induced by cyclical loading of normal bones with abnormal forces that are *fatigue fractures*, and b) those induced by normal forces in abnormal bone that are *insufficiency fractures* (Pentecost, Murray, Brindley 1964; Daffner and Pavlov 1992; Anderson and Greenspan 1996). Insufficiency fractures are seen in elderly women suffering from osteoporosis, in cases of Paget's disease, hyperparathyroidism, rheumatoid arthritis, diabetes, scurvy, osteomalacia, osteogenesis imperfecta, or rickets (Pentecost, Murray, Brindley 1964; Markey 1987). Fatigue failure is a rare (Provost and Morris 1969) but increasing cause of femoral shaft fractures (Bucholz and Brumback 1996; Boden and Speer 1997). Displacement of these stress injuries can occasionally occur (Bucholz and Brumback 1996).

The stress-fracture pathogenesis is multifactorial, it can be either intrinsic or extrinsic. Extrinsic causes have been a) training errors (excessive volume, excessive intensity; magnitude, duration and change of each strain cycle; excessive muscle fatigue, inadequate recovery or faulty technique), and b) impact attenuation (training surfaces and conditions, footwear and other equipment).

Intrinsic factors include 1) gait mechanics related to lower extremity alignment, b) muscle imbalance, 2) muscle weakness, 3) lack of flexibility due to generalized muscle tightness, focal areas of muscle thickening, or restricted joint range of motion, 4) decreased bone strength due to low bone mineral density (Carter et al. 1981), 5) small bone architecture caused by diet and nutrition, genetics, endocrine status and hormones, exercise, or bone disease (Giladi et al. 1987a; Giladi et al. 1987b), 6) gender, 7) high body mass index (BMI), 8) body composition (Brukner and Khan 1993), 9) bone turnover including low bone density, elevated bone strain, and inadequate repair of microdamage, 10) low calcium intake associated with greater rate of bone turnover, low bone density, or inadequate repair of microdamage, 11) caloric intake and eating disorders causing altered body composition, low bone density, greater rate of bone turnover, reduced calcium absorption, menstrual disturbances, and inadequate repair of microdamage, 12) hormonal factors such as sex hormones, menarcheal age, menstrual disturbances, 13) genetic predisposition (low bone density, greater rate of bone remodeling, psychological traits), and 14) even psychological factors such as excessive training, nutritional intake, or eating disorders (Brukner, Bennell, Matheson 1999).

The structural geometry varies more than bone material properties including bone mineral density (Martens et al. 1981). In a prospective observational cohort study of 295 male Israeli military conscripts, femoral shaft stress fractures were seen more in conscripts who had narrower tibias, a feature that may be an indication of the size of tubular bones in general (Giladi et al. 1987b). The cross-sectional moment of inertia about the anteroposterior axis has proven to be a better indicator than the tibial width (Milgrom et al. 1988). In another study, conscripts with stress fractures had a smaller tibial width, a smaller cross-sectional area, smaller moment of inertia, and a smaller modulus (Beck et al. 1996). The smaller cross-sectional dimensions were apparent in the long-bone diaphyses, not in the joint size, which suggests a specificity of the structural deficit in the fracture group and that these dimensions are influenced environmentally (Beck et al.

1996). This could indicate that the stress fracture group's bones had not been sufficiently loaded before basic training in order to develop cortices strong enough to withstand the subsequent stresses.

Skeletal alignment of the lower limb and foot alignment may predispose a person to stress fractures through either creation of stress-concentration areas in the bone or promotion of muscle fatigue. The high-arched (pes cavus) foot is more rigid and less able to absorb shock, so more force passes to the tibia and femur. In a prospective cohort study, the overall incidence of stress fracture in the low-arched (pes planus) group was 10%, as opposed to 40% in the high-arched group (Giladi et al. 1985b). A similar trend was noted when tibial and femoral stress fractures were analyzed separately. However, trainees with an 'average' arch had a stress-fracture incidence of 31%, or similar to that of the high-arched trainees. Skeletal alignment factors that may predispose to fatigue fractures are summarized in the Table 4.

Table 4. Skeletal alignment factors causing fatigue fractures in the literature.

Predisposing Factor	No Effect on Incidence (Study and Year)	Increases Incidence (Study and Year)
Leg length discrepancy	Cowan et al. 1996	Friberg 1982; Brunet et al. 1990; Bennell et al. 1996
High arched foot	Montgomery et al. 1989; Brunet et al. 1990; Bennell et al. 1996	Matheson et al. 1987: increase in femoral and metatarsal stress fractures; Giladi et al. 1985b; Simkin et al. 1989: increase in femoral and tibial stress fractures; Brosh and Arkan 1994
Pronated foot	Montgomery et al. 1989; Brunet et al. 1990; Bennell et al. 1996	Matheson et al. 1987: increase in tibial and tarsal stress fractures
Greater forefoot varus	Matheson et al. 1987	Cowan et al.1996; Hughes 1985:
Rearfoot valgus	Hughes 1985	
Subtalar varus	Matheson et al. 1987	
In-toe / Out-toe gait	Giladi et al. 1987a	
Genu valgum / Genu varum	Giladi et al. 1987a; Matheson et al. 1987; Montgomery et al. 1989; Bennell et al. 1996	Cowan et al.1996: increased with increased valgus
Genu recurvatum	Montgomery et al. 1989; Cowan et al.1996	
Tibia vara	Matheson et al. 1987	
Tibial torsion	Giladi et al. 1987a	
Q-angle	Montgomery et al. 1989; Winfield et al. 1997; Matheson et al. 1987	Cowan et al. 1996: increased with an angle >15º

2.8. Demography and incidence of femoral shaft fractures in adults

Femoral shaft fractures are commonly thought to be primarily associated with severe trauma in young persons. A femoral shaft fracture caused by indirect low energy trauma is an entity different from that of the direct-impact fracture in the young. Low energy violence as a cause of these fractures, especially among the elderly (Wong 1966; Hedlund and Lindgren 1986; Arneson et al. 1988; Bengnér et al. 1990). Although the incidence of fractures of the shaft of the femur in the elderly is considerably lower than that of many other fractures among aged persons (Knowelden, Buhr, Dunbar 1964), the number of senior citizens is increasing, and the clinicians will be more often confronted with the specific problems associated with these fractures.

Fatigue or stress fractures mainly located in the proximal or midshaft areas usually occur in military conscripts undergoing a marked and prolonged increase in physical activity (Giladi et al. 1985a; Bucholz and Brumback 1996). The incidence of stress fractures of the femoral shaft in civilian population appears to be rising along with the recent emphasis on physical fitness. Running accounts for most such fractures (McBryde 1975), which have been encountered after triathlon events and aerobic dancing as well (Clement et al. 1993).

Dencker studied 1003 recent femoral shaft fractures in adults in 992 patients treated at public hospitals in Sweden during a three-year period of 1952 to 1954, with a follow-up of 4 to 8 years. Kootstra studied 335 traumatic femoral shaft fractures in 329 adults in the province of Groningen in the Netherlands during 12 years from 1958 to 1969 (Kootstra 1973). Pathological fractures caused by primary and metastatic tumors were excluded in both studies (Dencker 1963; Kootstra 1973). The frequencies of femoral shaft fractures in adults were 334 fractures per year (Dencker 1963), and 17-36 fractures per year (Kootstra 1973). The ratio of men to women in Dencker’s series was 2.7:1, but the relation varied widely at different ages. In the Kootstra study (1973), 22.2% of the patients were females (N=73), compared with 21.5% - 27% in earlier studies (Dencker 1963; Blichert-Toft and Hammer 1970). The risk of sustaining a femoral shaft fracture was greatest in men between the ages of 20 and 29 years, while in women it was greatest between 80 and 89 years (Dencker 1963; Kootstra 1973). In Dencker’s study, the distribution was fairly even in the male groups 30 to 39, 40 to 49, and 50 to 59 years, ranging between 86 and 122. In the female age groups 20 to 29, 30 to 39, 40 to 49 and 50 to 59 years, the distribution was even, between 20 and 27. The number of fractures increased in women over the age of 60 (Dencker 1963). In patients of 60 years or over, fractures were twice as common in women as in men, 159 against 80. According to the study by Kootstra (1973), femoral shaft fractures most frequently occurred at an early age in males (Tables 5. and 6.). The incidence gradually diminished with increasing age, and attained its lowest value in age group 70-79, after which another increase occurred (Table 5.). The marked increase in femoral shaft fracture incidence in females after 50 can only be explained on the basis of a constitutional factor, i.e. the hormonal change during and after the menopause, which is associated with osteoporosis and increased fragility of the femoral shaft. The percentage of patients aged 70 or older and sustaining a femoral shaft fracture was 14.9%-15% (Dencker 1963; Blichert-Toft and Hammer 1970). This age group has been found to be overwhelmed by female patients: 72% by Dencker (1963), 66% by Blichert-Toft and Hammer (1970), and 63% by Kootstra (1973) (Table 6.)

Table 5. Incidence of femoral shaft fractures in males and females according to age group by Kootstra (1973) (N=329 patients).

Age Group	**Incidence per 1000 persons**	
Years	*Males*	*Females*
17-19	3.06	0.65
20-29	1.91	0.26
30-39	1.50	0.16
40-49	1.17	0.06
50-59	1.20	0.28
60-69	1.35	0.44
70-79	0.65	1.21
80-89	1.47	2.41
90-99	(10.98)	(3.77)

Table 6. Age- and gender-specific distribution of patients sustaining femoral shaft fractures by Kootstra (1973) (N=329 patients).

Age Group	**Males**	**Females**	**All**
Years	*Number of Patients (Percentage)*	*Number of Patients (Percentage)*	*Number of Patients (Percentage)*
17-19	40 (83%)	8 (17%)	48 (100%)
20-29	69 (88%)	9 (12%)	78 (100%)
30-39	35 (88%)	5 (12%)	40 (100%)
40-49	34 (94%)	2 (6%)	36 (100%)
50-59	32 (80%)	8 (20%)	40 (100%)
60-69	28 (74%)	10 (26%)	38 (100%)
≥70	18 (37%)	31 (63%)	49 (100%)

The seasonal frequency of fresh femoral shaft fractures has varied: the frequency has been lowest in January (2.7%) and highest in July (10.6%), as shown in Table 7. (Kootstra 1973).

Table 7. Seasonal frequency of patients sustaining femoral shaft fractures by Kootstra (1973) *(N = 329)*.

Season	**Frequency**	
	Number	*Percentage*
Winter (December - February)	56	17%
Spring (March - May)	73	22%
Summer (June - August)	94	29%
Autumn (September – November)	106	32%
All	329	100%

The distribution of pre-existing diseases among patients sustaining femoral shaft fractures has previously been 28.6%, and in patients aged 70 years or older 61% (Table 8.) (Kootstra 1973). The most common general disease involved the circulatory system (Kootstra 1973). The most common local disease of the same limb was osteoarthritis of the ipsilateral hip (Table 9.) (Kootstra 1973), a location that may contribute to the emergence of the fracture (Aufranc, Jones, Stewart 1965).

Table 8. Age-related distribution of pre-existing disease among patients sustaining femoral shaft fractures by Kootstra (1973) (N=329 patients).

Age Group	**Pre-existing Disease**	**No Pre-existing Disease**	**All**
Years	*Number (Percentage)*	*Number (Percentage)*	*Number (Percentage)*
17-19	3 (6%)	45 (94%)	48 (100%)
20-29	13 (17%)	65 (83%)	78 (100%)
30-39	10 (25%)	38 (75%)	48 (100%)
40-49	7 (19%)	29 (81%)	36 (100%)
50-59	17 (43%)	23 (57%)	40 (100%)
60-69	14 (37%)	24 (63%)	38 (100%)
≥ 70	30 (61%)	19 (39%)	49 (100%)

Table 9. Distribution of different pre-existing diseases among patients sustaining femoral shaft fractures (Kootstra 1973) (N=329 patients).

Pre-existing disease	Number (Percentage)
General	
Respiratory system	18 (5.5%)
Circulatory system	24 (7.3%)
Digestive tract	12 (3.6%)
Urogenital system	5 (1.5%)
Cerebrospinal system	16 (4.9%)
Endocrine diseases	9 (2.7%)
Mental disorders	15 (4.6%)
Other systemic diseases	10 (3.0%)
Pre-existent abnormalities of suspensory and locomotor apparatus	22 (6.7%)
Local (ipsilateral)	
Hip-joint disease (osteoarthritis)	13 (4.0%)
Condition after hip fracture	6 (1.8%)

For displaced fatigue fractures of the femoral shaft, previous studies have mainly been case reports (Asal 1936; Wolfe and Robertson 1945; Morris and Blickenstaff 1967; Hallel, Amit, Segal 1976; Orava 1980; Luchini, Sarokhan, Micheli 1983; Dugowson, Drinkwater, Clark 1991; Visuri and Hietaniemi 1992; Clement et al. 1993), although two more extensive studies have been published (Provost and Morris 1969; Bargren, Tilson, Bridgeford 1971), but the true incidence, the morphologic characteristics, and the long-term treatment results of these fractures have not been systematically examined before.

2.9. Location, morphology and soft-tissue injuries of femoral shaft fractures in adults

According to Dencker (1963), the predilection of femoral shaft fractures for the right side has been 53.1% versus 46.9% on the left side. The difference was non-significant when compared to the left side predilection (54.4% versus 45.6%) in the Kootstra study in 1973. The difference between the study by Dencker in 1963, with 471 fractures on the left side and 532 fractures on the right side, and that by Kootstra (1973), with 179 fractures on the left side and 150 fractures on the right side was statistically significant ($p<0.05$) (Kootstra 1973). The left femur was often involved in traffic accidents (59%) with right side traffic, and the right femur often in occupational accidents (75%) due to unknown reasons. The difference was significant ($p<0.001$) (Kootstra 1973). The left-right distribution in domestic accidents was almost equal (Table 10.) (Kootstra 1973). Dencker's study in 1963 concerned Sweden, where traffic kept to the left at that time, but Dencker presented no left-right distribution in relation to traffic.

Table 10. Accident type and laterality among femoral shaft fractures in adults (N=320*) (Kootstra 1973).

Type of Accident	Fracture Location	
	Left Femur Number (Percentage)	*Right Femur Number (Percentage)*
Traffic on foot	16 (55%)	12 (45%)
Traffic on two wheels	77 (59%)	53 (41%)
Traffic in car	49 (58%)	35 (42%)
Occupational, direct injury	5 (31%)	11 (69%)
Occupational, indirect injury	3 (21%)	11 (79%)
Sports	0 (0%)	2 (100%)
Domestic	22 (48%)	24 (52%)

*The injury mechanism was unclassifiable in 9 patients.

The distribution of open femoral shaft fractures has been 12-27% (Dencker 1963; Blichert-Toft and Hammer 1970; Kootstra 1973). By the definition of Kootstra (1973), in open fractures, the continuity of the skin at the fracture site is interrupted, from the inside or from the outside. Open femoral shaft fractures were caused in traffic accidents in 16%, at work in 19%, and at home in 2% (Kootstra 1973). In the traffic group, 11% of open fractures were related to moving on foot, 17% to moving on two wheels, and 18% occurred in a car (Kootstra 1973). Six open femoral shaft fractures occurred at work: three from direct and three from indirect injury (Kootstra 1973). Most of the open wounds were 1-6 cm (Kootstra 1973). In the direct injuries the skin lesion was more severe; the wound was larger than 6 cm in two and in one there was a skin defect. The wounds in the indirect injuries were all smaller than 6 cm (Kootstra 1973).

By morphology, Kootstra (1973) divided femoral shaft fractures into bending fractures (68.4%), encompassing transverse, oblique, and transverse or oblique fractures with a butterfly; comminuted fractures (19.1%); and torque fractures (9.7%), encompassing spiral fractures and spiral fractures with butterfly. In 2.7% of the studied fractures, the information was insufficient or the fracture unclassifiable or a double fracture (Kootstra 1973). The frequency of spiral fractures was higher among females (Table 11.).

Table 11. Gender-specific morphology of femoral shaft fractures (N=320 patients*) (Kootstra 1973).

Fracture morphology	Males Number (Percentage)	Females Number (Percentage)	All Number (Percentage)
Bending fractures	171 (76%)	54 (24%)	225 (100%)
Comminuted fractures	59 (94%)	4 (6%)	63 (100%)
Torque fractures	17 (53%)	15 (47%)	32 (100%)

*The injury mechanism was unclassifiable in 9 patients.

In the Dencker study, the most common fracture location was the middle third of the femoral shaft (60% of the fractures) (Dencker 1963). In most cases the fracture was transverse (32% of the fractures), which was more common fracture type (39%) in men aged 50 years or younger. Long oblique fractures were more frequent in elderly women aged 70 years or older (55%). Different morphologic types of femoral shaft fractures are shown in Figure 1.

Figure 1. Different morphologic types of femoral shaft fractures:
A. A simple transverse AO Type 32-A3.2 fracture with minimal comminution (Winquist-Hansen Grade I).
B. A simple oblique-transverse fracture without comminution (Winquist-Hansen Grade 0) of a femur that had a distal femoral fracture treated with a plate 16 years earlier. The AO Type depends on the size of the transverse or oblique component of the fracture.
C. A simple oblique AO Type 32-A2.2 fracture (Winquist-Hansen Grade 0).
D. A slightly comminuted (Winquist-Hansen Grade I) spiral AO Type 32-A1.2 fracture.
E. A spiral AO Type 32-B1.2 fracture with a bending wedge (butterfly fragment) (Winquist-Hansen Grade III).
F. A comminuted irregular complex AO Type 32-C3.1 fracture of Winquist-Hansen Grade IV.
G. A segmental, AO Type 32-C2.1 fracture.
H. An oblique fracture of the middle third of the femoral diaphysis with minimal comminution (Winquist-Hansen Grade I) and a dislocation of the knee.

Torque fractures were related to domestic accidents (75%) and to pre-existing hip-joint disease (40.6%) (Kootstra 1973). Of the 16 fractures caused by occupational direct injury, 6 fractures were comminuted. Traffic accidents caused 85% of the comminuted fractures, and the majority of these accidents were car crashes (39.2%) (Kootstra 1973). The largest percentage of open fractures was found among the comminuted fractures (32% of open fractures) (Kootstra 1973).

In motor vehicle accidents and auto-pedestrian accidents, a transverse fracture is usually sustained because of direct impact to the shaft or indirect force transmitted through the knee, subjecting the femur to a high bending load (Bucholz and Brumback 1996). Motorcyclists are frequently victims of a direct side impact, hence sustaining comminuted fractures (Bucholz and Brumback 1996). Gunshot wounds create spiral or comminuted fractures (Bucholz and Brumback 1996). A small caliber gunshot missile causes a comminuted fracture due to a direct impact of the bullet in the tubular bone of the diaphysis. In the metaphyseal bone it causes a drill hole fracture in the distal femoral metaphysis secondary to a direct impact of the missile on the cancellous bone (Smith and Wheatley 1984).

2.10. Concomitant injuries associated with femoral shaft fractures

Concomitant injuries related to femoral shaft fractures include ipsilateral injuries of the same lower extremity and other isolated injuries, as well as polytrauma. According to Dencker's study the prevalence of concomitant injuries has been 23% in 1963, and 45% by Kootstra in 1973.

The prevalence of *general associated injuries* has been 45% (Kootstra 1973) including shock (of which 24% were related to traffic accidents). General associated injuries were related to traffic accidents in 57%, occupational accidents in 31%, or domestic accidents in 4% (Kootstra 1973). A general associated injury was found in 77% of the patients who sustained a femoral shaft fracture while seated in car (Kootstra 1973). Overall, accidents sustained while seated in car comprised between 7.9% (Dencker 1963) and 25.5% (Kootstra 1973).

Craniocerebral injury has varied from 2.7% (Dencker 1963) to 10.9% (Kootstra 1973). Facial fractures have occurred in 12.1% of cases (Dencker 1963; Kootstra 1973). Other reported concomitant injuries are: injury in the humeroscapular area 20.0%, thoracic injury without respiratory disturbances 6.7%, thoracic injury with respiratory disturbances 3.6%, vertebral fracture 1.2%, upper arm or elbow injury 5.8%, forearm or hand injury 9.7%, contralateral femoral shaft fracture 1.8%, contralateral lower leg fracture from 1.4% (Dencker 1963) to 3.3% (Kootstra 1973) of the cases, supra- or intracondylar femoral fracture 1.2%, ankle or foot injury 2.4% or other injury 3.3% including ruptured auricle of the heart, ascending aorta, spleen, liver, bladder or renal contusion (Kootstra 1973).

Local injury associated with femoral shaft fracture is found in about every third case in the traffic accident and indirect occupational injury groups. No local associated injury was found in the direct occupational injury and domestic groups (Kootstra 1973).

Recognized injury of the superficial femoral artery occurs in less than 2% of patients with fracture of the femoral shaft (Isaacson, Louis, Costenbader 1975; Barr, Santer, Stevenson 1987; Kluger et al. 1994). Middiaphyseal femoral shaft fractures can be associated with a false aneurysm of the superficial femoral artery as an intimal flap or a pseudoaneurysm (Guemes et al. 1991; Kluger et al. 1994). A diagnostic arteriogram should be performed, followed by therapeutic embolization (Levade et al. 1983). The profunda femoris artery can be damaged in intramedullary nailing (Barnes and Broude 1985) for example during the placement of the anteroposterior proximal locking screw in retrograde nailing (Coupe and Beaver 2001).

Hip dislocation accounts for 0.3%, acetabular fracture 1.5%, and femoral neck or pertrochanteric fracture 3.4% of the femoral shaft fractures (Kootstra 1973). Ipsilateral pelvis and femoral shaft fractures form a *floating hip* (Wu and Shih 1993; Müller et al. 1999) and are often associated to chest trauma, other skeletal fractures or polytrauma (Müller et al. 1999). The incidence has varied from 6.7% (Kootstra 1973) to 13%-22% (Müller et al 1999). The pelvic fracture is mostly transverse or comprises posterior column or wall (Müller et al. 1999).

Femoral shaft fractures combined with *ipsilateral femoral neck fractures* were first described by Delaney and Street (1953). Hip fractures are detected in 1.2% (Kootstra 1973) to 2.5%-5% of patients with femoral shaft fractures (Ashby and Anderson 1977; Casey and Chapman 1979; Swiontkowski, Hansen, Kellam 1984; Friedman and Wyman 1986; Swiontkowski 1987; Wiss, Sima, Brien 1992; Leung 2002) and are quite often missed in polytrauma patients with femoral shaft fractures (Ostrum, Verghese, Santner 1993). Although about 1/4 to 1/3 of primary neck fractures are initially detected after stabilization of the shaft fracture (Bennett, Zinar, Kilgus 1993; Riemer et al. 1993), some of the fractures have occurred during intramedullary nailing (Harper and Henstorf 1986; Harper and Carson 1987). Diaphyseal fracture is usually comminuted, as the trauma energy dissipates through shaft fracture (Wu, Shih, Chen 1993; Alho 1997; Müller et al. 1999). Hip fracture remains relatively undisplaced or minimally displaced (Bennett, Zinar, Kilgus 1993) and usually represents the Pauwels grade II type with a vertical shear (Wiss, Sima, Brien 1992). The ratio between concomitant femoral neck fractures and concomitant intertrochanteric fractures is 7:1 (Bennett, Zinar, Kilgus 1993). The femoral neck fracture is not devoid of nonunion or malunion (Bucholz and Rathjen 1985; Bose, Corces, Anderson 1992; Wiss, Sima, Brien 1992; Bennett, Zinar, Kilgus 1993).

The incidence of fracture of the ipsilateral lower leg has varied from 0.5% (Dencker 1963) to 10.9% (Kootstra 1973). Ipsilateral femoral shaft and tibial shaft fractures cause a Type 1 *floating knee* (Blake and McBryde 1975). The classification by Letts has five subgroups depending on whether the fractures are closed and diaphyseal (A); closed, but the other fracture is metaphyseal (B); the other is intra-articular (C); the other is open (D); or both the fractures are open (E) (Letts, Vincent, Gouw 1986). Other classifications also exist (Fraser, Hunter, Waddell 1978). Besides being caused by a high energy trauma with extensive skeletal and soft-tissue damage, floating knee is also associated with potentially life-threatening injuries of the head, chest and abdomen (Veith, Winquist, Hansen 1984). Knee dislocation (Chen and Wang 1998) or ligament injury (Szalay, Hosking, Annear 1990; van Raay, Raaymakers, Dupree 1991) can also associate with the floating knee.

The incidence of arthroscopically verified concomitant *meniscal injuries* associated with ipsilateral femoral shaft fractures in adults has varied from 27% (Barber et al. 1988; Vangsness et al. 1993; Blacksin, Zurlo, Levy 1998) to 38% (DeCampos et al. 1994). In arthroscopies, lateral meniscus has accounted for 17% and medial meniscus for 11% of the meniscal tears which mostly are complex or radial (Vangsness et al. 1993). According to a MRI study in 34 patients with closed femoral shaft fractures, the posterior horn of the medial meniscus is most frequently torn (Blacksin, Zurlo, Levy 1998).

Ipsilateral injury to *knee ligaments* has been described in 17% to 48% of femoral shaft fractures in studies that have included 30-50 patients (Ritchey, Schonholtz, Thompson 1958; Shelton, Neer, Grantham 1971; Hughston et al. 1976; Nagel, Burton, Manning 1977; Dunbar and Coleman 1978; Fraser, Hunter, Waddell 1978; Noyes et al. 1980; Viano and Stalnaker 1980; Walker and Kennedy 1980; Rowntree and Getty 1981; Walker and Stein 1982; Barber et al. 1988; McAndrew and Pontarelli 1988; Szalay, Hosking, Annear 1990; Dickob and Mommsen 1992; DeCampos et al. 1994; Blacksin, Zurlo, Levy 1998). In a larger study including 309 patients the incidence of serious (Grade II and III) knee ligament injury was 5.3% (Moore, Patzakis, Harvey 1988). Partial ACL injury has accounted for 48% and total ACL injury for 5% of 40 arthroscopically examined knees associated with a closed femoral shaft fracture and without any previous knee injury (DeCampos et al. 1994). According to a MRI study, partial ACL tears were diagnosed in 6% of all 34 knees, while total ACL ruptures were not discovered at all (Blacksin, Zurlo, Levy 1998). The medial collateral ligament was the most frequent site of ligamentous injury (38%) followed by the posterior cruciate ligament (21%) verified by MRI (Blacksin, Zurlo, Levy 1998). Injury of MCL has been identified arthroscopically in 15% of cases (Barber et al. 1988) and clinically in 31% of cases (Walker and Kennedy 1980). The incidence of arthroscopically identified concomitant PCL injury has varied from 7.5% (DeCampos et al. 1994) to 15% (Barber et al. 1988). The proportion of LCL injuries has varied from 0% (Barber et al. 1988) to 6% (Blacksin, Zurlo, Levy 1998) and 13% (Walker and Kennedy 1980). Reports of collateral ligament injuries associated with femoral shaft fractures have been infrequent (Pedersen and Serra 1968).

Other ipsilateral knee injuries associated to a closed femoral shaft fracture and demostrated with MRI have been knee effusion (97%), injuries of the extensor mechanism (50%) including mainly abnormal signals of the patellar tendon in 41% and tears of patellar or quadriceps tendons in 9% , bone bruises (22%), articular changes of the patella (12%), ipsilateral fracture of the patella from 1.7% (Dencker 1963) to 5.8% (Kootstra 1973), fracture of the tibial plateau (3%), and meniscocapsular separation (3%) (Blacksin, Zurlo, Levy 1998). Articular changes or chondromalacia of the ipsilateral knee have been discovered in 50-53% of patients with femoral shaft fractures (Dunbar and Coleman 1978; Vangsness et al. 1993).

2.11. Diagnosis of femoral shaft fractures in adults

2.11.1. Clinical course

The clinical diagnosis of the fracture of the femoral shaft is usually obvious, with pain, deformity, swelling, and shortening of the thigh (Bucholz and Brumback 1996). A thorough physical examination is imperative, because most fractures are a result of high speed trauma and associated injuries are common. Orthopaedic assessment of the entire limb should be systematic and complete. The pelvic ring and the hip are inspected for tenderness, swelling or ecchymosis may signal concomitant pelvic disruption or hip fracture. Since the hip cannot be moved voluntarily by the patient, palpation of the groin and buttock is important (Chaturvedi and Sahu 1993; Riemer et al. 1993). Fullness of the buttock with flexion and adduction of the proximal femur can denote a posterior dislocation of the hip (Bucholz and Brumback 1996).

The ipsilateral knee should be carefully examined before the application of skeletal traction and again after intramedullary nailing due to a high incidence of ipsilateral knee injury in patients with femoral shaft fractures (Vangsness et al. 1993). Knee ligament injuries have been identified even in patients with an operated floating knee (Szalay, Hosking, Annear 1990; van Raay, Raaymakers, Dupree 1991). Routine arthroscopy of the ipsilateral knee has been recommended in several studies (Dickob and Mommsen 1992; De Campos et al. 1994). However, the clinical significance of concomitant complex and radial meniscal tears remains unclear, and routine arthroscopy of the knees of all patients with femoral fractures is unjustified (Bucholz and Brumback 1996).

Although neurovascular injuries are rarely associated with closed shaft fractures, a complete preoperative examination for vascular and neurologic damage is mandatory (Bucholz and Brumback 1996). Owing to severe pain and spasm accompanying femoral fractures, the motor strength of muscles below the knee may be diminished. A careful preoperative assessment of the hemodynamic stability of the patient is necessary, regardless of the presence or absence of associated injuries (Bucholz and Brumback 1996). Distal pulses should be palpated and circulatory status evaluated (Bucholz and Brumback 1996). Angiography is indicated in injuries associated with at least one “hard” symptom (pulse or neurological ischaemic deficiency) or at least two “soft” symptoms (haematoma, haemorrhage, hypotension, malleobrachial index smaller than 1) (Rezek 2002). Although few patients with isolated fractures of the femoral shaft are in hypovolemic shock (Ostrum, Verghese, Santner 1993), major blood loss more than 1200 ml into the thigh is present in most cases (Lieurance, Benjamin, Rappaport 1992).

In fatigue fractures, load–related pain is typical. Most runners report an increase in their training during or immediately before the onset of pain, which during the first two weeks becomes more strenuous after the training, but it may be delayed by several months (Greaney et al. 1983; Jones et al. 1989; Maitra and Johnson 1997). Symptoms, such as limping, local pain, tenderness, swelling or pitting edema of the surrounding soft-tissues, are related to fatigue fractures (Wilson and Katz 1969; Daffner 1978; Markey 1987; Sterling et al. 1992). Local tenderness can be detected by tapping the affected bone. To increase the accuracy of diagnosis, several tests as a fulcrum test (Johnson, Weiss, Wheeler 1994), a fist test (Milgrom et al. 1993), a hop test (Clement et al. 1993) have been introduced. The clinical diagnosis is still difficult and nonspecific (Sallis and Jones 1991). In displaced fractures, symptoms and clinical findings resemble those of a conventional bone fracture.

2.11.2. Radiographic findings

Before diagnostic radiographic studies of traumatic femoral shaft fractures are performed, longitudinal traction or splinting of the extremity is applied to ensure minimal additional soft-tissue injury to the thigh (Bucholz and Brumback 1996). If a Thomas splint is used, the metallic ring and caliber should not obscure any part of the fracture. Nondisplaced fractures of the femoral neck are frequently missed because of the overlying shadow of a splint or inadequate quality of the preoperative radiograph (Bucholz and Brumback 1996). If the hip is externally rotated on the preoperative radiograph, there can be a rotational artifact (Bucholz and Brumback 1996). In such cases, it is advisable to obtain an anteroposterior radiograph of the hip with the proximal femur internally rotated in the anesthetized patient before the operative procedure (Bucholz and Brumback 1996). Initial radiographs should include an AP view of the pelvis and AP and lateral views of the knee and the entire femur to allow detection of longitudinal cracks and nondisplaced comminution of the proximal and distal fragments (Bucholz and Brumback 1996). Lateral and oblique radiographs are recommended to rule out fractures of the femoral condyles in the coronal plane (the Hoffa fracture) (Bucholz and Brumback 1996).

In fatigue fractures radiographic changes can be seen 2-12 weeks after the onset of symptoms (Sullivan et al. 1984; Matheson et al. 1987). The sensivity of radiographs is 15-35% in the early stage (Daffner 1978; Greaney et al. 1983). Fatigue fractures are seen in 30-70% of cases only during the follow-up (Daffner 1978; Matheson et al. 1987). In cortical bone, a grey-looking hypodensic area seen in compact bone is related to the resorption phase of remodeling (Daffner 1978; Mulligan 1995). After that periosteal new bone forms and endosteal bone thickens (Daffner 1978; Martin and Burr 1982; Greaney et al. 1983). A fracture, if present, can be seen as a radiolucent line in compact cortical bone and as a sclerotic line in cancellous bone (Daffner 1978; Mulligan 1995).

In most cases CT is less sensitive than conventional radiography for the detection of fatigue injuries of bone. Certain fracture lines, such as longitudinal and spiral ones, can be seen more clearly with CT (Daffner 1978; Matheson et al. 1987).

Scintigraphy has long been considered to be the best diagnostic method for bone fatigue injuries (Daffner 1978) with a sensitivity close to 100% (Stafford e al 1986; Matheson et al. 1987). The scintigraphic classification according to Jones et al. (1989) has four different grades for fatigue fractures. False negative diagnoses have been reported, possibly because necrotic bone tissue is not labeled (Kanstrup 1997). An increase in uptake can be detected as early as 6-72 hours after the onset of symptoms (Greaney et al. 1983; Matheson et al. 1987; Kanstrup 1997). An oval signal, the intensity of which correlates the severity, can be seen with scintigraphy (Floyd et al 1987). Asymptomatic mild stress injuries are also visible with scintigraphy as clusters of increased uptake (Daffner 1978; Matheson et al. 1987).

MRI with specific classifications for fatigue fractures (Fredericson et al.1995; Yao et al. 1998; Kiuru in 2002) is as sensitive but more specific than scintigraphy (Daffner 1978; Stafford et al. 1986; Lee and Yao 1988; Meyers and Weiner 1991; Kiuru 2002). STIR (short tau inversion recovery)- and T2 (transverse relaxation)- techniques can detect non-specific edema (Daffner 1978; Stafford et al. 1986; Kiuru 2002), in the middle of which a lower signal intensity is a sign of a fracture (Daffner 1978; Stafford et al. 1986). MRI is most accurate during the first 3 weeks (Daffner 1978; Stafford et al. 1986; Martin, Healey, Horowitz 1993). In case of uncertainty one can repeat the radiographic and MRI examinations after 3-4 weeks (Lassus et al. 2002).

2.12. Treatment of femoral shaft fractures in adults

2.12.1. Development of conservative treatment of femoral shaft fractures

The history of femoral fracture management reflects the difficulties of maintaining the anatomic alignment while encouraging early functional rehabilitation of the limb (Kessler and Schweiberer 1989; Bucholz and Brumback 1996). Hippocrates (460-377 B.C.) treated femoral shaft fractures mainly with manual reduction (Rutkow 1993). Moreover, he emphasized the importance of maintaining adequate extension in order to avoid femoral shortening (van Loon 1935; Kootstra 1973). The treatment methods have evolved over time from the use of wooden splints in ancient civilizations (Bucholz and Brumback 1996) to fabrics encased with wax (Bucholz and Brumback 1996), bandages stiffened with clay (Kootstra 1973) or gum (Bucholz and Brumback 1996), and fabrics hardened with plaster of Paris (Mathijsen 1854; Bucholz and Brumback 1996). Mechanical inadequacies of traditional treatments to maintain the proper fracture alignment were demonstrated in the era of the skeletal radiography at the end of the 19th century (Bucholz and Brumback 1996). Charnley emphasized that if sound bony union can be secured in three months with conservative treatment, full recovery of the femoral shaft fracture will take about one year, and that in some cases early knee movement may be responsible for fibrous union (Charnley 1974). Böhler improved the systematic management and conservative treatment of fractures (Böhler 1957). At present, femoral shaft fractures in adults are usually not treated conservatively except in underdeveloped countries, in catastrophe medicine or war surgery (Dufour et al. 1988; Coupland 1991; Coupland 2000).

2.12.2. Traction

The skin traction method was first introduced by de Chauliac in the 14th century (van Loon 1935; Bucholz and Brumback 1996) and modified in the 19th century by Buck (Buck 1861). The major disadvantage of skin traction is the lack of means to apply sufficient forces to the limb to obtain fracture reduction (Bucholz and Brumback 1996) and to avoid possible skin necroses. Nowadays, traction has been used as a time-consuming primary treatment method mainly in femoral shaft fractures among children, performed as skin or skeletal traction with a percutaneous pin in the tibia or femur (Bucholz and Brumback 1996).

Skeletal traction techniques were introduced by Steinmann in 1907 (Steinmann 1907) and by Kirschner in 1909 (Dencker 1963; Mays and Neufeld 1974; Bucholz and Brumback 1996). The Thomas splint improved control of the traction forces in providing counteraction on the leg through its ring, and was used since World War I (Bucholz and Brumback 1996). Various skeletal tractions (Thomas splint with Pearson knee-flexion piece, Braun frame, Russell traction, Perkins traction, Fisk traction, 90º-90º-traction) represented the most common method of definitive treatment of femoral shaft fractures for decades before the 1970s (Charnley 1974; Bucholz and Brumback 1996). The distal femur has been successfully used for skeletal traction, as it offers a more direct longitudinal pull of the fractured femur than the proximal tibia in similar traction. Skeletal traction through the distal femur has associated with a higher rate of knee stiffness after fracture union due to, undoubtedly, scarring of the vastus medialis and vastus lateralis (Bucholz and Brumback 1996). Most skeletal traction methods require that the patient remains in the supine position (Bucholz and Brumback 1996). The goal of skeletal traction is at first to maintain the normal length of the limb. After 24 hours from injury, hematoma begins to develop, and pulling the fracture to its normal length requires an increasing amount of traction (Bucholz and Brumback 1996). With the traction, it is impossible to diminish the traction force alone without jeopardizing the reduction stability. Gravity can not be used to help in correcting the deformity of backward angulation, which should be corrected by traction in the axis of the tibia (Charnley 1974). Traction of the proximal tibia is contraindicated in concomitant ipsilateral knee injuries (Bucholz and Brumback 1996). Transverse fractures are more difficult to treat with traction than oblique ones (Charnley 1974). Skeletal traction therapy was continued for a patient until significant radiographic and clinical evidence of fracture union was apparent, which usually required a minimum of 6 weeks of in-hospital care (Bucholz and Brumback 1996). The aftertreatment consisted of progressive weightbearing with an unilateral weightbearing spica cast, (Bucholz and Brumback 1996). The spica cast was removed 3 to 6 months after injury, and range-of-motion exercises of the ipsilateral hip and knee were started (Bucholz and Brumback 1996). The Neufeld traction (Mays and Neufeld 1974) encases the limb and the Steinmann pin with plaster casts, while traction is applied through a roller system that permits greater early knee motion. The rotation of the foot can be maintained by the position of a cross-bar fixed to the sole of the plaster traction unit (Charnley 1974). The 90º-90º-traction method is not recommended for elderly patients for circulatory reasons (Miller and Welch 1978; Bucholz and Brumback 1996) and knee subluxation (Miller and Welch 1978). The results of traction therapy for fractures of the femoral shaft have been satisfactory (Dencker 1963; Moulton, Agunwa, Hopkins 1981). Nowadays skeletal traction is used as a supplementary treatment method of femoral shaft fractures in adults.

2.12.3. Cast bracing

The development of cast brace systems (Mooney et al. 1970; Mooney 1974; Lesin, Mooney, Ashby 1977; Meggitt, Juett, Smith 1981; Mooney and Claudi 1984) provides ambulatory treatment and prevented the hip and knee contractures that were frequent sequelae of the hip spica cast (Bucholz and Brumback 1996). In cast bracing of femoral shaft fractures shortening and angulation were frequent particularly in the proximal and midfemur (Sarmiento 1972). The cast brace permitted progressive weightbearing, leading to gradual functional improvement in the muscles and joints and to increasing skeletal stresses that stimulate fracture healing (Bucholz and Brumback 1996). The fracture itself controlled the loading in a cast brace of a smooth, total contact plaster or a plastic thigh cuff (Meggitt, Juett, Smith 1981) which carried 10% to 20% of the body weight, and resisted lateral angulation produced by the thigh musculature (Bucholz and Brumback 1996). The method was equally suitable for open fractures, fractures of the distal third, or comminuted midshaft fractures (Connolly and King 1973; Montgomery and Mooney 1981). Proximal shaft fractures, and simple transverse or oblique fractures were less amenable to cast bracing because of their high stress concentration and tendency toward angulation. Further, cast bracing was supplementary to a limited internal fixation with small-diameter nonlocked intramedullary nails (Sharma et al. 1993). Cast brace was used to substitute the hip spica casting after 6 to 8 weeks as traction or as a primary treatment after 1 to 2 weeks of traction. Serial radiographs were imperative to check the alignment and judge the advisability of early weightbearing (Bucholz and Brumback 1996).

2.12.4. Development of operative treatment of femoral shaft fractures

Early attempts of internal fixation of femoral fractures were complicated by infections and implant failures (Bucholz and Brumback 1996). Lane introduced plates and screws in 1905, Lambotte the fixateur externe in 1907, and Hey Groves in 1918 a massive nail that was used in the medullary cavity (Küntscher 1958; Bucholz and Brumback 1996). In 1939, Gerhard Küntscher from Kiel, Germany presented his first cases of intramedullary fixation of a femur using a V-shaped cross-section-designed nail (Küntscher 1940a; Küntscher 1940b; Küntscher 1967) utilizing the principle of nailing used earlier for femoral neck fractures (Küntscher 1940a). During the World War II, Küntscher served as a wartime army surgeon in Kemi, Lapland and introduced the intramedullary nailing technique to Finnish surgeons (Küntscher 1948; Küntscher 1953; Lindholm 1979; Lindholm 1980; Lindholm 1982; Seligson 2001). The first known Küntscher nailing on a Finnish patient was performed in 1942 (Lindholm 1979; Lindholm 1980; Lindholm 1982). In 1950s, Küntscher introduced the cloverleaf-sectioned nail and intramedullary reaming (Küntscher 1959; Küntscher 1968). The Küntscher nail was indicated for transverse or short oblique fractures of the middle third of the femoral shaft (Blichert-Toft and Hammer 1970). A special Y-nail was used in pertrochanteric or subtrochanteric fractures (Küntscher 1940). Of the dynamic or elastic pins, the Rush pin was elaborated on in the 1930s (Rush and Rush 1950; Rush 1968). The Küntscher nail had advantages compared with the Rush rod (Rush 1968) and the flexible Ender pins (Eriksson and Hovelius 1979). Although satisfactory results were obtainable for simple transverse and short oblique fractures, and for fractures with unicortical comminution, complex patterns involving long oblique, spiral, distal and comminuted fractures tended to shorten over the pins. Additional cerclage wiring, external fixation, cast or postoperative traction was used on rare occasions (Pankovich, Goldflies, Pearson 1979; Pankovich 1981). Despite techniques such as stacking multiple nails in the canal and diverging the rods in the proximal and distal fragments, the anatomic results have been poorer than those with interlocking nails. Later, improvements in the mechanical properties and design of intramedullary nails, innovations in instrumentation, modifications in the nail insertion technique, and the use of fluoroscopy greatly contributed to the treatment of more complex and demanding fractures (Bucholz and Brumback 1996; Street 1996).

In the 1960s the AO-group (Arbeitsgemeinschaft für Osteosynthesefragen) of the Association for the Study of Osteosynthesis (ASIF) developed osteosynthesis techniques consisting of intramedullary fixation as well as fixation by means of screws and plates, which further enhanced the stability of the osteosynthesis by interfragmentary compression (Müller et al. 1991). Other methods like screws alone, bone suture, or intramedullary pins did not suffice to maintain the stable immobilization (Watson-Jones 1955; Böhler 1957; Dencker 1963).

Many additional refinements in the nail system have been introduced since the original Küntscher nail, but the basic concept and system remain unchanged. Intramedullary nailing has been further developed by the methods of open and closed nailing, the introduction of interlocking nails (Klemm and Schellman 1972; Vittali, Klemm, Schellmann 1974; Kempf, Grosse, Beck 1985; Contzen 1987), unreamed interlocking nailing techniques (Krettek et al. 1994; Kröpfl et al. 1995), and retrograde modifications in the nail insertion (Stiletto and Baacke 2001; Krupp et al. 2003). Small-diameter nails are recommended in medullary canals smaller than 8 mm, in fractures below noncemented femoral prostheses, or in fractures requiring intramedullary fixation that avoids physeal plates in young children (Herscovici et al. 1992). At present, titanium nails are more frequently used in femoral shaft fractures also in adults (Im and Shin 2002).

There has been a nearly unendless debate over whether fractures of long bones should be operated on within 24 hours or with delay. Unstabilized fractures may cause soft-tissue damage, fat embolism, and respiratory insufficiency (Beck and Collins 1973; Rüedi and Wolff 1975; Wilber and Evans 1978; Seibel et al. 1985; Wald, Shackford, Fenwick 1993). Fracture stabilization also has a positive effect on the patient's pain, metabolism, muscle tone, and body temperature, and, as a result, cerebral function (Giannoudis et al. 2002a). Early works suggested that delayed fixation resulted in more rapid fracture healing (Charnley and Guindy 1961; Lam 1964; Smith 1964). Retrospective investigations (Riska et al. 1977; Goris et al. 1982; Riska and Myllynen 1982; Johnson, Cadambi, Seibert 1985; Meek, Vivoda, Pirani 1986; Boulanger, Stephen, Brenneman 1997) demonstrated improved survival of a multiply injured patient who received fracture fixation within 24 hours of injury resulting from a lower prevalence of sepsis due to a decrease in the rate of pulmonary insufficiency. Patients with a chest injury are most prone to deterioration after an intramedullary nailing procedure (Pape et al. 1993a). Higher incidences of pulmonary complications, and prolonged stay in the hospital or in the intensive care unit related to delayed femoral shaft fracture fixation were reported (Bone et al. 1989). In some studies early long bone stabilization had no effect on the outcome with regard to mortality rate, length of stay in the intensive care unit, need for mechanical ventilation, and total length of hospital stay in patients with a head injury (Dunham et al. 2001). The prevalence of ARDS has been significantly lower in plate fixation ($p<0.001$), in external fixation converted into intramedullary nailing ($p<0.002$), and in primary intramedullary nailing ($p<0.003$) (Pape, Giannoudis, Krettek 2002). The prevalence of early neurological deterioration was 38% in a group treated with early fixation without any early neurological deterioration

(Martens and Ectors 1988). No difference in the long-term neurological outcome has been found between the patients treated with early fixation or with delayed fixation (McKee et al. 1997). A significantly ($p<0.0001$) lower prevalence of perioperative neurological complications has been found in patients that have undergone early definitive fracture fixation compared with patients treated with delayed fixation (Poole et al. 1992). Opposite results in Glasgow Coma Scale have been found in multiply injured patients with head and femoral shaft injuries treated with fixation within 24 hours after the injury (Hofman and Goris 1991; Brundage et al. 2002). No increased risk of pulmonary or cerebral complications was demonstrated in randomized prospective investigations related to early femoral fixation in combination with head trauma (Lozman et al. 1986) and/or long bone fractures (Poole et al. 1992).

By the 1980s, the accepted care of major fracture was early fixation within 24-48 hours from injury or admission) fixation. Delayed fracture fixation was thus considered as detrimental (Riska and Myllynen 1982; Talucci et al. 1983; Johnson, Cadambi, Seibert 1985; Bone et al. 1989; Charash, Fabian, Croce 1994), which has been disputed (Rogers et al. 1994; Reynolds et al. 1995) or, especially in patients with head injury, challenging (Jaicks, Cohn, Moller 1997; Velmahos et al. 1998; Pape et al. 2000).

Nowadays, the damage control orthopaedics also concerns the treatment of femoral shaft fractures (O'Brien 2003; Harwood et al. 2005; Hildebrand et al. 2005). The femoral shaft fracture in multiply injured patient can be stabilized temporarily with an external fixation, and later treated with an intramedullary nailing within 6-8 days rather than 2-3 days due to increased inflammatory response ($p<0.0001$) (Pape et al. 1999b; Pape et al. 2003). The increased survival of multiply injured patients by immediate fixation of long-bone fractures was demonstrated in the 1970s and 1980s retrospectively (Riska et al. 1977; Goris et al. 1982; Riska and Myllynen 1982; Johnson, Johnston, Parker 1984; Seibel et al. 1985; Meek, Vivoda, Pirani 1986). A randomized prospective study showed that immediate stabilization of femoral shaft fractures in the multiply injured patient resulted in a decreased prevalence of ARDS, fewer days in the intensive care unit, and decreased hospital costs (Bone et al. 1989).

Intramedullary nailing has been suggested to represent *a second hit,* with systemic physiologic effects such as neutrophil activation, elastase release, and expression of adhesion molecules (Giannoudis et al. 1999), in a trauma patient who has already sustained the first hit of the initial injury. Damage control orthopaedics, with staged management of the multiply injured patient with femoral shaft fractures by means of later conversion of external fixation later to intramedullary nailing, has been proposed by several authors (Nowotarski et al. 2000; Scalea et al. 2000; Pape, Giannoudis, Krettek 2002; Pape et al. 2002; Giannoudis 2003; Hildebrand et al. 2005). The method is used for unstable patients (Pape et al. 2002; Roberts et al. 2005) and focuses on control of hemorrhage, management of soft-tissue injury, and achievement of provisional fracture stability. Along with severe chest (Hildebrand et al. 2005) and head trauma, haemorrhagic shock, coagulopathy, hypothermia and high ISS (Pape, Giannoudis, Krettek 2002), damage control orthopaedics may also be applicable to patients with bilateral femoral fractures or femoral and tibial fractures (Zalavras et al. 2005).

2.12.5. Plate fixation

During the 1960s and 1970s the treatment concepts of rigid internal fixation of femoral shaft fractures followed by early limb rehabilitation gained wide acceptance because of dissatisfactory results of nonoperative treatment (Dencker 1963; Seligson and Harman 1979; Hardy 1983). Open reduction with plating was employed on nearly all fractures of the femoral shaft (Riska et al. 1977; Rüedi and Lüscher 1979; Sprenger 1983; Cheng, Tse, Chow 1985) or its use was limited to fractures that were amenable to intramedullary nailing, with or without cerclage wiring (Petersen and Reeder 1950; Jensen, Johansen, Morch 1977; Roberts 1977; Sprenger 1983). Multiple 90º-90º plates were applied to the femoral diaphysis to obtain more secure fixation (Petersen and Reeder 1950; Marshall 1958; Rüedi and Lüscher 1979). Evacuation of the fracture and at least partial devascularization of the femoral cortex were inevitable. Improvements in plate strength and design permitted fracture site compression and allowed single plating of fractures of the femoral shaft. Routine bone grafting of comminuted femoral shaft fractures with open plate fixation was recommended (Rüedi and Lüscher 1979). Plate and screws were mainly indicated for transverse fractures and short oblique fractures, irrespective of their level on the femoral shaft (Böhler 1957; Dencker 1963). An "indirect reduction" technique was advocated by the ASIF -group to obtain fracture stabilization of complex injuries without excess dissection, surgical manipulation, and anatomic reduction of the comminuted fracture fragments (Riska et al. 1976; Mast 1989). Contraindications for plate fixation were multiply injured patients with coagulopathy, preexisting skin infection, cardiac instability, and severe head injury with uncontrollable and fluctuating intracranial pressure measurements (Bucholz and Brumback 1996). The AO-technique required an extensive surgical exposure of the lateral aspect of the femur for using a 10- to 12-hole dynamic compression plate (DCP) from the lateral approach. A minimum of five screws in both the proximal and distal fragments were recommended (Bucholz and Brumback 1996). A minimal number of intrafragmental screws, preferably through the plate, were inserted to prevent excessive damage to the soft-tissues. All medial cortical defects were advised to be grafted (Bucholz and Brumback 1996). Perioperative antibiotics were used to minimize the chance of infection (Thompson et al. 1985). Active range of motion exercises for the knee were encouraged soon after surgery. Full weightbearing was postponed until a complete radiographic union was present. The delay in weightbearing for 3 to 5 months was a major disadvantage of plating compared with closed reamed intramedullary nailing (Bucholz and Brumback 1996). The popularity of plating decreased since its peak in the early 1970s (Gant, Shaftan, Herbsman 1970; Fisher and Hamblen 1978). The only remaining advantage was that open plating did not require the wide spectrum of specialized operating room equipment and fluoroscopy that are necessary for closed intramedullary nailing (Bucholz and Brumback 1996). Nowadays the Less Invasive Stabilization System (LISS) has been used as a percutaneous plate osteosynthesis in distal femoral shaft fractures (Schandelmaier et al. 2001; Schutz et al. 2001; Weight and Collinge 2004).

2.12.6. External fixation

At the beginning of the 20th century, Lambotte was among the first to use transfixation in the treatment of fractures of the long bones and the method was improved by Anderson in 1933, Stader in 1937, Haynes in 1939, and Hoffmann in 1941 (Dencker 1963). External fixation using percutaneous pins inserted proximal and distal to the fracture gained initial popularity for the stabilization of fractures of the femoral shaft during World War II. The lateral half-pin external fixator designs, pioneered by Wagner (Seligson and Kristiansen 1978), was shown to provide adequate bone fixation and stabilization for more complex femoral shaft injuries (Dabezies et al. 1984; DeBastiani, Aldegheri, Renzi Brivio 1984; Hughes 1984; Gottschalk, Graham, Morein 1985; Chevalley, Amstutz, Bally 1992). The rigidity of femoral external fixators mainly depends on the pin diameter, which should be at least 5mm (Chevalley, Amstutz, Bally 1992). The chief advantage of external fixation is that exercise can be started early after the injury. The functional outcome with this method has been either excellent (Jackson, Jacobs, Neff 1978; Seligson and Kristiansen 1978; Dabezies et al. 1984) or decreased (Jackson, Jacobs, Neff 1978; Green 1982; Alonso, Geissler, Hughes 1989). Disadvantages include difficulties in securing a good fracture position and sufficient fixation.

External fixation of the femoral shaft has most often been used in high energy injuries in which rapid, rigid fracture stabilization is required because of associated injuries (Broos, Miserez, Rommens 1992). The major indication nowadays to use external fixation of the femoral shaft is grade III open fractures excluding IIIA injuries (Bucholz and Brumback 1996). Circular or small-wire external fixators (Ilizarov) used in limb lengthening and correction of posttraumatic deformity obstruct access to the thigh for the multiple debridements and dressing changes required with grade III fractures. A comparative study between external fixation and interlocking intramedullary fixation for closed fractures of the femoral shaft disclosed distinctly superior clinical results with the intramedullary technique, although the severity of injuries between the two treatment groups was not identical (Murphy et al. 1988). Thus, external fixation can not be indicated in the routine treatment of closed fractures of the femoral shaft (Murphy et al. 1988). A temporary fixation is replaced by internal fixation once the emergency situation has been resolved (Alonso, Geissler, Hughes 1989; Broos, Miserez, Rommens 1992; Bhandari et al. 2005).

2.12.7. Intramedullary nailing

2.12.7.1. Principle of intramedullary nailing

Intramedullary nailing provides a stable osteosynthesis through flexible impingement of the nail in the bone and represents the ideal treatment of fractures, because it requires no external fixation or special postoperative care (Küntscher 1958) and permits early joint movement and weightbearing (Küntscher 1965). Intramedullary nailing delivers fewer cases of malunion and fracture shortening; improved function, shorter hospitalization; earlier return to work, and generally a rapid healing of the fracture (Carr and Wingo 1973; Johnson, Johnston, Parker 1984). The nail involves longitudinal elasticity, as the Rush pin, but also elastic compressibility in cross section (Küntscher 1958). The nail is in line with the flow of forces (Küntscher 1935) of the femur (Küntscher 1968). Küntscher emphasized the role of inflammation in stimulating callus formation in intramedullary nailing (Küntscher 1967) even without a fracture (Küntscher 1940b; Küntscher 1970).

Küntscher's principles in intramedullary nailing of long bones are: 1) nailing must be performed under fluoroscope control without direct exposure of the fracture site in order to avoid infection, 2) the nail must be strong enough to resist the stresses caused by muscle contraction, joint movement, and weightbearing in order to to avoid nail bending or breakage, and 3) the nail must have sufficient elasticity to compress during insertion, and to re-expand once in place to bind the fragments firmly and thus to prevent rotation at the fracture (Küntscher 1965). The principles are valid even now: reaming should be performed cautiously, 1 mm wider than the diameter of the nail, and the sharpness of the tip of the reamer should be adequate (Küntscher 1959).

Intramedullary nails are *load-sharing devices* with a minimal stress shielding (Kaartinen 1993) with favourable loading conditions of the femur by gravitational, muscular, and ligamentous forces (Allen et al. 1968). The centrally located isthmus allows for endosteal purchase both proximally and distally by an intramedullary rod. The load is born primarily by the bone, which promotes fracture healing, prevents disuse osteoporosis, and reduces the effects of stress protection minimizing the possibility of breakage of intramedullary nails (Chapman 1996). The mechanical property of the nail-bone composite has benefits compared with plate fixation. Intramedullary nailing provides good bone stability with limited soft-tissue exposure and dissection. The fracture callus is loaded progressively, stimulating healing and remodeling (Bucholz and Brumback 1996).

Besides vascular changes, reaming also *results in thermal necrosis* of the inner cortex (Schemitsch et al. 1995; Leunig and Hertel 1996) and consequent *cortical porosity* (Husby et al. 1989; Müller, Frigg, Pfister 1993; Müller et al. 1993a; Schemitsch et al. 1998). In animal studies, the adverse effects of rigid intramedullary nailing on cortical bone were mediated predominantly through soft-tissue trauma (Kaartinen 1993). Extensive reaming of the medullary canal, especially when combined with open reduction of the fracture, should be preferably avoided, because it widens the medullary canal and increases the porosity of the cortical bone (Kaartinen 1993). *Pressure increases* in the intramedullary cavity and vessels are occluded by fat embolism and bone particles (Klein et al.1990; Müller, Frigg, Pfister 1993; Müller et al. 1993b, Stürmer 1993; Wozasek et al. 1994; Leunig and Hertel 1996; Kröpfl et al. 1997). Reaming of the femoral nail results in increased intramedullary pressure from 70 mmHg during unreamed nailing to 200-600 mmHg during reamed nailing and increased embolization (Martin et al. 1996) measured by echocardiography of the inferior vena cava and the right atrium (Wenda et al. 1993). The effect is increased by blunt reamer tips (Müller, Rahn, Pfister 1992; Müller et al. 1993a; Muller et al. 1993b; Müller et al 1993c; Müller et al 1994; Müller et al. 1998; Müller et al. 2000).

Fat particles and bone debris are pressed extraosseally through the fracture. In tibia, intramedullary nailing has increased temporarily the pressure in the adjacent compartments, the perfusion of the surrounding muscles and muscle blood flow (Schemitsch, Kowalski, Swiontkowski 1996; Hupel, Aksenov, Schemitsch 1998) and the excretion of the urinary metabolites of prostacyclin and thromboxane (Lindström 1999). Unreamed nailing, where the nail is inserted gently, avoids high pressure peaks (Heim, Schlegel, Perren 1993; Heim et al. 1995) and has been advocated as a method to reduce *bone* *marrow embolization to the lungs* (Pape et al. 1993c) and the rate of infection after open fractures (Canadian Orthopaedic Trauma Society 2003). Pulmonary capillary permeability is increased by the release of various mediators due to triclycerides, and other marrow elements (Pape et al. 1993a; Pape et al. 1993b; Wenda et al. 1993; Pape et al. 1994). Embolization may trigger the development of ARDS.

Other reported effects of reaming have been an increased *consumption of coagulation factors* (Pape et al. 1998; Robinson et al. 2001) *and an increased risk of infection* in open fractures (Canadian Orthopaedic Trauma Society 2003). Although unreamed nailing is preferred in the treatment of femoral shaft fractures in multiply injured patients (Pape et al. 1994; Pape et al. 1999b; Pape et al. 2002; Pape et al. 2004), reaming is in general still recommended (Goris et al. 1982; Winquist, Hansen, Clawson 1984; Dabezies and D'Ambrozia 1986; Lozman et al. 1986; Brumback et al. 1988a; Bråten, Terjesen, Rossvoll 1995; Grover and Wiss 1995; Williams et al. 1995; Bucholz and Brumback 1996; Brumback and Virkus 2000; Canadian Orthopaedic Trauma Society 2003).

Reaming of the canal deposits at the fracture site increases the amount of cortical bone fragments and marrow elements, which are thought to have *osteoinductive properties* (Kessler et al. 1986; Paley et al. 1986; Mizuno et al. 1990; Einhorn 1995; Furlong, Giannoudis, Smith 1997; Chapman 1998). Even though no biologic effect from the reaming has been ascertained (Reichert, MCCarthy, Hughes 1995), intensive new-bone formation around the reaming effluent, seen both on histological sections and on radiographs, has been described (Grundnes, Utvag, Reikerås 1994a; Grundnes, Utvag, Reikerås 1994b). Unreamed nailing has been associated with lower rates of fracture healing. However, good results after femoral nailing without reaming have been demonstrated as well (Kröpfl et al. 1995; Krettek et al. 1996). Recent studies have yielded contradictory results in the use of small diameter nails, with the average nail diameter of 10 mm, without reaming (Boyer et al. 1996; Tornetta and Tiburzi 1997; Hammacher, van Meeteren, van der Werken 1998; Tornetta and Tiburzi 2000, Canadian Orthopaedic Trauma Society 2003).

Intramedullary reaming enhances a greater fracture stability with a larger nail (Kessler et al. 1986; Reikerås, Skjeldal, Grogaard 1989). A tightly fit nail induces a greater periosteal reaction (Grundnes and Reikerås 1994). Concerning the *effect of rotational stability* or stiffness (Mølster 1985; Wang et al. 1985; Mølster et al. 1987) or thickness (Anderson, Gilmer, Tooms 1962; Reikerås 1990) of the intramedullary nail on fracture healing of a long bone, stress in the rat femur was reduced with stable intramedullary nails (Mølster 1985). Interlocking nailing controlled femoral length and rotation without the risks of tissue devitalization, quadriceps scarring, blood loss, and infection from plate fixation. Interlocking intramedullary nail (Kempf, Grosse, Beck 1985; Bhandari et al. 2005) enables treatment of the more severe degrees of comminution of the shaft. The treatment choice is influenced by the analysis of the type of the fracture, the nature of the fracture, and by the patient (age, functional demands), as well as the environment, and the skill of the surgeon (Bucholz and Brumback 1996). In simple midshaft fractures, large-diameter nails that fill the medullary cavity automatically rectify the normal alignment of the femur. Similar restoration of the anatomic length and alignment is possible with comminuted fractures, and those proximal or distal to the midshaft with higher technical precision

(Bucholz and Brumback 1996). Only severely comminuted and distal fractures may require protected weightbearing during the early stages of fracture healing. Nails allow cyclic compressive loading across the fracture site, which improves callus formation and remodeling.

Specialized instrumentation and radiographic facilities are needed in *closed intramedullary nailing*, where the fracture is reduced by external manipulation and the nail is inserted through the end of the bone without damage to the periosteal vasculature (Chapman 1996). Because the fracture hematoma is not evacuated with closed nailing, the early action of local cellular and humeral agents critical to normal fracture healing is not disturbed. The lesser surgical dissection indicates a lower infection rate and less quadriceps scarring (Bucholz and Brumback 1996). After closed nailing, shaft fractures predictably heal with abundant callus formation and little or no osteopenia of the major fracture fragments. Owing to the greater diameter of the callus and the neocortex at the fracture site, the strength of the bone may actually be greater than normal.

In *open nailing*, where fracture site is opened directly through the surrounding muscles to achieve reduction and insertion of the nail, the nailing is faster and does not always require visualization by fluoroscopy, but also predisposes the fracture site to possible nonunion by increasing the infection rate and decreasing the blood supply to the fracture (Chapman 1996).

Dynamic nailing has been recommended in simple fractures of the femoral shaft (Yamaji et al. 2002). Biomechanical studies have demonstrated that there is no significant difference in the torsional rigidity or axial load to failure when one, as opposed to two, distal 6 mm screw is used with slotted nails for midshaft or proximal fractures (Hajek et al. 1993). Limited clinical studies confirm the adequacy of a single locking screw for most proximal and midshaft injuries, although migration of the simple distal locking screw can occur (Hajek et al. 1993). For comminuted fractures, a certain type of interlocking is used depending on the fracture morphology (Winquist, Hansen, Clawson 1984). Most locking nails have a cloverleaf cross-sectional design with one proximal hole and two distal holes for locking of the major fracture fragments. Transfixation screws are inserted under radiographic control. Screws in the proximal hole or the distal holes alone yield a “dynamic” fixation for fractures with potential instability of axial compression and rotation. Static locking with screws in both proximal and distal fragments is indicated in fractures in which both shortening and malrotation are possible (Bucholz and Brumback 1996). Locking of the fracture fragments to the nail appears to have no deleterious effect on the rapid healing that is evident after simple Küntscher nailing. Routine static locking of all fractures eliminates postoperative loss of fixation secondary to unrecognized fracture comminution, which occasionally occurs after unlocked nailing (Bucholz and Brumback 1996). The clinical outcome has been similar regardless of which interlocking nailing system is used (Cameron et al. 1992). While a single screw may not provide adequate stabilization of distal-third fractures (Bucholz and Brumback 1996), the Brooker-Wills distal locking fins were equally inadequate and provided insufficient resistance to axial compression (Bankston, Keating, Saha 1992). The use of two distal locking screws with titanium intramedullary nails has been recommended (Im and Shin 2002).

The goals of interlocking nailing of femoral fractures are not so much to influence the normal cascade of fracture healing as to provide a stable nail-bone construct during the healing process. Interlocking nails were suited to handle severe fracture comminution, bone loss, and a proximal or distal fracture level of open fractures (Wiss et al. 1986; Johnson and Greenberg 1987). The biomechanical demands concerning the intramedullary nail depend on e.g. fracture location and comminution, patient size, and bone morphology (Bucholz and Brumback 1996). Simple transverse and short oblique midshaft fractures without associated fractures or soft-tissue injuries have been recommended to be treated by closed interlocking nailing (Bucholz and Brumback 1996). Standard cloverleaf nails have been found to be contraindicated for type III and type IV comminuted fractures due to the risk of fracture shortening around the nail. Small-diameter nails fail to fill the canal, allowing even type I and type II comminuted fractures to telescope around the nail. Before interlocking nails, standard cloverleaf nails supplemented with a minimum of two cerclage wirings of major cortical fragments were widely used for comminuted fractures (Bucholz and Brumback 1996) or for spiral or long oblique fractures (Dencker 1963). The treatment resulted in slow healing observed after open intramedullary nailing, and possible disruption of the fracture hematoma by cerclage. The clinical results with cerclage wiring are satisfactory, and inferior to those of closed static intramedullary nailing (Wu et al. 1993). Static locking of the major fracture fragments prevents postoperative shortening and malrotation. The results of interlocking nailing have been good (Johnson, Johnston, Parker 1984; Thoresen et al. 1985; Wu and Shih 1991).

The antegrade insertion of intramedullary nails can result in iatrogenic bursting of either the proximal or distal fracture fragments. The average antecurvature of the femoral shaft in an adult has a radius of curvature of about 110 cm (Harper and Carson 1987). Interlocking nails are prebent, but differences between the curvature of the nail and of the femur develop stresses in the femoral canal during nail insertion if the canal is not overreamed (Bucholz and Brumback 1996). The entrance portal should be located in line with the longitudinal axis of the femoral canal. An anterior starting hole in front of the piriformis fossa results in distortion of the nail and increased stress within the canal (Tencer, Sherman, Johnson 1985; Johnson, Tencer, Sherman 1987). An excessively lateral entrance portal can cause eccentric placement of the nail and medial comminution of the proximal fracture fragment (Bucholz and Brumback 1996).

A fractured femur fixed with a standard intramedullary nail of 12 to 14 mm in diameter is 50% to 70% as stiff as an intact femur in bending (Johnson et al. 1986), regardless of the nail design. With static interlocking, the nail fails at about four times body weight (Johnson et al. 1986). If the load is exceeded, proximal screw cuts out through the trochanter, or the nail bends at the fracture site. The Brooker-Wills interlocking nail has failed at a lower load of 1.5 times body weight by the distal fins cutting through the metaphyseal bone. The torsional stiffness of the nail is much less than that of the intact femur, with slotted nails being only 3% as stiff and nonslotted nails about 50% as stiff (Bucholz and Brumback 1996). The torsional flexibility of interlocking nails does not lead to rotational instability of the fracture despite the spring-back effect caused by interlocking the major fracture fragments (Bucholz and Brumback 1996).

The presence of a longitudinal slot, beginning at the distal end of the nail and extending to or within a few centimeters of the proximal tip, permits elastic impingement of the compressed nail on the endosteal surface of the bone (Bucholz and Brumback 1996). This minimizes malrotation and shortening of the fracture (Küntscher 1967). The slotted nail reduces the torsional stiffness by 15- to 20-fold compared with the nonslotted nail (Tencer et al. 1984), lowers the fatigue strength of the nail (Allen et al. 1968), and decreases the amount of metal around the locking screw holes. Thickening the wall of slotted nails can weaken the beneficial effects, but also diminish the elastic impingement of the nail on the proximal and distal fracture fragments. Close-section nonslotted nails increase the amount of metal around the screw holes lessening the risk of metal fatigue fracture. By varying the wall thickness, the bending stiffness of nonslotted nails can be changed to mimic that of slotted nails, particularly in the elderly patients in whom large-diameter nails are used (Alho et al. 1992).

Fixation stability concerning compression and rotation also diminishes, when the fracture is located in a distance proximal or distal to the isthmus of the medullary canal. Fracture angulation into varus or valgus is possible during surgery in eccentric nail insertion out of alignment with the longitudinal axis of the canal. Subtrochanteric and high proximal-third fractures are subjected to major muscular forces and high concentrations of tensile forces along the lateral cortex (Scheuba 1970). Supracondylar fractures have similar load concentrations in both the sagittal and frontal planes. Infraisthmal fractures include most distal third shaft fractures (Bucholz and Brumback 1996). Major loading of this region of the femur results in a higher nonunion rate with interlocking nails than seen in midshaft fractures (Bucholz and Brumback 1996).

2.12.7.2. Technique of intramedullary nailing of femoral shaft fractures and aftertreatment

Intramedullary nailing of fresh femoral shaft fractures can be performed with the patient in either the supine or lateral position on the fracture table (Acker, Murphy, D'Ambrosia 1985; McFerran and Johnson 1992; Baumgärtel et al. 1994), with a traction applied through the proximal tibial or distal femoral pin, with the knee bent 60º and in internal rotation of 10º-15º. The supine position is preferable in patients with multiple injuries, especially when associated with pulmonary injury, unstable spine or pelvic fractures, or contralateral femoral fracture, or in case of second-generation nails. The disadvantages include a limited entrance portal of the nail in the trochanteric fossa, a possibility of varus angulation of proximal third fractures, and a long incision needed for obese patients. Lateral position allows an easier entrance portal, while presenting problems in rotatory malalignment (Bucholz and Brumback 1996). Intramedullary nailing without a fracture table (Wolinsky et al. 1999) with the use of a distractor (Baumgärtel et al. 1994; McFerran and Johnson 1992) or manual traction (Stephen et al. 2002) has also been recommended.

From the lateral incision, extending from 1 cm distal to the tip of the greater trochanter superiorly for 8 to 10 cm, the fascia lata and the fibers of gluteus maximus are divided in line with the skin incision. The gluteus medius and minimus are freed from the underlying hip capsule. From the trochanteric or piriformis fossa, the awl is inserted and initial reaming is performed with the 6 to 9 mm reamers, after the bulb-tipped guide pin has passed into the medullary canal of the distal fragment at the intercondylar notch. A small-diameter Küntscher nail can be placed into a previously reamed proximal fragment.

In fractures of the distal third of the shaft, the distal fragment angles posteriorly and must be supported in the supine position (Bucholz and Brumback 1996). In the lateral position, the distal fragment sags into the valgus position. After the length of the possible nail is measured, flexible reamers starting with the 9 mm end-cutting reamer are used to enlarge the medullary canal. Proceeding at 0.5 mm increments, until endosteal cortical contact of the reaming heads over a segment of 2 to 3cm of both the proximal and distal fragments is achieved, the canal is overreamed at least 0.5 mm for simple cloverleaf nails, and 1 mm for interlocking nails, to avoid incarceration of the nail or iatrogenic comminution of the fracture (Bucholz and Brumback 1996). Distal third fractures especially require at minimum 1 mm to 1.5 mm overreaming of the proximal fragment. It has been documented that the cylindrical AO reamer design can occlude the canal resulting in a significant increase in pulmonary artery pressure and pulmonary capillary permeability damage compared with other reamers (Pape et al. 1994). The 3 mm bulb-tipped guidewire is exchanged to the 4 mm straight guide pin through a plastic medullary tube and the nail is driven into the proximal fragment (Bucholz and Brumback 1996).

Locking screws are indicated in Winquist-Hansen Grade III and Grade IV comminuted fractures, segmental oblique and comminuted, in long spiral, in proximal or distal oblique or comminuted fractures (Winquist, Hansen, Clawson 1984). Transverse midshaft fractures are considered appropriate for nailing without static locking of the major fracture fragments (Bucholz and Brumback 1996). Several targeting techniques (Granhed 1998) and hand-held targeting devices for inserting the distal locking screws have been introduced (Hansen and Winquist 1978; Medoff 1986; Levin, Schoen, Browner 1987; Blumberg et al. 1990; Coetzee and van der Merwe 1992), or a free-hand technique is used (Bucholz and Brumback 1996). After closed femoral nailing, a major advantage of interlocking nails is the relatively pain-free mobilization possible even with highly comminuted fractures (Bucholz and Brumback 1996). Dynamically locked nails with equivocal purchase on the unlocked fragment may need protection against malrotation until the patient’s muscle tone and strength return.

Quadriceps-strengthening exercises and progressive weightbearing are instructed. Weightbearing is delayed only in patients with very proximal or distal fractures that are at risk for implant fatigue failure, and in patients with ipsilateral extremity injuries, such as knee ligament tears (Bucholz and Brumback 1996). Full range of motion of the knee can be expected in 4 to 6 weeks after a simple nailing. Serial radiographs at 1, 3, 6, and 12 months after nailing should be obtained until fracture healing and remodeling are achieved and verified. Dynamization of the statically locked nail by removal of the screws farthest from the fracture has rarely been indicated, except in cases of delayed healing 3 to 4 months after injury (Brumback et al. 1988a; Brumback et al. 1988b). According to a previous report, significant axial femoral shortening has resulted from dynamization (Wu 1997). Routine nail removal is not mandatory (Miller et al. 1992). In young patients, the nail can be removed 1 to 2 years after injury if fracture remodeling has proceeded normally (Bucholz and Brumback 1996). Clinically important ($p=0.025$) bone loss measured by volumetric bone mineral density has been reported in the proximal femur of the fractured limb at the time of intramedullary nail removal (Kröger et al. 2002). No protection in the form of casts or delayed weightbearing is necessary after nail extraction (Brumback et al. 1992b).

In the elderly patients, the osteopenic cortical bone is often comminuted despite the low-velocity mechanism of injury (Moran, Gibson, Gross 1990), and rigid intramedullary fixation is recommended to allow full weightbearing on the leg (Hubbard 1974; Moran, Gibson, Gross 1990; Alho, Ekeland, Strømsøe 1992). On the other hand, a large, stiff nail can create a stress riser effect in the proximal femur, and thus predispose to subsequent femoral neck or peritrochanteric fractures (Moran, Gibson, Gross 1990).

The multiply injured patient with an open femoral fracture should be treated with immediate stabilization. Open fractures of the femoral shaft due to high energy accidents are frequently accompanied by injuries to multiple organ systems (Anderson and Gustilo 1980; Chapman 1980; Chapman 1986). Before the 1980s, closed intramedullary nailing was not commonly performed for open femoral fractures (Chapman and Mahoney 1979; Lhowe and Hansen 1988; Brumback et al. 1989). Delayed intramedullary nailing 5 to 7 days after wound closure, allowing the immune system to control existing fracture-site contamination in grade I and grade II fractures, was used (Chapman 1986). Immediate stabilization in grade I and II open injuries has been proved to be a safe technique (Winquist, Hansen, Clawson 1984), the prevalence of infection being 2% (Winquist, Hansen, Clawson 1984; Lhowe and Hansen 1988; Brumback et al. 1989; O'Brien et al. 1991; Grosse et al. 1993). The Gustilo classification categorizes any open fracture in which debridement is delayed for more than 8 hours as a grade III open fracture, where immediate intramedullary nailing has been contraindicated (Brumback et al. 1989). Farm accidents, gunshot blasts and explosions are considered grade IIIB open fractures, and they have high rates of infection, regardless of the method of fracture fixation (Chapman 1986). Grade IIIA open fracture can be safely treated with immediate intramedullary nailing, if the debridement is performed within 8 hours of injury. If the debridement is delayed, or if a grade IIIB injury is present, then external fixation and delayed conversion of external fixation to intramedullary nailing may be used for open femoral fractures. In patients without multiple injuries, grade IIIA and selected grade IIIB open femoral shaft fractures can be placed in temporary skeletal traction. Delayed intramedullary nailing is performed 5 to 7 days after soft-tissue coverage. Isolated open fractures with severe contamination require external fixation (Bucholz and Brumback 1996). Grade IIIB femoral shaft fractures with bone loss have also been treated successfully with primary interlocking intramedullary nailing and additional bone grafting (Court-Brown and Browner 1996; Court-Brown, Masquelet, Schenk 2002). Grade IIIC fractures require arterial lesion repair along the attachment of external fixation. After revascularization of the limb, this can be converted to intramedullary nailing even on the day of injury. The nailing is performed through a standard antegrade approach on a fracture table. Bone grafting is not necessary despite the loss of small devitalized cortical fragments from the injury and debridement (Brumback et al 1989).

The fixation of concomitant femoral neck fractures can be antegrade intramedullary nailing of the femoral shaft fracture combined with multiple pin or screw fixation of the femoral neck fracture (Wiss, Sima, Brien 1992; Bennett, Zinar, Kilgus 1993; Leung et al. 1993), or the second generation interlocking nail (femoral reconstruction nail) (Alho 1997).

The treatment methods of floating knee have varied (Blake and McBryde 1975; Karlström and Olerud 1977; DeLee 1979; Grana et al. 1984; Veith, Winquist, Hansen 1984; Klemm and Börner 1986; Behr et al. 1987; Schieldts et al. 1996; Lobenhoffer, Krettek, Tscherne 1997; Ostrum 2000; Arslan et al. 2003; Rios et al. 2004). At present, the most convenient treatment according to literature seems to be to stabilize both fractures through a single incision with retrograde intramedullary nailing of the femoral shaft and antegrade nailing of the tibia (Ostrum 2000; Rios et al. 2004).

2.13. Outcome and complications of the treatment of femoral shaft fractures

2.13.1. Fracture union

The goals of all fracture management are an acceptable and lasting functional recovery within a reasonable time considering the severity of the injury (Böstman et al. 1989), the degree of anatomic restoration and the duration of the bony consolidation (Stappaerts et al. 1986).

A femoral shaft fracture in adults is typically an injury of working age people (Kootstra 1973). Since the median value for the union time of this fracture lies between 12 and 18 weeks in most of the clinical reports, the financial and personal losses are considerable even with an uncomplicated healing course. Moreover, delayed union can complicate the healing of the fracture. The frequency of complications as well as the functional result are associated with the primary severity of the injury, and the choice of the method of treatment.

The rate of union has been 97-100% in closed fractures treated with traction (Buxton 1981). With cast bracing the fracture union rate of femoral shaft fractures has been 13 to 14 weeks from injury (Mooney et al. 1970; Hardy 1983; McIvor et al. 1984; Mooney and Claudi 1984; Sharma et al. 1993).

The overall fracture union rate has been 90% to 95% with plate fixation (Magerl et al. 1979; Rüedi and Lüscher 1979; Sprenger 1983) and fracture union has occurred at an average of 17.2 weeks (Riemer et al. 1992). Most series of interlocking nailing report a 97% to 100% rate of union (Warmbrod, Yelton, Weiss 1976; Klemm and Börner 1986; Wiss et al. 1986; Christie et al. 1988; Alho, Strømsøe, Ekeland 1991). Midshaft fractures of the femur have healed clinically and radiographically within 12 to 24 weeks after standard closed nailing (Stambough, Hopson, Cheeks 1991; Anastopoulos et al. 1993). However, uneventful healing course without delay and an acceptable restoration of the femur have been ascertained in 75% of patients with femoral shaft fractures treated with plate fixation or intramedullary nailing (Böstman et al. 1989). Other authors that have reported union rates approaching 100%, although some complications have been reported (Kempf, Grosse, Beck 1985; Johnson and Greenberg 1987; Bergman et al. 1993).

The mean time for femoral shaft fracture healing has been less than 16 weeks without reaming (Kröpfl et al. 1995; Krettek et al. 1996; Tornetta and Tiburzi 2000), but also more than 36 weeks for 57%, compared with 18% for those that had reaming (Clatworthy et al. 1998). In other retrospective studies, no difference in nonunion or time to union between reamed and nonreamed groups has emerged (Giannoudis et al. 1997; Reynders and Broos 2000).

The union rate has been 93.3-100%, when external fixation was exchanged into reamed intramedullary nailing 7-15 days after the initial procedure (Wu and Shih 1991; Höntsch et al. 1993; Nowotarski et al. 2000).

2.13.2. Complications

Most of the patients who sustain femoral shaft fractures are young, and any complication can have long-term effects. Complications necessitating prolonged time for recovery and secondary surgery imply considerable personal and financial losses, even if the ultimate radiographic and functional result would turn out satisfactory (Kootstra 1973; Böstman et al. 1989). Historically, permanent disability has followed femoral shaft fractures in 25% of the adult patients (Kootstra 1973).

Undesirable results has been related to intramedullary nailing by open technique (Kamdar and Arden 1974, Lozman et al. 1986), open nailing with cerclage wiring (Johnson, Johnston, Parker 1984; Tscherne, Haas, Krettek 1986), and open reduction and plating of open femoral shaft fractures (Magerl et al. 1979; Rittman et al. 1979; Rüedi and Lüscher 1979; Bach and Hansen 1989; Green and Trafton 1991), or certain concomitant injuries such as floating knee (Hee et al. 2001).

Mortality has varied from 0.2% related to pulmonary embolism after intramedullary nailing or pneumonia after plate fixation of a femoral shaft fractures to 2.2% due to fat embolism during traction treatment (Dencker 1963). Bilateral femoral fractures indicate severe systemic and local injuries (Wu and Shih 1992a) and are in polytraumatized patients associated with a higher mortality rate (Copeland et al. 1998).

Respiratory failure secondary to ARDS, fat embolism (Müller, Rahn, Pfister 1992, Müller et al. 1993a; Müller et al. 1993b; Müller et al. 1993c; Müller et al. 1994), pulmonary embolism, or pneumonia develops in 2-3% of patients sustaining a single femoral fracture without other injuries (ten Duis 1997; Hofmann, Huemer, Salzer 1998), and in 10-75% of patients with associated injuries depending on the surgical management (Johnson, Cadambi, Seibert 1985; Pape et al. 1993a; Charash, Fabian, Croce 1994; Bosse et al. 1997). Bone marrow fat and inflammatory mediators are embolized to the lungs following a femoral shaft fracture due to the movement of fracture fragments (Hauser et al. 1997). The effect is decreased by fracture fixation (Riska et al. 1977; Johnson, Cadambi, Seibert 1985; Lozman et al. 1986). The mechanical effect of embolic capillary obstruction is accompanied by the biochemical effect of alveolar-capillary membrane damage by the mediator-activated neutrophils (Hofmann, Huemer, Salzer 1998; Hauser et al. 1999; Robinson 2001; Giannoudis et al. 2002b) with increased levels of elastase and interleucin-6

(Giannoudis et al. 1999; Pape et al. 2000; Pape et al. 2003). Femoral fracture induces site-specific changes in T-cell immunity (Buzdon et al. 1999). Intramedullary nailing has shown to result in impairment of immune reactivity (Smith et al. 2000).

The importance of intramedullary reaming in the development of *ARDS* has been remarkable (Pape et al. 1995) or negligible (Bosse et al. 1997; Norris et al. 2001). Simultaneous intramedullary nailing of bilateral femoral shaft fractures has been considered a safe procedure (Bonnevialle et al. 2000) or questionable (Kerr, Jackson, Atkins 1993; Giannoudis et al. 1998; Pape et al. 1999a; Giannoudis et al. 2000). The probability for respiratory failure increases in multiple intramedullary nailing procedures to 33%, in thoracic injuries (Pape et al. 1993a; Pape et al. 1993b; Pape et al. 1995; Bosse et al. 1997) to 79%, and in both to 95% (Zalavras et al. 2005). Pulmonary complications are related to the severity of injury and not the timing of surgery (Reynolds et al. 1995; Zalavras et al. 2005).

Fat embolism occurs in 2% to 23% of patients with isolated femoral shaft fractures and in a substantially higher proportion of victims of polytrauma. Floating knee has a high risk of fat embolism (13%) (Veith, Winquist, Hansen 1984; Schieldts et al. 1996).

The distribution of *thromboembolic complications* has varied from 5% (Dencker 1963) to 10% (Suiter and Bianco 1971), and, in elderly subgroups, 25 % (Kootstra 1973). Volkmann's contracture can also be associated with a femoral shaft fracture (Grosz et al. 1973).

Most of the problems associated with the treatment of femoral shaft fractures are bone related (Böstman et al. 1989). Unsatisfactory results are due to technical errors or iatrogenic complications (Böstman et al. 1989). The overall frequency of *local complications,* including malunions in femoral shaft fractures treated with internal fixation, has been 24% (Böstman et al. 1989) ranging from 5% (Schwarzkopf, Kirschner, Ahlers 1981; Winquist, Hansen, Clawson 1984; Leighton et al. 1986) to 19% of cases (Böstman et al. 1989) in intramedullary nailing with an increased (Green, Larson, Moore 1987), decreased (Leighton et al. 1986), or indifferent (Böstman et al. 1989) complication rate related to open nailing. Reoperations have been needed in 6% of cases (Böstman et al. 1989). In plate fixation, the rate of local complications has varied from 10% (Cheng, Tse, Chow 1985; Thompson et al. 1985; Gärtner and Rudolph 1987) to 24% (Roberts 1977; Magerl et al. 1979; Rüedi and Lüscher 1979; Loomer, Meek, DeSommer 1980) and 36% of cases (Böstman et al. 1989). Reoperations had to be performed in 25% of cases (Böstman et al. 1989).

Local complications have been more frequent among patients 65 years old or older (39%) probably because of decreased density of bone resulting in mechanical failures of fixation and because of diminished circulation with subsequently compromised infection resistance and tissue repair capacity in the lower extremities (Böstman et al. 1989); with segmental comminuted fractures (38% versus 16% in the non-comminuted fractures treated with intramedullary nailing, and 67% versus 25% in the non-comminuted fractures treated with a dynamic compression plate). As a result, it has been recommended to avoid intraoperative additional splitting of the femur (Böstman et al. 1989) or to perform primary cancellous bone grafting of the comminuted medial femoral cortex (Sprenger 1983; Müller et al. 1991) especially with the fixation with a dynamic compression plate (DCP) (Johnson and Greenberg 1987) and with the presence of concurrent lower extremity fractures (Böstman et al. 1989).

Adult patients are fortunately devoid of avascular necrosis of the femoral head seen in adolescents following intramedullary nailing of the femur through the piriformis fossa due to injury to the branch of the medial circumflex artery (Mileski, Garvin, Crosby 1994).

Acute compartment syndrome (Moore, Garfin, Hargens 1987) is relatively infrequent due to the capacity of the three compartments of the thigh to accommodate substantially higher blood volumes compared with those of the lower leg and the forearm. Severe bleeding into one or more compartments of the thigh is necessary to elevate the compartment pressure above the critical level (Tarlow et al. 1986).

As a traction complication in intramedullary nailing of bilateral femoral fractures delayed *perineal sloughing* needing urethroplasty has been reported (Callanan, Choudhry, Smith 1994).

Nerve injuries include the common peroneal nerve (due to compression against the proximal fibula during skeletal traction), pudendal and femoral nerves (due to compression by unpadded post of the fracture table caused by excessive traction during intramedullary nailing) (Kruger et al. 1990; Brumback et al. 1992a). The prevalence of the sciatic nerve injury complication has been 0.4% and for the peroneal nerve 2% (Dencker 1963).

The rate of *heterotopic ossification* in the abductor region of the hip after reaming and intramedullary nailing of femoral shaft fractures has either been low (Küntscher 1967; Winquist, Hansen, Clawson 1984; Wiss et al. 1986; Johnson and Greenberg 1987; Wiss, Brien, Stetson 1990; Steinberg and Hubbard 1993), around the proximal tip of the nail in up to 20% of cases of closed nailing (Marks, Paley, Kellam 1988; Miller et al. 1992; Steinberg and Hubbard 1993), or as high as 68% (Brumback et al. 1990), probably due to the procedure itself (Marks, Paley, Kellam 1988; Brumback et al. 1990; Steinberg and Hubbard 1993). Range of motion of the hip has decreased (Coventry and Scanlon 1981) in 5% of cases (Marks, Paley and Kellam 1988) to 11 % of cases (Brumback et al. 1990). Küntscher suggested that heterotopic ossification was due to the prominence of the proximal part of the nail, significant hematoma, and some osteogenic factor which is transferred via the medullary nail over a long distance (Küntscher 1967). Most authors have agreed that the formation of heterotopic bone depends on local or systemic factors (Chalmers, Gray, Rush 1975). Reported local factors include transformation of local cells to osteoprogenitor cells (Puzas and Miller 1989); osteogenic reaming (Brumback et al. 1990); anatomic location (Kewalramani 1977); trauma to the gluteus muscle during reaming (Burwell 1971; Paley et al. 1986) or during a posterior or a transtrochanteric approach (Vicar and Coleman 1984); soft-tissue injury or concomitant trauma of a joint (Garland, Blum, Waters 1980); hematoma formation, foreign bodies, and immobilization. Possible systemic factors include head injury (Steinberg and Hubbard 1993), spinal injury, multiple trauma, infection, ISS (Baker et al. 1974), or ventilator and intensive care unit days, or delay to surgery (Steinberg and Hubbard 1973; Marks, Paley, Kellam 1988); male gender (Steinberg and Hubbard 1973); or diffuse idiopathic skeletal hyperostosis, hypertrophic osteoarthritis, and ankylosing spondylitis (Kewalramani 1977). Otherwise, no correlation between the degree of heterotopic ossification and the age or gender of patient, injury severity, presence or absence of closed intracranial injury, level or type of comminution of fracture, timing of nailing, or type of intramedullary fixation, or proximal prominence of nail has been reported (Brumback et al. 1990). Absence of reflex-protective mechanisms, presence of spasticity, or muscle injury have been proposed as causative factors (Bucholz and Brumback 1996). Different classifications of heterotopic ossification have been based on the distance of ossification on the ilium and the greater trochanter (Brooker et al. 1973; Marks, Paley, Kellam 1988; Brumback et al. 1990).

The overall prevalence of *infection* has been 3% and of osteomyelitis 0.4%. The most common causative organisms for postoperative infection are Staphylococcus aureus, Staphylococcus epidermidis, and Enterococcus (Böstman et al. 1989). The prevalence of infection is related to the technique of fracture treatment and has earlier been 6% in operations of closed fractures (Dencker 1963). The overall infection rate after intramedullary nailing has been 4% (Whittle and Wood 2003), 1.7% to 9%-12% after open intramedullary nail insertion (Burwell 1971; Kovacs, Richard, Miller 1973; Kamdar and Arden 1974; Warmbrod, Yelton and Weiss 1976; Jenkins, Lewis, Downes 1978; Hansen and Winquist 1979; Singer and Seligson 1990) and 14% after open non-interlocking intramedullary nailing with additional cerclage wiring (Johnson, Johnston, Parker 1984). In a total of 1950 femoral shaft fractures treated by open nailing, the deep infection rate averaged 3.5% of the cases (Chapman 1996). In closed nailing, the infection rate has been lower (Harper 1985; Leighton et al. 1986; Schatzker 1980; Whittaker et al. 1982), varying from 0% (Rothwell and Fitzpatrick 1978; Rothwell 1982; Johnson, Johnston, Parker 1984; Wiss et al. 1986) to 0.5% (Winquist and Hansen 1980) or to 0.8%-0.9% (King and Rush 1981; Esser, Cloke, Hart 1982; Winquist, Hansen, Clawson 1984) or to 2-5% (Dencker 1963). In an accumulated experience of 1499 closed nailing procedures of femoral shaft fractures with different nail types, the infection rate has been 0.4% (Chapman 1996). The infection prevalence has been 9% with the traction through the distal part of femur (Dencker 1963). The rate of infection in plate fixation has varied from 0.7% to 11%, mainly 2-6% (Magerl et al. 1979; Rüedi and Lüscher 1979; Böstman et al. 1989) of the reported cases (Evans, Pedersen, Lissner 1951; Horwitz 1972; Rüedi and Lüscher 1979; Tarlow et al. 1986; Hanks, Foster, Cardea 1988; Leung et al. 1991; Moed and Watson 1995). Factors predisposing to infection can be: additional cerclage wiring in closed nailings of comminuted fractures (Partridge and Evans 1982; Tscherne, Haas, Krettek 1986; Johnson and Greenberg 1987), and fractures with gross contamination, exposed bone, and extensive soft-tissue necrosis (Grade IIIB) (Bucholz and Brumback 1996). Winquist and Hansen Grade I, II and IIIA open fractures can be safely nailed with a low risk of infection (Chapman and Mahoney 1979; Winquist, Hansen, Clawson 1984; Lhowe and Hansen 1988; Brumback et al. 1989). Osteomyelitis following femoral shaft nailing has occurred in 1.0-1.5% of cases (Strecker, Suger, Kinzl 1996). The risk of infection following intramedullary stabilization after external fixation has not been markedly greater than in definitive intramedullary nailing (Winkler et al. 1998): 0-14.3% (Wu and Shih 1991; Höntsch et al. 1993; Nowotarski et al. 2000). In external fixation, pin track infection has been detected even in 50% of the cases (Green 1982; DeBastiani, Aldegheri, Renzi Brivio 1984; Habboushe 1984; Broekhuizen 1988).

Technical errors occurred in Dencker's study of the treatment of femoral shaft fractures in 14% of the cases: most usually (in 5.4%) the nail was too short (Dencker 1963). Other causes for technical errors are the use of too thin nail, impaction, nail perforation through the proximal or distal fragment or into the knee joint, splitting the femur, and nailing in diastasis (Dencker 1963).

Failure of plate *fixation* has occurred in 5% to 10% of the reported cases (Jensen, Johansen, Morch 1977; Roberts 1977; Magerl et al. 1979; Rüedi and Lüscher 1979; Sprenger 1983; Riemer et al. 1992). The incidence of mechanical failure of fixation in intramedullary nailings and plate fixations has been 7.1%, including intraoperative additional splitting of the femur, osteoporotic bone in elderly patients, intraoperative iatrogenic fracture of the femoral neck in intramedullary nailing, and unstable nailing causing angulation (Böstman et al. 1989). Technical difficulties can be created by malalignment, eccentric reaming, pre-existing deformity of the femur, and previous nailing (Ebraheim and Paley 1993). Some intramedullary nail types, e.g. Brooker-Wills, have shown more technical intraoperative complications than others (Ebraheim and Paley 1993; Barrick and Mulhern 1990; Brumback et al. 1987; Hanks, Foster, Cardea 1988; Webb 1988).

Load-shielding implants, such as plates, are prone to failure more often than load-sharing implants, like nails (Böstman et al. 1989; Bucholz and Brumback 1996). The rate of uninfected early loosening of the plate has been 12% in the plated femoral shaft fractures (Böstman et al. 1989). Plastic deformation (bending) and fatigue failure after intramedullary nailing of the femoral shaft are usually associated with small-diameter nails of 10 mm or less (Soto-Hall and McCloy 1953; Hunter 1982; Franklin et al. 1988; Laforest et al. 1995; Ingman 2000; Canadian Orthopaedic Trauma Society 2003), with a nail insertion through a tight, narrow canal; or with loading of the leg before fracture union (Bucholz and Brumback 1996). Fatigue failure through the midportion of a standard, large-diameter (12 to 15 mm) nail, or a thick-walled, smaller-diameter nail, is rare. Deformation and breakage is more common at the proximal or distal ends of interlocking nails, and over-reaming of the medullary canal with using undersized interlocking nails (Bucholz and Brumback 1996), or nails having a proximal weld between the cylindrical and slotted portions (Franklin et al. 1998). Fatigue failure, usually at the most proximal of the two distal locking holes, can occur if fracture healing is delayed or early excessive loading is permitted in the proximal-third fractures (Bucholz and Brumback 1996). If a fracture is located within 5 cm of this hole, stresses are generated in the nail above its endurance limit (Bucholz, Ross, Lawrence 1987). Once fracture healing restores 50% of the normal stiffness of the distal femur, the stresses are diminished below that of the endurance limit of the nail. Infraisthmal fractures stabilized with interlocking nailing should be managed with delayed weightbearing until bridging callus is evident on radiographs (Bucholz and Brumback 1996). An angulated nail can be managed either by manipulation over the apex of the angle, by open transection of the nail, or using exchange nailing (Bucholz and Brumback 1996). Extraction of a bent nail after fracture healing may be impossible (Bucholz and Brumback 1996). According to Dencker, bending of the intramedullary nail occurred in 16% during the first two to four months after intramedullary nailing of femoral shaft fractures. The nail broke in 2% of treated femoral shaft fractures (Dencker 1963).

The rate of *refracture* of femoral shaft fractures without relevant retrauma is 1% (Böstman et al. 1989), or, in different populations, 2.4% - 12.5% (Hartmann and Brav 1954; Dencker 1963; Seimon 1964, Richon, Livio, Saegesser 1967, Kootstra 1973). Refracture can occur during the early phases of callus formation at the time of hardware removal (Bucholz and Brumback 1996). More than 75% of the refracture cases occur within the first 12 weeks of cast immobilization of the patient, especially during quadriceps exercises with limited knee motion (Seimon 1964). Premature plate removal (before the minimum of 18 months from the time of application) has caused refractures in 13% (Breederveld, Patka, van Mourik 1985). The generous callus envelope that develops after closed intramedullary nailing protects the fracture site from refracture after nail removal. Refracture at a different level has been reported with Zickel nails (Ovadia and Chess 1988). The risk of refracture after static intramedullary nailing is negligible (Brumback et al. 1992b), including a theoretic possibility of the locking screws acting as stress risers and of the static nail causing stress-shielding (Bucholz and Brumback 1996; Whittle and Wood 2003). A refracture after removal of a femoral plate is a known complication in nearly 10% of cases, especially if supplemental interfragmental lag screws are used for the initial internal fixation, due to cortical atrophy under the plate and the stress riser effect on the screw holes (Böstman 1990). According to bone density studies using computed tomography, the stress-reducing effect of static nails is small (Bråten et al. 1992). Refractures can be successfully managed by intramedullary nailing (Böstman et al. 1989).

If clinical union of the femoral shaft fracture has not taken place within 24 weeks of the accident, *delayed union* is considered to be present (Böstman et al. 1989). The rate of delayed union has been 1.6% (Böstman et al. 1989) and usually less than 5% (Dencker 1963; Bucholz and Brumback 1996). According to Dencker, delayed union was less common following traction (5%) or plate fixation (5%) than after intramedullary nailing or other open procedures as well as cerclage wiring (12-15%) in closed fractures (Dencker 1963). The prevalence of delayed union has been 6% in traction and 18% in intramedullary nailing of open femoral shaft fractures, and 18-21% in the treatment of comminuted fractures (Dencker 1963). However, delayed union has occurred in up to 30% of cases with traction possibly from continual distraction of the fracture site (Carr and Wingo 1973). Delayed union with plate fixation has needed bone grafting in 9% of cases (Rüedi and Lüscher 1979). In the study of the conservative treatment of tibial shaft fractures severe fracture comminution, smoking, severe compounding of the fracture, female gender, and high age of the patient lengthened the fracture union time (Kyrö 1998).

Nonunion can be defined as pain and motion at the fracture site, and radiographic persistence of a radiolucent line without progressive callus formation on three sequential radiographs following fracture fixation (Canadian Orthopaedic Trauma Society 2003). Nonunion signifies a condition which will not proceed to union without active measures (Böstman et al. 1989), and its reported frequency among femoral shaft fractures in uninfected cases has been from less than 1% (Winquist, Hansen, Clawson 1984), 1-2% (Strecker, Suger, Kinzl 1996) to 2.4% (Böstman et al. 1989) or 2-5% depending on the method used (Dencker 1963). The reported nonunion rate has been 14% with plating (Rüedi and Lüscher 1979), 0.8% with closed intramedullary nailing (Winquist and Hansen 1980), from 0% (necessitating dynamization in 0.2%) (Brumback et al. 1992b) to 4% with interlocking intramedullary nailing (Johnson, Johnston, Parker 1984), and 22% with open noninterlocking nailing and additional cerclage wiring for comminuted fractures (Johnson, Johnston, Parker 1984), which may constitute the worst of both techniques (Whittle and Wood 2003). In open fractures, the rate of nonunion has been in 3% when the fracture was treated with traction and 5% with intramedullary nailing (Dencker 1963). In an accumulated experience of 1499 closed nailing procedures of femoral shaft fractures with different nail types, the nonunion rate has been 1% (Chapman 1996). In a total of 1950 femoral shaft fractures treated by open nailing, the nonunion rate averaged 2.1% (Chapman 1996). The rates of nonunion and hardware failure have been higher in high proximal third and subtrochanteric fractures (Scheuba 1970). If a pseudarthrosis occurs or if the nail bends or breaks, it is primarily due to an incorrect size of the nail or otherwise unstable osteosynthesis (Küntscher 1958). The relative risk of nonunion has been 4.5 times greater without reaming and with the use of relatively small-diameter nails (Canadian Orthopaedic Trauma Society 2003).

Nonunion can be manifested as spontaneous breaking of the plate 4 to 8 months after fracture treatment (Böstman et al. 1989). Deficient bone healing may arise from insufficient blood supply at the fracture site, uncontrolled repetitive stress, or infection (Bucholz and Brumback 1996). Specific factors that may predispose to delayed union and nonunion include open fractures, extensive operative stripping of soft-tissues around the fracture site in plate fixation, inadequate fracture stabilization in dynamic intramedullary nailing, and diastasis between the fracture fragments in intramedullary nailing (Böstman et al. 1989; Bucholz and Brumback 1996). Treatment options include replating with cancellous bone grafting, or simple intramedullary nailing after nonunion related to plate fixation (Böstman et al. 1989); or renailing and cancellous bone grafting in nonunions following intramedullary nailing (Böstman et al. 1989); or an exchange reamed nailing with a larger diameter nail (Bucholz and Brumback 1996), performed in nearly 80% without exposing the nonunion site (Webb, Winquist, Hansen 1986); or, in cases of fracture diastasis after interlocking nailing, dynamization of a statically locked nail, bone grafting around the fracture gap, or exchange reamed nailing with a larger-diameter nail (Bucholz and Brumback 1996). Slight shortening of the extremity has been possible after dynamization, even after 6 months of static interlocking (Brumback et al. 1988b). Autogenous bone grafting (reaming of the canal used to supplement graft taken from the posterior iliac crest or the greater trochanter) is advisable after excision and open nailing of a synovial pseudarthrosis, but unnecessary after nailing in most cases of hypertrophic nonunion (Bucholz and Brumback 1996). In animal studies, an extensive exchange reaming and nailing has seemed favourable in nonunions of diaphyseal fractures (Utvag, Grundnes, Reikerås 1998c). Solid bony union rate with these treatment methods have varied from 95% (Webb, Winquist, Hansen 1986) to 100% (Böstman et al. 1989) within 7 to 18 months of the original accident and femoral fracture (Böstman et al. 1989).

A *malunion* has been observed in 9.8% of patients with femoral shaft fractures, and 35% of them might have another local complication as well (Böstman et al. 1989). The incidence of simple malunion without other local complications has been 6.3% (Böstman et al. 1989). Malunion commonly complicates treatment with traction or plaster immobilization. The rare malunion after internal fixation is caused by technical errors, such as fixation of the shaft in a malalignment (Bucholz and Brumback 1996) producing a simple type of malunion (Böstman et al. 1989). The rate of malunion has varied from 5% with closed intramedullary nailing (Winquist, Hansen, Clawson 1984) to 11% of the nailed and 6.9% of the plated femoral shaft fractures (Böstman et al. 1989). Malunion of a femoral shaft fracture can lead to abnormal gait, limb length discrepancy, and posttraumatic arthritis of the knee (Bucholz and Brumback 1996). Angulatory and longitudinal malunions have been documented more often (Winquist and Hansen 1978; Winquist and Hansen 1980; Rothwell 1982; Winquist, Hansen, Clawson 1984; Harper 1985; Kempf, Gross, Beck 1985; Huckstep 1986; Tscherne, Haas, Krettek 1986; Wiss et al. 1986; Hooper and Lyon 1988; Wiss, Brien, Stetson 1990; Wiss, Brien, Becker 1991; Wiss and Brien 1992; Bergman et al. 1993) than rotational (Winquist, Hansen, Clawson 1984; Harper 1985; Wiss et al. 1986; Wiss, Brien and Stetson 1990; Wiss, Brien, Becker 1991; Sharma et al. 1993), which may even be undocumented (Winquist and Hansen 1978; Bergman et al. 1993).

Previously, *femoral shortening* often followed from conservative treatment (Kootstra 1973), and later, more infrequently, dynamic or simple nailing of an unstable fracture pattern in oblique or comminuted femoral shaft fractures (Rokkanen et al. 1969; Clawson, Smith, Hansen 1971; Gillquist, Liljedahl, Rieger 1971; Rascher et al. 1972; Winquist, Hansen, Clawson 1984; Chadwick and Hayes 1988). The reported frequency of shortening has been 4.1% (Böstman et al. 1989). Shortening of up to 1 to 1.5 cm is compatible with good function, while in 1.3% of the fractures, shortening exceeds 2 cm (Böstman et al. 1989).

Angular malunion exceeds 15º in only 0.5% of the fractures (Böstman et al. 1989). An anterior bow is well compensated for by hip and knee motion, and better tolerated than a posterior bow or a lateral angulation (Bucholz and Brumback 1996). The frequency of posterior bowing has been 2.6% (Böstman et al. 1989) and valgus angulation 1.8% (Böstman et al. 1989).

Torsional malunion usually results from conservative treatment, but can be related to operative treatment independent of the method used, and also to simple as well as comminuted fractures (Ecke, Neubert, Neeb 1980; Mockwitz 1982; Wolf, Schauwecker, Tittel 1984; Wissing and Spira 1986; Sennerich et al. 1992), or to the presence of additional ipsilateral injuries complicating identification of rotation (Bråten, Terjesen, Rossvoll 1993). More torsional deformity has been described after intramedullary nailing than after plate fixation (Svenningsen, Nesse, Finsen 1986). In unlocked (Winquist, Hansen, Clawson 1984; Hooper and Lyon 1988) or dynamically locked nailings, malrotation can occur several times during the treatment course (Tornetta, Ritz, Kantor 1995) due in unlocked nails to the pull of the iliopsoas on the proximal fragment, operative malpositioning (Sennerich et al. 1992; Bråten, Terjesen, Rossvoll 1993), early postoperative rotation (Winquist, Hansen, Clawson 1984), inability to control rotation in unstable and proximal fracture patterns (Winquist, Hansen, Clawson 1984), and falling at home afterwards (Winquist, Hansen, Clawson 1984). The rate of rotational malunion seems to be extremely low after locked intramedullary nailing (Wissing and Spira 1984; Kempf, Grosse, Beck 1985; Wissing and Spira 1986; Johnson and Greenberg 1987; Dugdale, Degnan, Turen 1992; Wiss, Brien, Stetson 1990; Alho, Strømsøe, Ekeland 1991; Tornetta, Ritz, Kantor 1995), the only exception being the fractures that are dynamically inappropriately locked (Brumback et al. 1988a). The frequency of malrotation has been 1.8% including plate fixation and intramedullary nailing (Böstman et al. 1989). Wiss reported rotational malunion from 1% to 7% (Wiss et al. 1986; Wiss, Brien, Becker 1991). The overall incidence of malrotation exceeding 10º has been 3.6% (King and Rush 1981; Rothwell 1982; Hogh and Mikkelsen 1983; Winquist, Hansen, Clawson 1984; Harper 1985; Johnson, Cadambi, Seibert 1985; Kempf, Grosse, Beck 1985; Thoresen et al. 1985; Bone and Bucholz 1986; Klemm and Börner 1986; Wiss et al. 1986; Brumback et al. 1988a and. 1988b, Christie et al. 1988, Graham and Mackie 1988; Hanks, Foster, Cardea 1988; Hooper and Lyon 1988; Murphy et al. 1988).

Malrotation of the femur is accommodated to during gait (Tornetta, Ritz, Kantor 1995). An anteversion difference of 15º or more after femoral fracture can be regarded as a true torsional deformity (Bråten, Terjesen, Rossvoll 1992), although torsional deformity of less than 20º will not usually be a handicap (Sudmann 1973; Sennerich et al. 1992, Bråten, Terjesen, Rossvoll 1993). Side differences exceeding 30º will cause serious problems (Bråten, Terjesen, Rossvoll 1993). Depending on the diagnostic method, which can be clinical (Kempf, Grosse, Beck 1985; Thoresen et al 1985; Wiss et al 1986; Johnson and Greenberg 1987; Alho, Strømsøe, Ekeland 1991), biplanar method on radiographs (Dunlap et al. 1953; Rippstein 1955; König 1972; Sudmann 1973), ultrasound (Terjesen, Anda, Svenningsen 1990; Bråten, Terjesen, Rossvoll 1993), or computed tomography measurements (Weiner et al. 1978; Grote, Elgeti, Saure 1980; Wissing and Spira 1986; Murphy et al 1987; Høiseth, Reikerås, Fønstelein 1989, Lausten, Jørgensen, Boesen 1989; Sennerich et al. 1992), the frequency of rotational malunion of over 10º has varied from 7% (Wiss et al. 1986) to 30% (Wolf, Schauwecker, Tittel 1984) or 40% (Sennerich et al. 1992; Bråten, Terjesen, Rossvoll 1993), and of over 20º from 16% (Sennerich et al. 1992) to 21% (Sudmann 1973). Studied with computed tomography, the average malrotation of the fractured femur has been 16º (4-61º) and the median malrotation 14º in patients fully ambulatory for at least 6 months (Tornetta, Ritz, Kantor 1995). Furthermore, it has been observed that no significant relationship exists between a true torsional deformity (> 15º) and age or gender of the patient, fracture type or comminution, nail dimension, fracture level or length of follow-up (Bråten, Terjesen, Rossvoll 1993). Acute postoperative loss of rotational alignment has been reported (Winquist, Hansen, Clawson 1984; Harper 1985). A relatively high incidence has been noted with the use of unlocked intramedullary nails to stabilize comminuted fractures (Hooper and Lyon 1988). The determination of rotation of the femur during intramedullary nailing procedures can be difficult, particularly when the comminuted (Winquist-Hansen III or IV) fracture pattern does not lend itself to interdigitation (Tornetta, Ritz, Kantor 1995). Postoperatively, better tolerated external rotational deformity can follow intramedullary fixation with small-diameter, unlocked nails (Bucholz and Brumback 1996), and on average has been more common than internal malrotation (Mockwitz 1982; Wolf, Schauwecker, Tittel 1984), although also opposite results have been published (Sennerich et al. 1992). Once the amount of malrotation is known, simple derotation can be performed with unlocked nails (Harper 1985; Winquist, Hansen, Clawson 1984), whereas statically locked nails (Brumback et al. 1988b) require removal and reinsertion of the distal locking screws (Thoresen et al. 1985). After bony union, the need for corrective osteotomy must be estimated early (Winquist, Hansen, Clawson 1984), particularly in patients with associated head injuries who have been shown to heal more rapidly and with more exuberant callus (Perkins and Skirving 1987).

Traction of femoral shaft fractures has resulted in *knee stiffness* in up to 53% of cases (Dencker 1963; Buxton 1981; Schatzker 1996). Residual knee motion after cast bracing has been at follow-up of less than 100º (Mooney et al. 1970; Hardy 1983; McIvor et al.1984; Mooney and Claudi 1984). According to literature, plate fixation of femoral shaft fractures has resulted in 20%-30% of patients a major residual loss of knee motion, generally attributed to excessive scarring of the quadriceps muscle (Thompson et al. 1985; O'Beirne et al. 1986). In external fixation, loss of knee joint motion has been due to tethering of the quadriceps muscle and related to the severity of the injuries (Jackson, Jacobs, Neff 1978; DeBastiani, Aldegheri, Renzi Brivio 1984).

Other complications with traction of femoral shaft fractures have included prolonged hospitalization, decubitus ulcers, osteoporosis, and muscle wasting (Dencker 1963; Geist and Laros 1979; Moulton, Agunwa, Hopkins 1981; Schatzker 1996).

3. AIMS OF THE PRESENT STUDY

The study aims at answering the following questions:

1. What are the age- and gender-specific incidence rates and morphologic fracture characteristics related to femoral shaft fractures of different etiology including traumatic high energy and low energy injuries, and displaced fatigue fractures in adults? (I, II, III)

2. What are the predisposing factors to femoral shaft fractures caused by low energy injury in adults? What is the nature of the actual cause of the problem especially in association with the treatment of femoral shaft fractures due to low energy injury in adults? (II)

3. What kind of symptomatology is related to displaced femoral shaft fractures in military conscripts? What is the clinical course of treatment of displaced fatigue fractures of the femoral shaft in military conscripts? (III)

4. Which preventive methods against femoral shaft fractures of different etiology should be focused on? (I, II, III)

5. What are the factors predisposing to and the exact clinical course of patients seen with failed femoral shaft fracture union after initial treatment with an intramedullary nail in adults? What is the effectiveness of different surgical options in the treatment of failed union of intramedullary nailed femoral shaft fractures in adults and how should they be assessed? (IV)

4. PATIENTS AND METHODS

The clinical studies were performed with the permission of the Ethics Committee of the Central Hospital of Central Finland (I, II), the Defence Staff of the Finnish Defence Forces (III), and the Ethics Committee of the Department of Orthopaedics and Traumatology, Helsinki University Central Hospital (IV).

4.1. Definitions used in the study (I, II, III, IV)

The femoral diaphysis was defined as the portion of the bone located between a point 5 cm distal to the lesser trochanter and a point 8 cm proximal to the adductor tubercle (Böstman et al. 1989) in all studies (I, II, III, IV). Skeletal maturity of the patients was judged to be present in cases of closed (mature) growth plates of the femur on the radiographs taken at the time of fracture onset (I, II, III, IV).

An injury was considered a high energy trauma if it involved a motor vehicle accident or a fall from a height of three meters or more (I, II, IV), a severe sports injury or a violent crush (I), and a low energy trauma if the fracture resulted from slipping or stumbling at ground level or falling from a height of less than one meter (I, II, IV). Bone stress injuries included fatigue fractures, which occur after abnormal, repetitive stress to normal bone with normal elastic resistance, and insufficiency fractures, which result when normal stress is exerted on abnormal bone with deficient elastic resistance (Pentecost et al. 1964; Markey 1987). A fatigue fracture was considered if a history of localized pain of insidious onset, worsened with progressive activity and relieved by rest (Worthen and Yanklowitz 1978; Greaney et al. 1983; Markey 1987; Jones et al. 1989; Hershman and Mailly 1990; Knapp and Garrett 1997; Shaffer 2001), was related to the fracture. In healthy young adults, the following activities during the fracture onset were considered indicative of a fatigue fracture: (1) ordinary physical activity such as walking, running, or bending the knee or the hip, (2) straining or struggling, (3) slipping and stumbling at ground level, or (4) a fall from a height of less than one meter (III).

Fractures of the femoral diaphysis were classified in terms of their site, configuration, degree of comminution, and soft-tissue injury (I, II, III, IV). The exact site of the center of the main fracture line was localized into proximal, middle, or distal thirds of the femoral diaphysis. For true segmental fractures extending over more than 1/3 of the diaphysis, the site was determined according to the most proximal fracture line. The fracture pattern was defined according to classifications based on fracture biomechanics: spiral fracture due to torsion load, transverse fracture due to bending load, and oblique fracture due to axial compression with bending and torsion (Alms 1961; Gozna 1982; Bucholz and Jones 1991); or more biomechanically specified with an additional oblique–transverse fracture type with a nonfractured or fractured butterfly fragment due to axial compression and bending (Alms 1961; Gozna 1982). Fracture comminution was determined according to the original classification by Winquist and Hansen in the low energy study (II): a segmental fracture (double fracture of the femoral shaft), a Grade I fracture (fracture with a small fragment 25% or less of the width of the femoral shaft), a Grade II fracture (fracture with a fragment 25% to 50% of the width of the femoral shaft), a Grade III fracture (fracture with a fragment over 50% of the width of the femoral shaft), and a Grade IV fracture (fracture with circumferential comminution over a segment of bone) (Winquist and Hansen 1980; Winquist, Hansen, Clawson 1984; Bucholz and Jones 1991; Bucholz and Brumback 1996). For the epidemiologic study (I) and the studies III and IV, more specific classification (Johnson, Johnston, Parker 1984; Johnson and Greenberg 1987) with additional Grade 0 presenting a noncomminuted fracture was used. Fracture morphology was classified according to the AO (Arbeitsgemeinschaft für Osteosynthesefragen), and the Association for the Study of Internal Fixation (Müller et al. 1990), and the Orthopaedic Trauma Association (Orthopaedic Trauma Association 1996) into three main types (simple, wedge and complex) with three main groups (spiral, oblique and transverse for simple fractures; spiral, bending or fragmented wedge for wedge fractures; and spiral, segmental, and irregular for complex fractures); and three subgroups for each group based on to the fracture location with additional two to five ramifications in the complex type of fractures. The fracture angle was estimated between a line perpendicular to the long axis of the femur and the main fracture line. Fractures with an angle of less than 30 degrees were considered transverse (Müller et al. 1990) (I, II, III, IV).

Concerning the displaced fatigue fractures of the femoral shaft (III), the morphologic fracture classifications were compared with the gradings previously presented in the literature (Provost and Morris 1969; Hallel, Amit and Segal 1976).

Concerning soft-tissue injuries, closed fractures were defined as fractures without skin wound, and graded by the classification of Tscherne and Oestern: Grade C0 = none or negligible soft-tissue damage because of indirect violence, CI = superficial abrasion caused by a fragment from within, CII = deep, skin or muscle contusion from direct trauma including impending compartment syndrome, CIII = extensively contused skin and possible severe muscle damage (Tscherne and Oestern 1982; Oestern and Tscherne 1984) (I, II, III, IV). Open fractures (i.e. fractures with a soft-tissue damage) were classified by the grading of Gustilo et al. (Gustilo, Mendoza, Williams 1984; Gustilo, Merkow, Templeman 1990): Grade I: clean puncture wound 1 cm or less; Grade II: laceration less than 5 cm without contamination or extensive soft-tissue flaps, loss, avulsion, or crush; Grade III: extensive soft-tissue damage with contamination or crush including Grade IIIA: an adequate soft-tissue coverage of bone; Grade IIIB:extensive soft-tissue loss with periosteal stripping and bone exposure; and Grade IIIC: major arterial injury present demanding vascular repair (I, IV).

Significant concomitant injuries were categorized as bilateral femoral shaft fracture, other diaphyseal long bone fracture, cranio-facio-cerebral injury, thoraco-abdominal injury, spinal injury, or pelvic injury (I, IV).

Complications were judged to be early or late, and general or local. Solid union was defined as painlessness on weightbearing, with mature bone crossing the fracture site on both anteroposterior and lateral radiographs (Böstman et al. 1989). Delayed union was considered to be present if bony union of the fracture had not occurred within 24 weeks of the injury (Böstman et al. 1989) (III). Nonunion was regarded as a condition of a fracture that on three consecutive radiographs, taken at one month intervals, did not show any progression of solid healing, and would obviously not unite without active measures (Böstman et al. 1989) (III, IV). This definition included patients with frank nonunion, as well as those with delayed union in whom operative treatment was necessary in the study IV. Malunion was defined to exist unless varus or valgus angulation was less than 7º, anterior or posterior bowing less than 10º, shortening less than 15 mm, and rotational malposition not more than 10º (Böstman et al. 1989) (II, III).

In the study of displaced femoral shaft fatigue fractures (III), the body mass index (BMI) at the time of the fracture onset was calculated as body weight in kilograms divided by body height in meters squared (kg/m2). For an adult male, younger than 30 years, a BMI of 18.5-24.9 kg/m^2 was considered normal (WHO 1995b). For comparison, the average height of a 19-year-old Finnish conscript was 178.1 cm in 1978 (Dahlström 1981).

4.2. Patient data (I, II, III, IV)

The present study comprises four clinical series. The number of patients was altogether 480 with 491 femoral shaft fractures. Of the total number, 236 patients with 246 femoral shaft fractures were more precisely analyzed.

STUDY I

For the epidemiological study (I), during a 10-year period from January 1, 1985 to December 31, 1994, a total of 201 consecutive fresh fractures of the femoral diaphysis were analyzed in 192 skeletally mature patients admitted to two hospitals (Central Hospital of Central Finland, Jyväskylä, and Jokilaakso Hospital, Jämsä) providing surgical care for the population of the province of Central Finland. The median age of the patients, including 70 women (36%) and 122 men (64%), was 27 years (range, 15-92 years). The median age for women was 50 years (range, 15-92 years), and for men 23 years (range, 15-75 years). The mean population at risk during the 10-year period consisted of the 202 592 residents 15 years of age or older of a catchment area that is a semiurban, semirural county. During the observation period, 50% of this population lived in towns and cities, whereas the corresponding figure in the whole country was 62% (Statistical Yearbook of Finland 1994).

STUDY II

In the study concerning femoral shaft fractures caused by low energy injury (II), among the femoral shaft fractures in skeletally mature patients observed during a 10-year period, from January 1, 1985 to December 31, 1994, at the Central Hospital of Central Finland, Jyväskylä, and Jokilaakso Hospital, Jämsä, the diaphyseal fractures caused by low energy injuries were further analyzed. The median age of the 50 patients with 50 femoral shaft fractures at the time of the injury was 71 years, 79 years (range, 17-92 years) for 32 women (64%) and 60 years (range, 17-75 years) for 18 men (36%).

STUDY III

In the study of femoral shaft fatigue fractures (III), all displaced fatigue fractures of the femoral shaft treated during a 20-year period, from January 1, 1980 to December 31, 1999, at the Central Military Hospital of Finland were analyzed. The hospital provides the main surgical services for the Finnish Defence Forces. The mean population at risk per year during the 20-year period consisted of 33 000 conscripts, 18 to 29 years of age, completing their military service (Public Information Division of the Defence Staff 2004). Among all fatigue fractures treated at the Central Military Hospital during the 20-year period, there were 10 displaced diaphyseal femoral fractures in 10 previously healthy male conscripts with a median age of 19 years (range, 18-20 years).

STUDY IV

In the study examining nonunion of a femoral shaft fracture after intramedullary nailing (IV), the records of 278 patients aged 15 years or older, with 280 fresh femoral shaft fractures treated by intramedullary nailing at the Helsinki University Central Hospital (Department of Orthopaedics and Traumatology, Töölö Hospital) during a 7-year period, from April 1, 1989 to March 31, 1996, were retrospectively reviewed to identify a subgroup of patients with failed union. The median age of the 34 patients with 35 fractures at the time of the injury was 31 years (range, 15 to 72 years), 34 years (range, 15-72 years) for 17 women (50%) and 30 years (range, 20-54 years) for 17 men (50%).

4.3. Study arrangement (I, II, III, IV)

For the epidemiologic (I) and the low energy related fracture study (II), annual census data for the population of the province of Central Finland, selected by age and gender, was obtained from the official statistics of the country (Statistical Yearbook of Finland 1994). Nationwide data on the need for hospital stay owing to a femoral shaft fracture were retrieved for the corresponding 10-year period from the National Hospital Discharge Register, kept by the National Research and Development Center for Welfare and Health and covering all hospitals in Finland (I).

In all studies (I, II, III, IV), a computer search was used to identify from the hospital discharge register of the concerned hospital all patients with a fresh femoral shaft fracture registered according to the International Statistical Classification of Diseases and Related Health Problems, version ICD-8 from 1969 to 1986 (I, II, III), version 1CD-9 from 1987 to 1994 (I, II, III, IV), and version ICD-10 from 1995 on (WHO 1995a) (I, II, III, IV). For the study on failed union after intramedullary nailing, fractures treated with intramedullary nailing were retrieved from the database of surgical operations of the hospital (IV). The original, complete medical records, including radiographs of each patient (I, II, III), and of each patient of the subgroup (IV), were retrieved and reviewed.

Fractures within bone sections affected by metastatic or primary malignancy, local bone disease, or areas weakened by prior surgery were categorized as pathologic, and were not included in the morphologic analysis of the study (I, II, III, IV). Periprosthetic fractures were excluded (II). Traumatic fractures attributable to generalized osteopenia were not considered pathologic in this context. Five patients with five pathologic femoral shaft fractures, and 39 patients with periprosthetic fractures after total hip or knee arthroplasty were excluded from the morphologic analysis of the epidemiologic study (I).

For the study of displaced fatigue fractures, patients with a history of more severe trauma were not included (III). The rest of the fractures were judged by previous symptoms and by possible signs of a periosteal reaction on radiographs (III). The injury season was recorded for the epidemiologic study (I). The injury mechanism, any possible concomintant injury, as well as the patient's previous health condition, including continuous medication, cigarette smoking, sports participation, possible previous injuries, fractures, or operations, were registered (II, III, IV). Military training level and prior pain, or other symptoms of the lower extremity after the beginning of the service, were recorded and evaluated for the study of displaced fatigue fractures (III).

Skeletal maturity, fracture morphology, and bony union of the fractures were judged on the basis of radiographs by two reviewers (I, II, III, IV). Fractures were classified in terms of their configuration, site, degree of comminution, and soft-tissue injury (I, II, III, IV). In the studies II, III, and IV, the time to bony union of the fractures was judged clinically and radiographically. All general and local intraoperative and postoperative complications, as well as their consequences, were recorded (II).

4.4. Fracture management (II, III, IV)

The clinical course of the fracture treatments, with any possible intraoperative or postoperative complications, and the ultimate results of the treatments were recorded (II, III, IV). Although the fracture treatment policies varied from time to time, the main primary treatment method was intramedullary nailing.

STUDY II

In the study concerning femoral shaft fractures caused by low energy injuries (II), 47 fractures were treated operatively. Three patients were managed nonoperatively: two patients using plaster cast and one with skeletal traction. The reasons for refraining from operative procedures for these three patients were 1) tetraplegia caused by poliomyelitis, 2) numerous extremity deformities resulting from rheumatoid arthritis, and 3) severe heart disease. The method of internal fixation was intramedullary nailing for 35 fractures, plate fixation for 9 fractures, and DCS fixation for 3 fractures. The intramedullary nail types used were Küntscher nail for 10 fractures, Grosse-Kempf interlocking nail for 21 fractures (since 1987), Vari-Wall interlocking nail for 2 fractures (since 1994), and Ender nailing for 2 fractures. Of the 23 interlocked nailing procedures, 17 were performed by static interlocking and 6 by dynamic interlocking. Open reduction and additional cerclage wiring were performed with two intramedullary nailings when the Küntscher nail was used. The perioperative routine did not include prophylactic administration of antibiotics.

The mean duration of the hospital stay was 16 days (range, 2-87 days). After discharge from the hospital, the patients visited the outpatient department at 6-week intervals until the fracture was clinically and radiographically judged to be united.

STUDY III

In the study of displaced fatigue fractures of the femoral shaft (III), all fractures were operated on within 48 hours of the diagnosis. At surgery, all patients were given a prophylactic antibiotic, and low-molecular heparin was used as antithrombosis medication. Five fractures were treated with intramedullary nailing: three with a Küntscher nail, one with a static Grosse-Kempf interlocking nail, and one with a dynamic AO interlocking nail. Four fractures were treated with a DCP, one of them with additional bone grafting. One fracture was managed with a DCS. The mean duration of the hospital stay was 12 days (range, 6-20 days). After discharge from hospital, the conscripts visited the outpatient clinic at 2- to 4-week intervals until fracture union. The aftertreatment comprised partial weightbearing on crutches, active knee mobilization, and quadriceps muscle exercises.

STUDY IV

In the study of nonunion after intramedullary nailing of femoral shaft fractures (IV), the general policy of the department was to treat femoral shaft fractures operatively within 24 hours of admission. The initial operations were performed by the surgeon-on-duty, usually an orthopaedic resident. Intramedullary nailing with reaming was the rule in the treatment of closed fractures and open Gustilo Type I, II and IIIA fractures. In the whole series of 280 fractures, three different types of intramedullary nails were used. A conventional Küntscher nail was used in 76 principally transverse or short oblique fractures at the isthmus that had a Winquist and Hansen Grade I or Grade II comminution. Interlocking nailing was used in 204 cases. During the early years of the study, a Klemm-Schellmann nail was used as an interlocking nail (93 cases). From 1991 on, the AO Universal nail largely replaced the Klemm-Schellmann nail and was used in 111 fractures. The AO nail provided two holes available for proximal locking: a round hole for static locking and a slotted hole for dynamic locking. The nail type used in the primary intramedullary nailing procedure among the 34 patients with 35 fractures with failed union was a Küntscher nail in seven, a Klemm-Schellmann nail in eleven, and an AO Universal nail in seventeen cases. The mean duration for hospital stay was 18 days (range, 6-62 days).

Surgical intervention was considered at the earliest four months after the initial intramedullary nailing if there was no radiographic progression of consolidation at four months and significant local pain on weightbearing persisted.

In the treatment of ununited fractures, nonoperative management of nonunion, such as electrical stimulation or pulsed ultrasound, was not used. The operative treatment methods used for ununited fractures included dynamization of static interlocking with or without autogenous extracortical bone grafting, autogenous bone grafting alone with the nail in situ, and exchange intramedullary nailing with or without autogenous bone grafting. Autogenous bone grafting was performed by inserting onlay corticocancellous bone chips from the iliac crest through a lateral wound onto the fracture site. Reamed exchange nailing was performed by using a larger-diameter nail. In eight primary renailing procedures, a Küntscher nail was used in two, a Klemm-Schellmann nail in one, and an AO Universal nail in five cases. The choice between the different treatment modalities and nail types depended on the fracture and on the disturbed union pattern, as well as the personal preferences of the surgeon-in-charge. After discharge from hospital, the patients visited the outpatient department first at six-week and later at twelve-week intervals until the fracture was united. (IV)

4.5. Follow-up time (II, III, IV)

STUDY II

Forty patients could be followed up until bony union of the fracture was achieved. The mean follow-up time was 14 months: 25 months for patients younger than 60 years and 10 months for patients 60 years or older. Four elderly patients died within 2 months after sustaining the fracture. Three elderly patients had a general condition too poor to allow follow-up visits. For three patients, further information regarding fracture healing was unavailable due to a remote place of residence. (II)

STUDY III

All 10 of the former conscripts arrived to a physical and radiographic examination for follow-up. The mean follow-up time was 7 years (range, 2 to 16 years). (III)

STUDY IV

The mean length of the follow-up time of the 34 patients with disturbed union process of the fracture was 33 months on average (range, 12 to 70 months).

4.6. Statistical methods (I, II, III)

For statistical analysis, the chi square test (I, II), Fisher's exact test (I), and Kruskal-Wallis test (I) were used, with a *p* value of less than 0.05 considered significant. The 95% confidence intervals were calculated with a statistical computer program, and interpreted as the range of values that has a 95% chance of including the true values (I, II) (Dawson-Saunders and Trapp 1990; Dicker 2002). The age- and gender-specific incidence rates of diaphyseal femoral fractures were calculated by dividing the number of cases in each age group by the number of the corresponding average age- and gender-specific population during the period concerned (I, II, III).

5. RESULTS

5.1. Demography of femoral shaft fractures in adults (I, II, III)

STUDY I

Among an average population of 202 592 skeletally mature residents, the all-fracture incidence was 12.1 per 100 000 person-years. The incidence of 201 traumatic fractures was 9.9 per 100 000 person-years (95% confidence interval 9 to 11). The incidence in male patients from 15 to 24 years of age clearly exceeded that of any other male age group (Figure 2.). Only among individuals 75 years of age or older was the age-specific rate for women notably higher.

The seasonal distribution showed that the incidence was highest in August with 30 patients (frequency 0.16, 95% confidence interval 0.11 to 0.22, expected frequency based on even distribution 0.08) (Figure 3.). This was attributable to the high energy injuries (25 of 30 fractures) (Figure 4.). Sixty-eight patients sustained their femoral shaft fracture in the third quadrant of the year (July-September) (frequency 0.35, 95% confidence interval 0.29 to 0.43, expected frequency 0.25) (Figure 3.).

The number of inpatient hospitalization periods required to treat the patients was 23 per 100 000 person-years. The corresponding figure for the whole country was 22 per 100 000 person years.

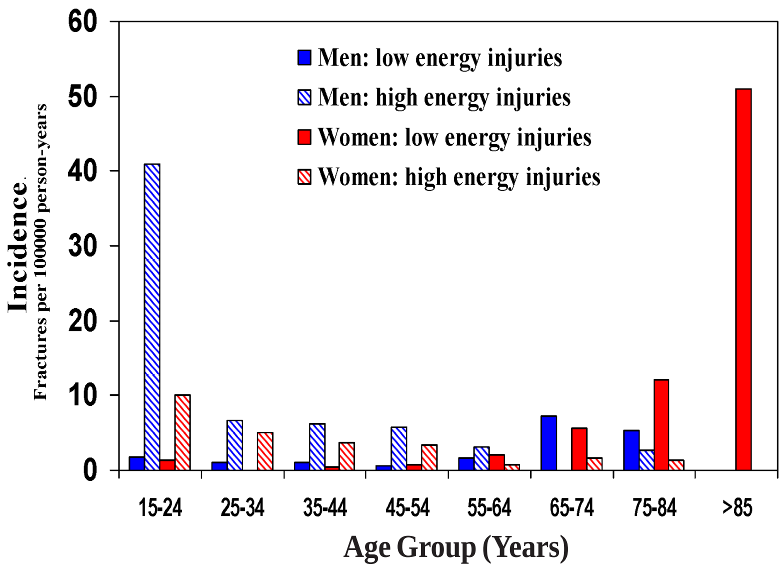

Figure 2. Age- and gender-specific fracture incidences in fractures caused by high energy and low energy injuries. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

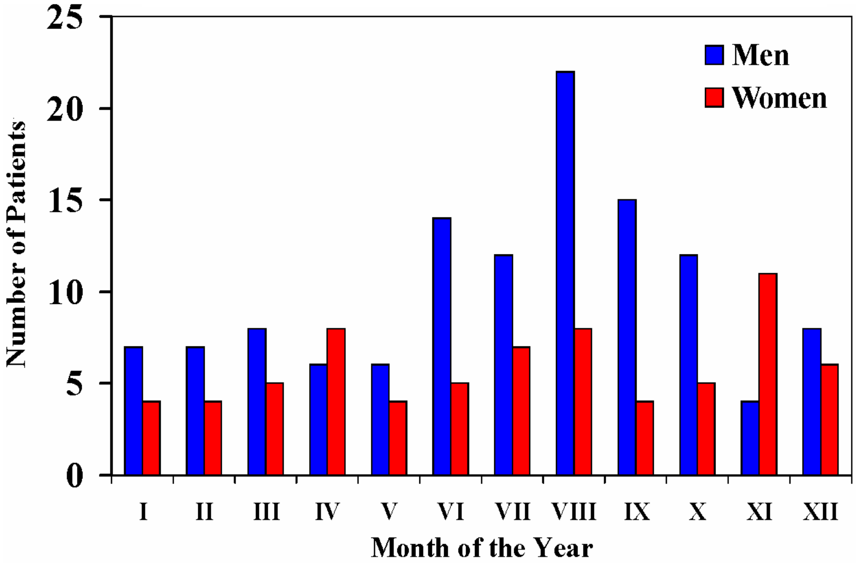

Figure 3. Seasonal distribution of the occurrence of traumatic femoral shaft fractures in both genders in adults. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

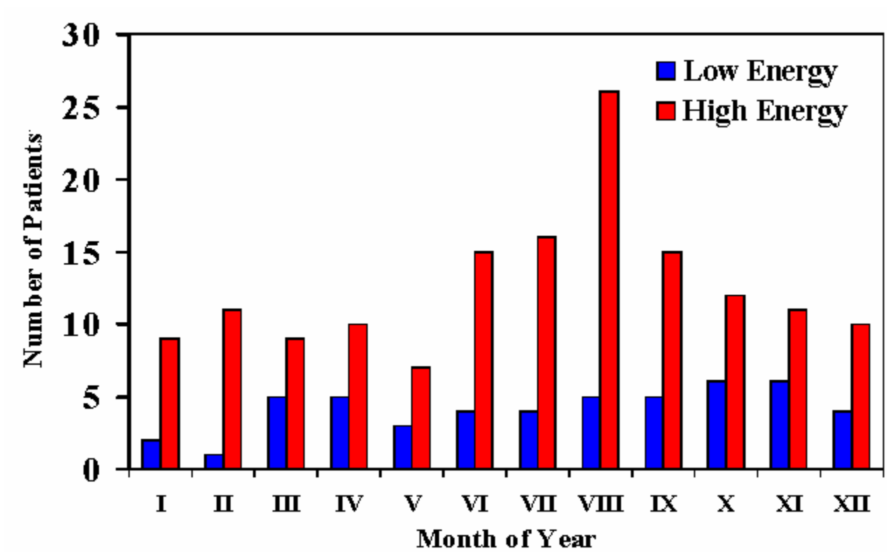

Figure 4. Seasonal distribution of traumatic femoral shaft fractures caused by low energy or high energy injuries in adults. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

STUDY II

Of the 50 patients, 13 were younger than 60 years and 37 were 60 years or older. The total incidence of femoral shaft fractures due to low energy injury was 2.5 per 100 000 person-years. For people aged 15 to 60 years, including nine men and four women, it was 0.8 per 100 000 person-years, and for people aged 60 years or older, including nine men and 28 women, it was 7.8 per 100 000 person-years. The 95% confidence interval for the fractures was 0.19 to 0.31.

STUDY III

The incidence of displaced fatigue fractures among conscripts during the 20-year period was 1.5 per 100 000 person-years in military service. There were no female conscripts sustaining displaced femoral shaft fatigue fractures.

The median time from the beginning of the military training to the onset of the fracture was 53 days (range, 15-178 days). All but one conscript experienced preceding pain mainly in the distal thigh on weightbearing for 1 to 6 weeks. In five men with a subsequent fracture in the middle or the distal third of the femoral diaphysis, the pain radiated to the knee. The first sensations of the pain were related to a combat exercise in five patients, and marching in five patients. Only two conscripts had sought medical attention because of the preceding pain symptoms, and had been exempted from heavy military service for 2 to 6 days, but radiographs had not been taken before the fracture occurred.

5.2. Injury mechanism (I, II, IV) or activity at the fracture onset (III)

STUDY I

High energy trauma caused 151 (75%) fractures, 131 (87%) of which occurred in road traffic accidents (Table 12.). In 47 (36%) of these cases, the automobile driver was injured. There were no gunshot injuries. In the low energy group (50 cases), there were 37 patients 60 years of age or older. There was no increasing trend in the number of high energy or low energy fractures during the 10-year period.

Table 12. Injury mechanisms and occurrence of significant concomitant injuries in 192 patients with 201 traumatic femoral shaft fractures. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

Injury Environment	Number (192)	Percentage (%)	Median Age (Years, Range)	Significant Concomitant Injuries						
				Bilateral Femoral Shaft Fracture	None	Cranio-Facio Cerebral Injury	Thoraco-Abdominal Injury	Spinal Injury	Pelvic Injury	Other Diaphyseal Long Bone Fracture
Car or Truck										
Driver	47	24	24 (18-64)	4	22	11	8	1	6	12
Front seat passenger	12	6	24 (16-57)	0	6	2	3	0	1	2
Rear seat passenger	5	3	25 (16-37)	0	3	0	0	0	1	2
Other motor vehicle										
Motorcycle	22	12	17 (15-35)	0	16	0	0	0	0	6
Motorbike	14	7	17 (15-52)	1	8	0	1	0	1	5
Snowmobile	2	1	39 (37-40)	0	1	0	1	1	1	0
Bicyclist	8	4	26 (15-59)	0	7	0	0	1	1	0
Pedestrian	14	7	29 (16-77)	2	7	3	4	0	2	5
Free fall										
Height	8	4	40 (22-81)	1	5	2	1	0	1	2
Low (≤ 1 m)	8	4	76 (21-90)	0	8	0	0	0	0	0
Slipping or stumbling	38	20	71 (17-91)	0	38	0	0	0	0	0
Miscellaneous low energy	4	2	64 (30-92)	0	4	0	0	0	0	0
Crush	3	2	36 (21-61)	1	3	0	0	0	0	0
Sports	7	4	20 (15-41)	0	4	0	3	0	0	0
All	192	100	27 (15-92)	9	132	18	21	3	14	34

STUDY II

In 38 patients, the mechanism of injury was falling at ground level. Eight patients fell from a height of less than one meter. Four fractures occurred without any actual trauma (being turned in bed, moving from wheelchair to bed, lifting one leg over another, and one manifested itself as pain for one week). Thirty-two patients (64%) had at least one general or local factor (Table 13.) that predisposed them to a fracture by weakening the mechanical strength of the femur. For 18 patients (36%), 8 of whom were under 60 years and 10 of whom were over 60 years, no such factors could be identified when high age alone was not considered.

Table 13. Summary of individual factors predisposing to a femoral shaft fracture caused by low energy injury in 50 patients of different age. Modified from Salminen S, Pihlajamäki H, Avikainen V, Kyrö A, Böstman O: Specific features associated with femoral shaft fractures caused by low energy trauma. J Trauma 43:117-122, 1997; with permission from Lippincott, Williams & Wilkins. (II)

Predisposing Factor	Age Group	
	< 60 years (Number)	≥ 60 years (Number)
Factors predisposing to generalized osteopenia (other than high age)		
- Diabetes mellitus	0	8
- Chronic alcohol abuse	2	5
- Chronic obstructive pulmonary disease with cortisone medication	0	4
- Rheumatoid arthritis with cortisone medication	1	0
Factors predisposing to localized disuse osteopenia		
- Previous major fracture of the same extremity	2	6
- Neuromuscular disorders	3	3
- Severe osteoarthritis of the ipsilateral hip or knee	0	4
- Previous total replacement of the ipsilateral hip or knee	1	2
- Previous ipsilateral knee ligament rupture	1	0
Patients with one predisposing factor	1	16
Patients with two or more predisposing factors	4	11
Patients without predisposing factors	8	10

STUDY III

The exact activity during the onset of the fracture was slipping at ground level (two patients), walking or stumbling down stairs (two patients), bending the knee (two patients), stumbling while running, rushing from a dugout, hurrying to carry mines, and starting to ride a bike (Table 14.).

STUDY IV

Thirty-one fractures were caused by high energy trauma, twenty-eight of which involved a road traffic accident. In four patients with low energy trauma, the initial injury mechanism was slipping or stumbling at ground level.

Table 14. Characteristics of Femoral Shaft Fatigue Fractures in 10 Conscripts. Modified from Salminen ST, Pihlajamäki HK, Visuri TI, Böstman OM: Displaced fatigue fractures of the femoral shaft. Clin Orthop Relat Res 409:250-259, 2003; with permission from Lippincott, Williams & Wilkins. (III)

Patient	Age (Years)	BMI (kg/m^2)	Prior Pain (Weeks)	Fracture Onset (Months)	Activity during Fracture Onset	Fracture Site (R/L, Third)	Additional Complications	Fracture Treatment	Reoperations	IAC	Fracture			Bony Union (Months)
											Angle	AO	W-H	
1	20	18.3	thigh and knee, 2	1.5	Carried mines	R, distal	no	DCP and bone grafting	no	yes	Oblique, 50°	A2.3	0	5
2	20	23.7	knee, 2	0.5	Walked stairs	L, middle	Shortening of 1.6 cm	Küntscher IM-nail	no	no	Oblique, 60°	C3.1.1	II	4
3	20	21.3	thigh, 3	6 *	Stumbled while running	R. middle	Suspected fat embolism	Küntscher IM-nail	no	yes	Oblique-transverse 35°, 1°	A2.2	0	3.5
4	19	22.5	knee, 6	3	Began to ride a bicycle	R, distal	Long distal screw	DCP	Exchange of the screws	yes	Oblique-transverse 65°, 2°	A2.3	0	3
5	18	20.2	no**	3	Slipped at ground level	L, middle	no	G-K IM-nail (static)	no	no	Spiral, 60°	B1.2	I	3
6	19	20.8	knee, 1	2	Knee banding in the varus	L, distal	Superficial wound infection	DCP	no	yes	Oblique, 45°	A2.3	0	5
7	19	21.6	distal thigh, 4	3	Slipped at ground level	L, distal	no	DCP	no	yes	Spiral, 55°	A1.3	I	3
8	19	21.6	thigh, 3	1.5	Ran from dugout	L, proximal	Axial instability; comminution at 2nd operation	Küntscher IM-nail	Renailing with AO IM-nail (static)s	yes	Oblique, 50°	A2.1	0	4
9	19	20.1	distal thigh, 1	1.5	Stumbled down stairs	R, distal	no	AO IM-nail (dynamic)	no	no	Oblique-transverse 30°	B2.3	I	3.5
10	19	32.2	knee, 1	0.5	Bended knees	R, distal	no	DCS	no	no	Oblique-transverse. 70°, 4°	A3.3	0	3

5.3. Concomitant injuries (I, II, III, IV)

STUDY I

Among the 60 (31%) patients who sustained significant concomitant injuries (Table 12.), 34 had a second diaphyseal long bone fracture. In 14 patients, there was a concomitant fracture of the patella, of which nine were ipsilateral. All significant concomitant injuries were associated with high energy trauma. Fifty-four of the patients with concomitant injuries had been injured in road traffic accidents.

STUDY II

In the low energy group (II), none of the patients had significant concomitant injuries. One patient had a lesion of the femoral artery caused by the fracture.

STUDY III

In the study concerning displaced fatigue fractures of the femoral shaft (III), there were no concomitant injuries.

STUDY IV

In the study of nonunion after intramedullary nailing (IV), 18 patients had sustained significant concomitant injuries. These included a thoracoabdominal injury in 12 cases, other diaphyseal long bone fractures in six cases, a craniofacialcerebral injury in four cases, a spinal injury in two cases, and a pelvic fracture in four cases.

5.4. Fracture characteristics (I, II, III, IV)

STUDY I

There were 92 fractures in the right femur (46%) and 109 in the left femur (56%). Nine patients had bilateral, contemporary fractures (4% of all fractures). Of the 176 closed fractures, 80 were Tscherne and Oestern Grade C II (46%), in which a contaminated abrasion is associated with localized skin or muscle contusion from direct high energy trauma, 53 were Grade C I (30%), 34 were Grade C0 (19%), and nine were the very severe Grade CIII (5%). Of the 25 open fractures, 14 were Gustilo Type II, six Type III, and five Type I. All six Type III open fractures were Type IIIA. The main fracture line was in the middle third of the diaphysis in 79% of the fractures. There was a significant association between increasing age and a distal third location (*p* value 0.02). There were eight true segmental fractures. When using biomechanical classification, the majority, 155 (77%), of all fractures were transverse, oblique, or oblique-transverse (Table 15.). In 93 (46% of the fractures), the angle between a line perpendicular to the long axis of the femur and the main fracture line was less than 30 degrees (Table 15.). There was a significant association between increasing age and occurrence of a spiral fracture ($p < 0.001$).

Table 15. Distribution of fracture patterns according to biomechanical classification. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

Fracture Pattern	Number of Fractures	Percentage (%)	Median Age of Patients (Years, Range)
Transverse	80	40	24 (15-87)
Oblique-transverse	34	17	22 (15-84)
Oblique	41	20	26 (15-89)
Spiral	46	23	55 (15-92)
Total	201	100	27 (15-92)

Regarding the degree of comminution (Table 16.), the Winquist and Hansen Grade 0 fracture (noncomminuted) was the most common type (48%), followed by Grade II fractures (22%), Grade IV fracture (13%), and Grade I fracture (9%).

Table 16. Degree of comminution according to Winquist and Hansen Classification. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

Winquist and Hansen Grading	Number of Fractures	Percentage	Median Age of Patients (Years, Range)
0	96	48	34 (15-92)
I	19	9	22 (17-70)
II	44	22	23 (15-81)
III	15	8	58 (16-84)
IV	27	13	26 (15-56)
Total	201	100	27 (15-92)

Forty-eight percent of the fractures were AO Type A, 39% were Type B, and 13% were Type C fractures (Table 17.). The A3 transverse femoral shaft fracture was the most common, followed by the B2 group with a bending wedge type and an intact butterfly fragment. The C1 and C2 groups (spiral and segmental complex fractures) were the least common. Only seven of the 27 possible subgroups occurred with a frequency of at least 3.7%. In a few cases, the exact typing of the fracture according to the AO classification was difficult.

Table 17. Distribution of 201 fractures according to AO classification. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

Fracture Type	Number of Fractures	Percentage (%)	Median Age of Patients (Years, Range)
A1	17	9	75 (15-92)
A2	22	11	41 (15-89)
A3	57	28	24 (15-87)
B1	21	10,5	52 (16-84)
B2	36	18	21 (15-68)
B3	21	10.5	22 (15-66)
C1	8	4	34 (20-52)
C2	8	4	22 (15-56)
C3	11	5	26 (16-49)
Total	201	100	27 (15-92)

The association between an AO category A fracture and a middle third location (*p* value 0.002) and between a Winquist and Hansen Grade 0 fracture and a middle third location was statistically significant (*p* value 0.02) (Table 18.).

Table 18. Fracture characteristics in relation to the site. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

Fracture Characteristic	Proximal (n=18)	Middle (n=159)	Distal (n=24)	P value
Median age of patients (years, range)	26 (15-83)	25 (15-92)	43 (16-87)	0.02
Fracture [Number(%)]				NS
Closed	17 (8.5)	136 (67.5)	23 (11.5)	
Open	1 (0.5)	23 (11.5)	1 (0.5)	
AO Type [Number(%)]				0.002
A	4 (2.0)	81 (40.0)	11 (5.5)	
B	7 (3.5)	58 (29.0)	13 (6.5)	
C	7 (3.5)	20 (10.0)	0 (0.0)	
Fracture pattern [Number(%)]				NS
Transverse	5 (2.0)	68 (34.0)	7 (3.5)	
Oblique-transverse	4 (2.0)	29 (14.0)	1 (0.5)	
Oblique	2 (2.0)	32 (16.0)	7 (3.5)	
Spiral	7 (2.0)	30 (15.0)	9 (4.5)	
Winquist and Hansen Grade				0.02
0	4 (2.0)	81 (40.0)	11 (5.5)	
I	1 (2.0)	16 (8.0)	2 (1.0)	
II	4 (2.0)	31 (15.5)	9 (4.5)	
III	2 (2.0)	11 (5.5)	2 (1.0)	
IV	7 (2.0)	20 (10.0)	0 (0.0)	

STUDY II

Of the 50 fractures, there were 18 fractures of the right femur and 32 fractures of the left femur. The difference was statistically significant (p value < 0.05). The 95% confidence interval for the proportion of the left femur was 51 to 77%. All fractures were closed: the soft-tissue injuries related to the fractures were of the C0 type in 34 fractures and of the CI type in 16 fractures. In 33 cases the site of the fracture was in the middle third of the femur. The most common biomechanical fracture pattern was a spiral one (Figure 5.) (Table 19.). The distribution of other fracture configurations were as follows: transverse in 10, oblique transverse in 7, and oblique in 4 cases. The different configuration types were evenly distributed along the shaft (p value 0.37).

With regard to the degree of comminution, 36 fractures were of type I (minimal or no comminution) of the Winquist-Hansen classification, 4 were of type II, and 10 were of type III. When using the AO classification, the most common fracture patterns were a simple spiral AO 32-A1.2 type (13 fractures) and a simple transverse AO 32-A3.2 type (7 fractures).

Table 19. Biomechanical configuration and fracture site. Modified from Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM: Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res 372:241-249, 2000; with permission from Lippincott, Williams & Wilkins. (I)

Fracture Configuration	Proximal third Number of Patients	Middle third Number of Patients	Distal third Number of Patients	Total Number of Patients
Tranverse	1	5	4	10
Oblique-transverse	0	7	0	7
Oblique	1	2	1	4
Spiral	2	19	8	29
Total	4	33	13	50

Figure 5A-B. A comminuted spiral fracture of the middle femoral diaphysis caused by low energy trauma (II).

STUDY III

Five conscripts had a fracture of the right femur, and five of the left femur. There were no bilateral fractures. All fractures were closed. Six fractures were located in the distal third, three in the middle third, and one fracture in the proximal third of the diaphysis. Four fractures were oblique-transverse, four oblique, and two had a spiral configuration. There were no pure transverse fractures. Six fractures were primarily noncomminuted (Grade 0 by the Winquist-Hansen classification). Three fractures were Grade I, and one was Grade II. The most common pattern was a noncomminuted oblique or oblique-transverse fracture, AO Type A2.3, in the distal third of the shaft (three fractures) (Table 14.). Only four fractures were consistent with the fracture classification by Provost and Morris (Provost and Morris 1969), of these, one fracture belonged to Group II, and three fractures to Group III.

STUDY IV

There were 13 fractures of the right femoral shaft (41%) and 19 fractures of the left femoral shaft with nonunion (59%). One patient had fractures of both femurs, but not at the same time. Another patient had also a bilateral femoral shaft fracture, but nonunion occurred only in one of the fractured femur. Of the 27 closed fractures, three were Tscherne Grade C0, nineteen Grade CI, three Grade CII, and two Grade CIII. Of the eight open fractures, two were of Gustilo Type I, three Type II, and three Type IIIA. The principal fracture line was located in the middle third of the femoral diaphysis in nineteen fractures, in the proximal third in ten fractures, and in the distal third in six cases. According to the biomechanical classification, the majority (26 fractures) were oblique-transverse. There were six pure transverse and three spiral fractures. There were eight Winquist and Hansen Grade 0 fractures (noncomminuted), one Grade I, seven Grade II, eleven Grade III, and eight Grade IV. The AO and OTA fracture types were as follows: nine fractures of Type A, fifteen of Type B, and eleven of Type C.

5.5. Outcome and complications of fracture treatment (II, III, IV)

STUDY II

Altogether 29 of the 40 patients (73%) who could be followed up until union showed concomitant complications. Four elderly patients died within 2 months postoperatively, one from a pulmonary embolism, and 3 from a heart disease. In only 11 cases was the healing of the fracture uneventful. During the follow-up time, 18 reoperations for complications were performed on 12 patients (Table 20.). Ten reoperations on 7 patients were performed due to nonunion. The predominant pathogenesis of the nonunions seemed to be soft-tissue interposition between the extensive fracture surfaces of the fragments with spiral configuration (Figure 6.). One patient underwent three reoperations for nonunion. In the first reoperation, a Küntscher nail with severe shortening of the femur was replaced by static interlocked nailing with autogenous bone transplantation. In the second reoperation, bone transplantation was performed, and the third operative procedure was aimed at proximal dynamization of the nail. In another patient, a dynamic compression plate broke 26 weeks postoperatively as a result of an ununited fracture, and was replaced by a Küntscher nail. In one case, a dynamic interlocked nail without distal interlocking screws perforated the knee joint on the first postoperative day, and necessitated a rereduction and insertion of distal interlocking screws. The most common mode of malunion was a moderate shortening and valgus. Of the 13 patients with malunion, 9 had shortening of the femur. The patients with malunion experienced only mild symptoms and did not undergo reoperations. Because of shortening of the leg, six patients used a continuous shoe lift.

STUDY III

The four fractures that were stabilized with a dynamic compression plate showed additional comminution to Grade II on the Winquist-Hansen classification during the operation. Additional comminution also occurred in two intramedullary nailings.

In one conscript, suspicion of a fat embolism was present because of respiratory distress on the first postoperative day after Küntscher nailing, but he recovered in 3 days. One conscript had a superficial wound infection. The conscripts returned to light duty military service 6 weeks postoperatively, on the average. Two conscripts were exempted from military service for 2 years.

Figure 6.
A.-B. A 72-year-old woman fell in sauna at ground level and got a spiral fracture of the middle diaphysis of the left femur.
C. The fracture was treated with a static Grosse-Kempf nail.
D. Due to delayed union, a bone grafting from the iliac crest was performed.
E. The fracture healed 5 months later (II).

Two reoperations were necessary. One Küntscher nail proved to be axially unstable causing difficulties in mobilization, and was exchanged to a static AO Universal nail after 2 weeks. An excessively long distal screw was replaced after plate fixation in one patient. Otherwise, the clinical courses were uneventful (Figures 7. and 8.). The median time to solid bony union was 3.5 months (range, 3-5 months). In all cases, the fixation devices were removed 1 to 3.5 years postoperatively. In two fractures, the screw holes were still detectable more than 10 years after the fracture fixation. The only patient with malunion had a shortening of 1.6 cm of the femur, confirmed by radiographs measuring the exact leg length inequality (orthodiagram), attributable to initial comminution of the fracture. The patient also had a 25-degree external rotation of the lower extremity. At follow-up, the ranges of movement of the knees and hips were normal in all patients. One patient had persisting pain in the knee after a distal fracture stabilized with a dynamic condylar screw. By the last re-examination, none of the conscripts had sustained additional fatigue fractures.

Table 20. Characteristics of the 29 patients with postoperative local complications. Modified from Salminen S, Pihlajamäki H, Avikainen V, Kyrö A, Böstman O: Specific features associated with femoral shaft fractures caused by low energy trauma. J Trauma 43:117-122, 1997; with permission from Lippincott, Williams & Wilkins. (II)

Patient	Age/ Gender	Predisposing Factors	Fracture Configuration	Fracture Comminution	Internal Fixation/ Immobilization	Complications and Secondary Measures	Comments
1	35/F	-	Spiral	W-H III	DCP and bone grafting	Nonunion and breakage of the plate; re-osteosynthesis using a Küntscher IM nail	IM nailing should have been used
2	37/M	CAB, ND, KLR	Spiral	W-H II	DCP and plaster cast	Delayed union, malunion (1.5 cm shortening)	Inadequate plating
3	17/M	-	Spiral	W-H II	G-K IM nail with distal interlocking	Malunion (1.5 cm shortening)	Static interlocking should have been used
4	40/M	PF, ND	Spiral	W-H I	G-K IM nail with static interlocking	Wound breakdown	
5	52/M	ND	Spiral	W-H III	V-W IM nail wih static interlocking	Malunion (varus 7 degrees)	
6	34/M	-	Oblique-transverse	W-H II	Open reduction and Küntscher	Nonunion; (1) reoperation: G-K IM nail with static interlocking and bone grafting; (2) reoperation: bone grafting; (3): reoperation: proximal IM nail with cerclage wire dynamization	Closed reduction and static interlocking could have prevented the nonunion
7	67/F	-	Transverse	W-H I	Küntscher IM nail	Malunion (2.5 cm shortening)	Undetected intraoperative comminution
8	66/M	-	Oblique-transverse	W-H III	G-K IM nail with static interlocking	Malunion (2 cm shortening)	Severe comminution
9	89/F	DM, COPD, OA	Spiral	W-H I	G-K IM nail with distal interlocking	Axial shortening and recurvatum within 2 weeks; skeletal traction	Static interlocking should have been used
10	60/F	CAB	Spiral	W-H II	G-K IM nail with static interlocking	Nonunion and migration of a distal interlocking screw; distal dynamization	Static interlocking in diastasis
11	91/F	CAB/PF	Spiral	W-H I	Open reduction and Ender nailing	Migration of an Ender nail; removal of an Ender nail in three separate reoperations	
12	73/F	-	Transverse	W-H I	Küntscher IM nail	Deep wound infection, delayed union	
13	79/F	-	Spiral	W-H III	G-K IM nail with static interlocking	Nonunion and migration of a distal interlocking screw; distal dynamization	
14	92/F	-	Spiral	W-H I	Küntscher IM nail	Malunion (valgus 7 degrees)	
15	84/F	TP	Spiral	W-H III	G-K IM nail with proximal interlocking	Severe axial shortening and nail perforating the knee joint within 1 week, finally malunion (valgus 10 degrees); closed reduction and application of distal interlocking screws	Static interlocking should have been used
16	72/F	COPD	Spiral	W-H III	G-K IM nail with static interlocking	Nonunion and migration of an interlocking screw; bone grafting and tightening of an interlocking screw	
17	83/F	DM, OA	Transverse	W-H I	G-K IM nail with proximal interlocking	Nonunion and finally malunion (shortening 1.5 cm); (1) renailing: G-K IM nail with proximal interlocking; (2) renailing: G-K IM nail with static interlocking and bone	

						grafting	
18	87/F	-	Spiral	W-H I	G-K IM nail with distal interlocking	Malunion (shortening 4 cm and internal rotation 10 degrees)	Non-ambulatory patient, no secondary measures
19	71/M	-	Spiral	W-H I	G-K IM nail with static interlocking	Nonunion and migration of an interlocking screw, finally malunion (shortening 1.5 cm); proximal dynamization	
20	61/M	DM, ND	Oblique	W-H I	Ender nailing	Deep wound infection, delayed union, finally malunion (external rotation 10 degrees); removal of Ender nails	
21	66/M	COPD	Spiral	W-H I	G-K IM nail with static interlocking	Deep wound infection	
22	75/M	ND	Spiral	W-H I	Küntscher IM nail	Malunion (shortening 1.5 cm)	
23	84/F	-	Spiral	W-H III	G-K IM nail with static interlocking	Wound breakdown, delayed union	Because of old age and poor general condition, no secondary measures were performed
24	62/F	DM	Transverse	W-H I	DCS	Loosening of the plate part of DCS within 1 month; (1) nailing: Küntscher IM nail, which subsequently broke; (2) nailing: G-K IM nail with staic interlocking	IM nailing should have been used
25	66/M	PF	Oblique-transverse	W-H I	V-W IM nail with distal interlocking	Delayed union	
26	66/F	ND	Oblique	W-H I	Plaster cast	Delayed union	IM nailing should possibly have been performed despite tetraplegia
27	88/F	PF	Spiral	W-H I	DCP	Malunion (2.5 cm shortening)	
28	75/F	-	Spiral	W-H I	DCP	Supracondylar refracture; reosteosynthesis using a 95-degree condylar plate and cerclage	
29	79/F	DM, PF	Spiral	W-H I	DCP	Superficial wound infection	

F, Female; M, Male; DM, diabetes mellitus, CAB, chronic alcohol abuse; COPD, chronic obstructive pulmonary disease with cortisone medication; PF, previous major fracture of the same extremity; ND, neuromuscular disorders; OA, severe osteoarthritis of the ipsilateral hip or knee; TP, previous total prosthesis replacement of the ipsilateral hip or knee; KLR, previous ipsilateral knee ligament rupture; W-H, Winquist-Hansen classification; DCP, AO dynamic compression plate; DCS, AO dynamic condylar screw; IM nail, intramedullary nail; G-K, Grosse-Kempf; V-W, Vari-Wall.

Figure 7.
A.-B. A 20-year-old conscript (Case 5., Table 14.) had had no previous pain before he slipped at ground level and sustained a spiral fracture with some periosteal reaction.
C.-E. The AO 32-B1.2 fracture was treated with a static Grosse-Kempf nail, and the fracture healed in 3 months without complications (D-E).

Figure 8.
A.-B. A 19-year-old previously healthy conscript (Case 9, Table 14.) stumbled down stairs 1.5 months after beginning his military service and sustained a distal oblique-transverse slightly comminuted (Winquist-Hansen Grade I) AO 32-B2.3 fracture.
C.-D. The fracture was treated with an AO intramedullary nail without complications.
E.-G. The fracture healed in 3.5 months.
H.-I. The nail was removed after two years. The situation at the last follow-up control.

STUDY IV

Severe primary comminution of the fracture was present on the radiographs of nineteen patients after the initial intramedullary nailing (Table 21.). In eight cases, the comminution of the fracture increased in severity intraoperatively because of technical faults during the primary nailing procedure. Likewise, in eight cases, a clear diastasis could be detected on the postoperative radiographs (Table 22.).

In the analysis of the sequence of postoperative radiographs, the principal finding at the time of diagnosis of disturbed union was a diaphyseal fracture gap with arrested consolidation in eight, poor bony apposition due to angulation between the fracture fragments in five, scanty callus with acceptable bony apposition in twenty, and hypertrophic nonunion in two cases.

In eight fractures, a fatigue failure of the intramedullary nail or the locking screws occurred before surgical measures were undertaken (Figures 9. and 10.). Failure of consolidation resulted in a complete breakage of the nail in six cases (including five static 10-mm-13-mm AO intramedullary nails as well as one dynamically and one statically locked 13-mm Klemm-Schellmann nail), three of which occurred within six months after the initial operation, and the remaining three between six and twelve months.

Table 21. Summary of specific clinical and radiographic characteristics observed in patients with failed union of femoral shaft fractures after intramedullary nailing (N = 35); two or more itemized characteristics are present in 31 cases. Modified from Pihlajamäki HK, Salminen ST, Böstman OM: The treatment of nonunions following intramedullary nailing of femoral shaft fractures. J Orthop Trauma 16:394-402, 2002; with permission from Lippincott, Williams & Wilkins. (IV)

Characteristic Factors	Number of Fractures
Factors related to fracture pattern	
- Severe primary comminution of fracture (W-H III or IV) [a]	19
- Displaced butterfly fragment with potential muscle interposition	12
- Concomitant injury interfering with mobilization	17
- Rheumatoid arthritis with cortisone medication	8
Factors related to soft-tissues	
- Open fracture	8
- Severe closed soft-tissue injury (Tscherne C II or III) [b]	6
Iatrogenic factors	
- Opening of fracture site during intramedullary nailing	8
- Increased comminution during intramedullary nailing	8
- Diastasis after intramedullary nailing	8
- Severe angulation with poor bony apposition after nailing	5
- Malpositioning of an interlocking screw through fracture surfaces	1
- Early renailing due to unstable primary nailing	6
- Other early reoperation due to local complications	2

[a] Winquist-Hansen Grade according to the preoperative radiographs.[b] Tscherne classification.

Figure 9.
A. A 34-year-old woman experienced a comminuted (Winquist-Hansen Grade II) AO Type 32-B3.2 fracture of the right femoral shaft when she was hit by a car.
B. The fracture was treated with open Küntscher nailing.
C. Due to axial instability, the fracture was renailed one month later with a static AO nail.
D.-E. Due to fracture alignment, fracture healing necessitated bone grafting 5 months later.
F.-G. The nail broke after 10 months.
H.-I. The nail was replaced with an AO nail, which was dynamized 9 months later.
J. The fracture finally healed almost three years after the initial trauma (IV).

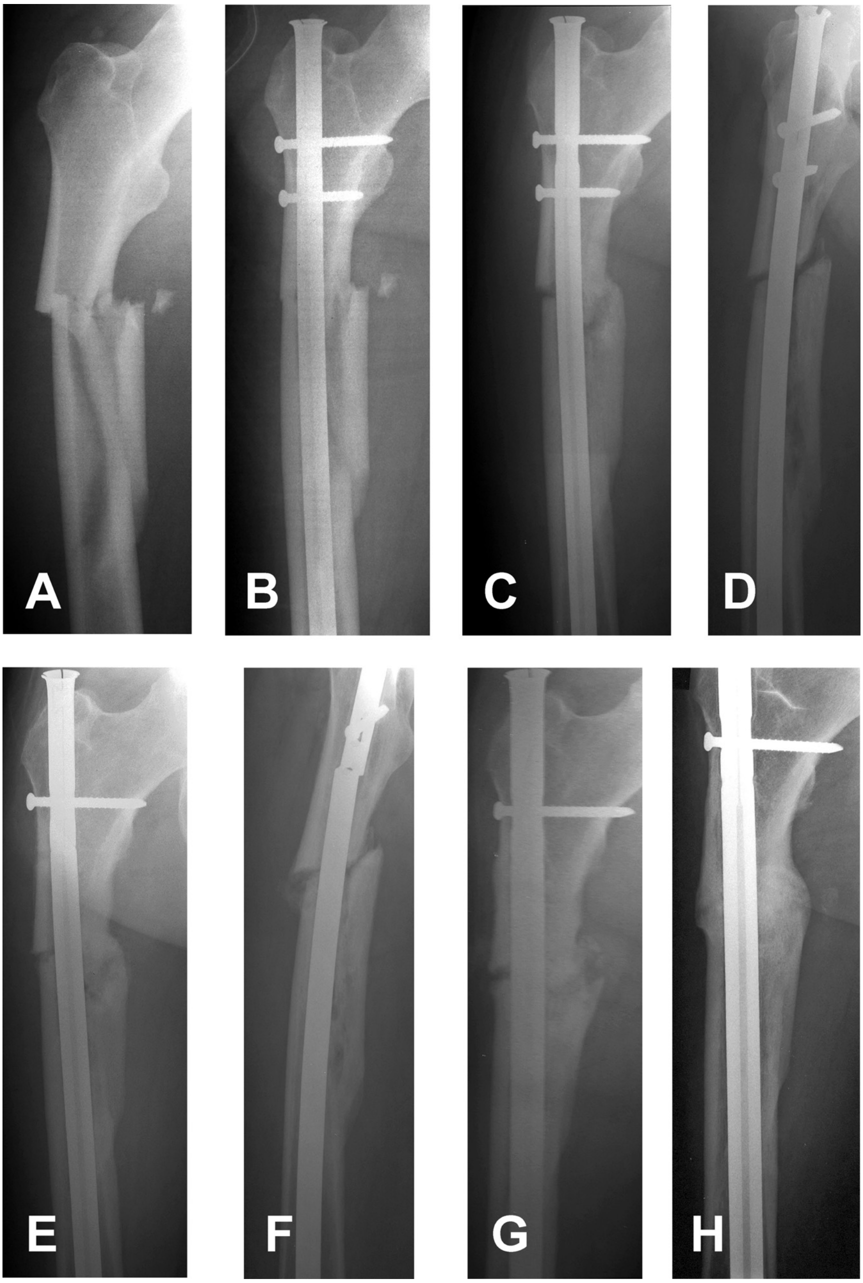

Figure 10.

A. A 36-year-old man fell from a height of eight meters resulting in a proximal comminuted (Winquist-Hansen Grade III) femoral shaft fracture, a facial bone fracture, and a distal radius fracture.

B. The right-sided femoral shaft fracture was treated with a static AO nail.

C.-E. Dynamization was performed after 8.5 months.

F. After 1.5 months the nail broke at one of the proximal screw holes.

G. Exchange nailing with a static 15-mm-nail with autogenous bone grafting was performed.

H. The fracture eventually showed signs of healing (IV).

Table 22. Patients with failed union of femoral shaft fractures after intramedullary nailing (N = 35). Modified from Pihlajamäki HK, Salminen ST, Böstman OM: The treatment of nonunions following intramedullary nailing of femoral shaft fractures. J Orthop Trauma 16:394-402, 2002; with permission from Lippincott, Williams & Wilkins. (IV)

Pa-ti-ent	Gender and Age (Years)	Winquist and Hansen Grade	IM-Nailing, Nail and Interlocking Types	Early Complications and Early Reoperations	Procedure for Failed Consolidation and Its Timing (Months)
1	F, 45	I	C, K, dynamic	Renailing for rotational instability	Dynamization (8)
2	F, 46	IV	C, K, dynamic	Iatrogenic intraoperative comminution open renailing for axial instability	Dynamization (5)
3	M, 28	III	C, AO, static	Iatrogenic intraoperative comminution	Exchange nailing (16)
4	F, 20	0	O, K-S, dynamic, two distal screws	Intraoperative comminution, a cross screw placed on the fracture level	Exchange nailing with autogenous bone grafting (4)
5	F, 18	IV	C, K-S, static	9º varus angulation, superficial wound infection	Dynamization and autogenous bone grafting (10)
6	F, 35	III	C, AO, static	Diastasis, 25º antecurvatum	Autogenous bone grafting (8)
7	M, 30	II	C, AO, dynamic, one dynamic proximal screw	None	Dynamization (5)
8	F, 37	IV	C, AO, static	Iatrognic intraoperative comminution, superficial wound infection	Exchange nailing (7)
9	F, 27	II	O, AO, static	Diastasis, delayed would closure	Dynamization (7)
10	F, 72	III	O, K, dynamic	Superficial wound infection	Exchange nailing (8)
11	M, 36	III	C, AO, static	None	Dynamization (9)
12	M, 53	III	C, K-S, dynamic, two distal screws	9º valgus angulation, a cross screw was placed on the fracture level, reapplication of a cross screw in a reoperation for axial instability	Autogenous bone grafting (7)
13	M, 46	0	C, K, dynamic	Intraoperative comminution, renailing for axial and rotational instability	Dynamization with autogenous bone grafting (17)
14	M, 54	0	O, K-S, static	Intraoperative comminution, renailing because of nail breakage after stumbling	Exchange nailing with autogenous bone grafting (13)
15	F, 27	II	C, K, dynamic	None	Exchange nailing (51)
16*	F, 27	III	C, K-S, static	None	Exchange nailing (52)
17	M, 31	0	C, AO, static	None	Dynamization (8)
18	M, 27	IV	O, K-S, static	None	Dynamization (10)
19	M, 20	IV	C, K-S, static	Intraoperative shortening	Dynamization (5)
20	M, 21	II	C, AO, dynamic, one dynamic proximal screw	None	Exchange nailing with autogenous bone grafting (14)
21	M, 43	IV	C, K-S, static	Intraoperative bending of the nail	Autogenous bone grafting (5)
22	F, 50	III	C, AO, dynamic, one static proximal screw	None	Autogenous bone grafting (21)
23	M, 40	III	C, K-S, dynamic, one proximal screw	Diastasis	Dynamization (11)
24	F, 27	0	C, K, dynamic	10º recurvatum	Exchange nailing (9)
25	M, 25	III	C, AO, static	None	Dynamization (9)
26	F, 45	IV	C, AO, static	Renailing for axial instability caused by osteoporotic bone	Dynamization (6)
27	M, 23	II	O, AO, dynamic, one dynamic proximal screw	Reapplication of a distal cross screw because of rotational instability	Exchange nailing (9)
28	F, 15	II	C, AO, static	Diastasis and cortical defect	Dynamization (4)
29	F, 34	II	O, K, dynamic	Renailing for axial instability, 20º antecurvatum	Autogenous bone grafting (6)
30	F, 34	IV	C, K-S, static	None	Dynamization (7)
31	M, 21	0	C, AO, static	Diastasis	Dynamisation (6)
32	M, 22	0	C, AO, static	Diastasis	Dynamization (3)
33	F, 51	0	C, AO, dynamic, one dynamic proximal screw	Proximal distal screw hole is on the fracture level	Exchange nailing (9)
34	F, 21	III	C, AO, static	Diastasis and cortical defect	Dynamization (8.5)
35	M, 31	III	O, K-S, static	Diastasis	Dynamization (5.5)

W-H, Winquist and Hansen classification; C, closed intramedullary nailing; O, open intramedullary nailing; K, Küntscher nail; AO, AO Universal Nail; K-S, Klemm-Schellmann nail,* the other femur of the same patient number 15.

The timing of the surgical treatment of the disturbed union process varied considerably. In eleven cases, the reoperation was performed between three and six months, in seventeen cases between six and twelve months, in five cases between one and two years, and in two cases more than two years after the primary nailing procedure.

In 25 fractures, one reoperation for nonunion was sufficient to unite the fracture. Six fractures were reoperated twice, and four needed three reoperations. The first reoperation consisted of dynamization of the nail alone in seventeen fractures, dynamization with autogenous bone transplantation in two cases, bone grafting alone with the nail in situ in five cases, exchange nailing alone in eight cases, and exchange nailing with autogenous bone grafting in three cases. All patients with autogenous bone grafting alone required a further reoperation for nonunion. After a dynamization procedure, four of seventeen patients required a further reoperation. After eight primary exchange nailing procedures, only one patient underwent subsequent surgery for nonunion. No deep infections complicated the reoperations.

The ununited fractures transformed into solid union within six months after the final successful reoperation. The ultimate functional recovery was compromised by shortening of the femur in six cases as follows: six centimeters in one, three centimeters in three, 2.5 centimeters in one, and two centimeters in one case. Four of these shortenings occurred in patients who had undergone dynamization. In one case, a valgus malunion of 9 degrees was seen after unsuccessful bone grafting and subsequent successful dynamization procedure. Excluding the patients with significant shortening of the femur, the final functional recovery was acceptable.

Figure 11.
A. A 20-year-old man hit a car with a motorbike and sustained a Grade II comminuted transverse open fracture of the left femoral midshaft.
B. The fracture was treated with open intramedullary nailing with a 11-mm Küntscher nail.
C.-D. The nail broke 2 months after the operation.
E. The nail was replaced with a reamed 13-mm Küntscher nail resulting in additional comminution and 4 cm shortening at the fracture site.
F. The newer nail was axially unstable.
G.-I. After bony union, the nail was removed 1.5 years after the initial trauma. A leg length discrepancy of 6 cm was detected.

Figure 12.
A. A 21-year-old woman who was injured in a truck that hit another car. She sustained a closed comminuted AO Type C 3.1.1-fracture of the left femoral shaft, rupture of the spleen and liver, a gallbladder contusion, a mesenterial hematoma, fractures of the pelvis and medial malleolus as well as fractures of the distal radius and metacarpals of the opposite side and a cardiac tamponation.
B.-D. The femoral shaft fracture was treated with a static 10-mm AO intramedullary nail.
E.-F. The fracture healing was delayed.
G.-H. The nail was dynamized after 8.5 months from the initial injury.
I.-J. The fracture healed after 1.5 years from the initial injury, and the nail was removed 2 years later.

Figure 13.

A. A 40-year –old man with gout arthritis hit a lamp post when driving a car, and sustained a closed, gradus III comminuted AO Type 32-B2.1 fracture of the left proximal femur.

B.-C. The fracture was initially treated with a dynamic 13-mm Klemm-Schellmann nail. A broken drillbit is also seen on the postoperative radiographs.

D.-E. A refracture has developed after removal of the nail.

F. Refixation was performed with an AO nail using two proximal interlocking screws.

G.-H. The nail was dynamized later, resulting in consolidation of the fracture. After 4 years from the initial trauma, the leg length discrepancy was 2 cm.

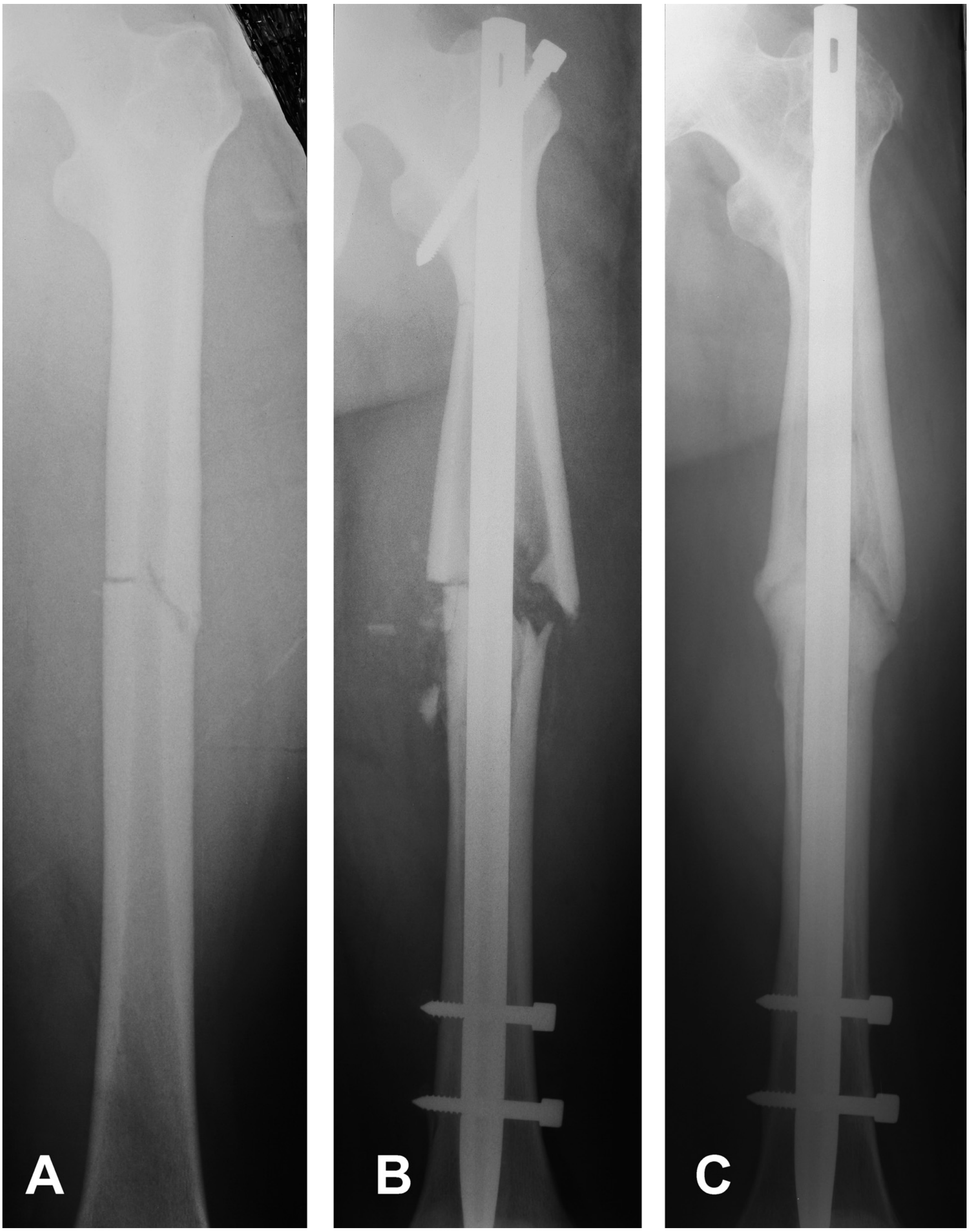

Figure 14.
A. A 46-year-old man twisted his left femoral diaphysis when he slipped from a pile of stones and sustained a Grade II open, non-comminuted (Winquist-Hansen Grade 0), AO Type 32-A3.2 fracture.
B. The fracture was treated with a 15-mm Küntscher nail (closed nailing) that caused additional comminution of the proximal part. After 4 days, the nail was exchanged for a static 14-mm Klemm-Schellmann nail without additional reaming.
C. Autogenous bone grafting and dynamization of the nail was performed at 17 months resulting in bony union 6 months later.

Figure 15.
A.-B. A 20-year-old car driver had a collision with another car and sustained a comminuted AO Type 32-C3.3. fracture.
C.-E. The fracture was treated with a 13-mm Klemm-Schellmann nail. The 4 cm shortening was a result of the initial fracture.
F.-G. Dynamization of the nail proximally and additional bone grafting were performed 5 months later.
H.-I. After the removal of the nail, the use of a 2 cm shoe lift was necessary.

6. GENERAL DISCUSSION

6.1. Incidence of femoral shaft fractures

The risk of sustaining a femoral shaft fracture is thought to vary in different populations. The peak occurrence of femoral shaft fractures in males from 15 to 24 years of age is a well known phenomenon, but the incidence figures reported vary considerably. The incidence in that age group, 39 per 100 000 person-years in the epidemiologic study (I), was found to be as high as 64.6 per 100 000 person-years in Rochester, Minnesota (122 fractures during 20 years) (Arneson et al. 1988). The incidence in a male age group from 20 to 29 years was 191 per 100 000 inhabitants, and in a female group 26 per 100 000 inhabitants in the Netherlands (Kootstra 1973). In a Swedish population-based study (including 362 fractures during 33 years), the average annual incidences in male age groups from 10 to 19 years and from 20 to 29 years were 14.7 and 9.2 per 100 000 inhabitants in the 1980s (Bengnér et al. 1990).

In addition, the age-related features in the incidence of femoral shaft fractures appear to vary in different populations. Only one previous study, examining the mixed Asian population in Singapore, as well as the study from the Netherlands (Kootstra 1973), showed a tendency similar to that observed in the epidemiologic study (I): an increase in incidence with aging was observed only among women (Wong 1966). A few other, earlier studies indicated that the incidence of diaphyseal femoral fractures increased with age in men and women. This was the case in the urban populations of Dundee and Oxford in the United Kingdom (Knowelden, Buhr, Dunbar 1964), of Stockholm (Hedlund and Lindgren 1986) and Malmö (Bengnér et al. 1990) in Sweden, and of Rochester, Minnesota (Arneson et al. 1988). Of these, only the Rochester data showed a clear increase in distal femoral fractures with age, similar to the findings of the epidemiologic study (I), but the Rochester survey also included fractures distal to the diaphyseal section of the bone.

In the study concerning displaced femoral shaft fatigue fractures (III), the incidence in conscripts to sustain a displaced femoral shaft fatigue fracture was 1.5 per 100 000 person-years in military service. Previous studies have mainly been case reports (Asal 1936; Wolfe and Robertson 1945; Morris and Blickenstaff 1967; Hallel, Amit, Segal 1976; Orava 1980; Luchini, Sarokhan, Micheli 1983; Dugowson, Drinkwater, Clark 1991; Visuri and Hietaniemi 1992; Clement et al. 1993), although two more extensive studies have been published (Provost and Morris 1969; Bargren, Tilson, Bridgeford 1971), but the true incidence, the morphologic characteristics, and the long-term treatment results of these fractures have not been systematically examined before (Table 23.). For the study III, the age distribution of the patients was more specific: the majority of conscripts are 19 years of age at the beginning of their basic training. In general, military service is completed within two years following call-up, at the age of 19 to 20. It is possible to volunteer at 18, and deferment can be granted until the end of the year in which the man turns 28. Conscripts enter the Army, the Air Force and the Navy twice a year. Military service lasts 180, 270 or 362 days. Military service on a voluntary basis for women in Finland started in 1995 (Public Information Division of the Defence Staff 2004).

For a military conscript, the risk of sustaining a fatigue fracture has been reported to increase due to poor physical condition (Gilbert and Johnson 1966; Shaffer et al. 1999), low level of prior physical activity (Gilbert and Johnson 1966; Shaffer et al. 1999), low tibial and femoral bone density (Beck et al. 1996), small diaphyseal dimensions of the tibia and the femur (i.e. a short and thin femoral shaft) (Beck et al. 1996), malalignment and length differences of the lower extremities (Sahi 1984; Matheson et al. 1987), poor strength of the lower leg muscles (McBryde 1985), poor training procedures (Gilbert and Johnson 1966; Greaney et al. 1983), and excessive training in specific subunits (Gilbert and Johnson 1966; Hallel, Amit, Segal 1976; Meurman, Somer, Lamminen 1981; Sahi 1984; Shwayhat et al. 1994). During common conscript training, identical weight packs and other equipment are carried, regardless of the conscript's body stature. Provost and Morris (1969) observed that a large weight gain during the early weeks of basic training and minor prior physical activity were typical of patients sustaining a displaced femoral shaft fatigue fracture. Obese individuals may be at an increased risk for stress fractures in general, although several studies on the epidemiology of stress fracture types in military service failed to find an association between stress fractures and anthropometric variables in either gender (Schmidt Brudvig, Gudger, Obermeyer 1983; Shaffer et al. 1999). In one recent study, it was reported that soldiers with stress fractures detectable in scintigraphy weighted and smoked less than control subjects (Givon et al. 2000). In the study III, the median body mass index of the concripts was normal, while only one conscript was underweight and one was obese.

Before the fracture displacement, nine conscripts experienced thigh or knee pain for 1 to 6 weeks. According to Provost and Morris (1969) and Hershman et al. (Hershman, Lombardo, Bergfeld 1990), the pain is usually poorly localized and vague. To increase the accuracy of diagnosis, a fulcrum test (Johnson, Weiss, Wheeler 1994), a fist test (Milgrom et al. 1993), a hop test (Clement et al. 1993), radiographs every 2 weeks (Bargren, Tilson, Bridgeford 1971), and scintigraphy (Visuri and Hietaniemi 1992) or MRI (Kiuru 2002; Lassus et al. 2002) in suspected cases have been recommended. However, displacement can occur even without preceding symptoms (Luchini, Sarokhan, Micheli 1983), as was the case with one patient of the study III.

Table 23. Cases of Displaced Femoral Shaft Fatigue Fractures Reported in Previous Studies. Modified from Salminen ST, Pihlajamäki HK, Visuri TI, Böstman OM: Displaced fatigue fractures of the femoral shaft. Clin Orthop Relat Res 409:250-259, 2003; with permission from Lippincott, Williams & Wilkins. (III)

Study and Year	Number of Patients	Population Type	Age and Gender (Years)	Prior Pain Symptoms	Fracture Location	Fracture Type	Fracture Treatment
Asal 1936	1	Military conscript	20, M	2½ weeks, knee and thigh	Middle-distal	Not reported	Nonoperative
Wolfe and Robertson 1945	1	Military conscript	18, M	4 weeks, thigh	Middle-distal	Not reported	Skin traction
Morris and Blickenstaff 1967*	1	Military conscript	22, M	1 week, thigh	Proximal-middle	Not reported	Küntscher IM nail and bone grafting
Provost and Morris 1969	16	Military conscripts	19–24, M	1 week, knee ½-2 weeks, knee 2-3 weeks, thigh	1 Proximal 6 Middle 9 Distal	Not reported Spiral-oblique Transverse	Not-reported Skeletal traction Skeletal traction
Bargren et al. 1971*	8	Military conscripts	Not reported	Not reported	Not reported	Not reported	Not-reported
Hallel, Amit, Segal 1976 *	1	Military	Not reported	1 week, knee	Distal	Not reported	Plate fixation
Orava 1980 *	3	conscripts	Not reported	Not reported	Distal	Not reported	AO plate fixation
Luchini, Sarokhan, Micheli 1983	2	Athletes Runners	38, M; 23, F	No symptoms	Middle	Long oblique and transverse	IM nail
Dugowson, Drinkwater, Clark 1991	1	Runner	32, F	3 weeks, thigh	Proximal-middle	Comminuted	IM nail
Visuri and Hietaniemi 1992 **	3	Military conscripts	19–20, M	2-6 weeks	Distal	Oblique	IM nail, AO plate
Clement et al. 1993 *	1	Athlete	32, F	5 weeks	Middle	Not reported	IM nai
Current Study	10	Military conscripts	18–20, M	1-6 weeks, knee and/or thigh	1 Proximal 3 Middle 6 Distal	4 Oblique 4 Oblique-transverse 2 Spiral	5 IM nail 4 DCP 1 DCS

*F = female; M = male; DCP = Dynamic Compression Plate; DCS = Dynamic Condylar Screw; *Included also undisplaced fatigue fractures; **Patients included in the present study*

6.2. Injury season and injury mechanisms of femoral shaft fractures in adults

The epidemiologic study (I) showed that a third of the fractures occurred between July and September, suggesting a similar tendency as in the Kootstra study (1973). Based on the data of the epidemiologic study (I), the main group sustaining high energy trauma in road traffic accidents composed of automobile drivers.

Even if three-fourths (3/4) of the femoral shaft fractures were caused by high energy trauma, the number of low energy fractures was remarkable (I, II). The most common cause of a diaphyseal fracture in the elderly was low energy trauma. This observation and the excess of female patients indicate that osteoporosis is a major causative factor among the older age group.

Previous data regarding the specific features of femoral shaft fractures caused by low energy trauma are limited. In two-thirds of our patients, there was a pre-existing condition likely to cause osteopenia of the femur. According to a prior study of cadaver femora and tibia, a consistent decrease with age of all mechanical properties has been evident, with the exception of plastic modulus in femoral but not in tibial specimens (Burstein, Reilly, Martens 1976). Consequently, weakening of the mechanical strength of the femora could be expected to be present in the older patients, even without any other predisposing factors.

It has been estimated that every third person older than 64 years falls at least once each year (Campbell et al. 1981; Prudham and Evans 1981; Lach et al. 1991; Forinash and Meade 2000; Carter, Kannus, Khan 2001), and that 3.5-10% of these falls can cause a fracture (Baker, O'Neill, Karf 1984; Tinetti et al. 1988; Campbell et al. 1990; Forinash and Meade 2000). Using this data, the incidence of low energy femoral shaft fractures in the elderly, 8 cases per 100 000 person-years in the study II, indicates that one out of 400 fractures in the elderly is a low energy femoral shaft fracture. Kannus et al. (1997) examined the trends in the incidence of fall-induced injuries in Finland for 1970-95. They discovered that the number of elderly patients with fall-induced injury increased considerably, from 4019 in 1970 to 17 604 in 1995. The average increase was 13.5% per year. The age-adjusted incidence (per 100 000 60-year-old or older individuals) of injuries showed a clear increase from 1970 to 1995: 840 to 1911 in women, and 484 to 1167 in men. In 1995, 65% of these injuries were bone fractures.

6.3. Concomitant injuries related to femoral shaft fractures in adults

As expected, the occurrence of concomitant injuries was related to high energy trauma (I). Fractures caused by low energy injuries seemed to occur without concomitant injuries (II), which was likewise to be expected owing to the low energy nature of the injury. In contrast, 47% of patients with femoral shaft fractures from high energy impacts have been reported to exhibit significant associated injuries (Taylor, Banerjee, Alpar 1994).

6.4. Morphology of femoral shaft fractures in adults

In concordance with a previous study (Wong 1966), most of the femoral shaft fractures occurred in the middle third of the femur (I). The epidemiologic study (I) showed that the patients with spiral fractures were older than those with other types of fractures. The study of the femoral shaft fractures caused by low energy injuries (II) showed that spiral fractures are typical of a low energy mechanism.

Regarding the degree of comminution, only 1/5 of the fractures represented the severely comminuted Winquist and Hansen Grade III and Grade IV fractures (I). The original Winquist and Hansen classification was intended for grading of comminuted fractures only (Winquist and Hansen 1980), but, later other authors added Grade 0 to represent a noncomminuted fracture (Johnson, Johnston, Parker 1984). However, the benefit of separating Grade 0 and Grade I from each other seems questionable or even meaningless for the treatment of the fracture.

The distribution of femoral shaft fractures according to the AO Type in the epidemiologic study (I): Type A 48%; Type B 39%; and Type C 13%, was close to the percentages reported by some AO clinics (Type A 53%, Type B 34%, and Type C 13%) (Müller et al. 1990). However, with 27 subgroups with additional ramifications, the AO classification seems unnecessarily detailed and complex in classifying femoral shaft fractures. This observation has been pointed out by other authors as well (Bucholz and Jones 1991; Lichtenhahn, Fernandez, Schatzker 1992; Bernstein et al. 1997). In the epidemiologic study (I), the use of three B types appeared to offer limited value. Moreover, it was impossible to elect a precise AO subtype categorization for some fractures, particularly within the B category.

In femoral shaft fractures caused by low energy injury (I), the most common fracture pattern was a simple spiral fracture, with minimal comminution, in the middle third of the femoral shaft. Furthermore, in a previous series focusing on longitudinal femoral shaft fractures, 56% of the cases were found to have been caused by low energy trauma (Varjonen et al. 1990). From the radiological fracture patterns and the mechanisms of injury, the amount of energy involved in producing the fractures can be estimated (Alms 1961). A simple spiral fracture results from a torsional low energy injury mechanism. Accordingly, comminution of the fragments was rare in the present series.

The displaced fractures were mainly located in the distal third of the femoral shaft (III). This is also in concordance with several prior reports on femoral shaft fatigue fractures (Wolfe and Robertson 1945; Provost and Morris 1969; Hallel, Amit, Segal 1976; Visuri and Hietaniemi 1992). With regard to their morphologic features, the fatigue fractures clearly differed from femoral shaft fractures caused by low energy trauma (I). In the distal third of the diaphysis, most of the fatigue fractures were noncomminuted oblique or oblique-transverse types. One displaced fracture had an exceptional location in the proximal third, a site reported only once before in the literature (Provost and Morris 1969). No explanatory differences in the constitution of this patient could be identified.

A displaced fatigue fracture can be primarily comminuted (Dugowson, Drinkwater, Clark 1991), like one fracture with a Grade II comminution in the current study. The bone at the fracture tended to be brittle, and likely to be more easily shattered during the fixation procedure. Gentle handling of the bone during surgery is imperative also in fatigue fractures. (III)

6.5. Treatment, outcome and complications of femoral shaft fractures in adults

When dealing with a semiurban population similar to the one presented in the epidemiologic study (I), extensive resource allocation for allied subspecialties, such as plastic surgery or vascular surgery, is probably not required for femoral shaft fractures, because severe open fractures, Gustilo Types IIIB and IIIC, seem to be rare. Based on the epidemiologic data from this study (I), most of the femoral shaft fractures in this population can be treated adequately with conventional intramedullary nails, with the stability of fixation and fracture alignment maintained.

In femoral shaft fractures caused by low energy injuries (II), complications occurred in nearly two-thirds of our patients, and thus the complication rate associated with these fractures must be considered high. The failures of fixation resulting in shortenings were clearly iatrogenic complications, which could have been avoided by using static interlocking nailing. In a previous study, 14 patients out of 133 with femoral shaft fractures suffered a similar loss of postoperative fixation and reduction (Brumback et al. 1988b). Meticulous preoperative planning of surgical treatment of fatigue fractures is important, because errors in surgical judgement attributed to inadequate preoperative analysis of the pattern of the fracture, undetected intraoperative comminution during reaming or insertion of the nail, or postoperative failure to recognize an increase in comminution and instability of the fracture were noted in that study. Undoubtedly, those conclusions are valid for the study II as well.

In previous studies, with the high age of the patients, the complication rates recorded have been slightly lower than in our study. In a study of patients over 65 years of age with 25 subtrochanteric, 47 shaft, and 33 supracondylar femoral fractures, the overall complication rate was 45% (Boyd and Wilber 1992). In that study, the local complication rate (wound infection, nonunion, malunion, and implant failure) was found to be 15%. In another study, 24 patients over 60 years of age with femoral shaft fractures were treated with locked nailing, and the total complication rate was 54% (Moran, Gibson, Gross 1990). Earlier mortality rates, reported within 30-60 days of injury, have ranged from 10 to 17% (Moran, Gibson, Gross 1990; Boyd and Wilber 1992). These rates approach the rate of 10% of the study II. Infection after closed intramedullary nailing of the femur has been previously reported to occur in less than 1% of patients (Winquist, Hansen, Clawson 1984). This is considerably less than the infection rate of 10% in the study II. As for the infection rate, a local soft-tissue lesion caused by a direct-impact injury seems to be less important than the compromised general infection resistance among elderly patients with multiple pre-existing diseases. Such patients could possibly benefit from routine perioperative administration of antibiotic prophylaxis.

Despite the low energy nature of the violence, and simple fracture configuration, uninfected nonunion and malunion were common in the study II. Some of these complications could be regarded as iatrogenic. A pre-existing general or local condition weakens the mechanical strength of the femur and is likely to make the internal fixation of these fractures technically very demanding. Even with an adequate and accurate preoperative planning and operative technique, a subsequent nonunion or malunion might be unpreventable among some patients with a low energy femoral shaft fracture.

Compared with the femoral shaft fractures caused by high energy trauma, the fractures attributable to fatigue osteopathy (III) healed well, despite comminution, with a median union time of 3.5 months. No delayed unions or nonunions occurred. In comparison, in a recent prospective series including 83 patients with trauma treated by reamed intramedullary femoral nailing, the fractures united within 3.8 months, the average time to union being 2.7 months (Tornetta and Tiburzi 2000). The frequency of local complications, including infection, mechanical failure, delayed union, uninfected nonunion, refracture, or simple malunion, has been 20% in traumatic femoral shaft fractures of young patients (Böstman et al. 1989). Overuse injuries present the physician a number of challenges: to determine the diagnosis, and etiology of the injury to judge the most suitable treatment, and to ensure that the fracture does not recur (Brukner, Bennell, Matheson 1999).

In the study IV, the nonunion rate of femoral shaft fractures treated with intramedullary nailing was 12.6% (IV). When compared with this, the complication rate seems, not unexpectedly, to be lower in fatigue fractures (III).

More than one tenth of the patients of the study IV required additional surgery for failed consolidation. The incidence of this complication was noteworthy. Two prior studies on femoral shaft fractures also reported a nonunion rate as high as 10 percent (Kempf, Grosse, Beck 1985; Hanks, Foster, Gardea 1988), with one study even as high as 13.6 percent (Eid and Deif 1980). In contrast, some authors have reported considerably lower nonunion rates, such as 0.9 percent in 520 patients with unlocked intramedullary nails (Winquist, Hansen, Clawson 1984), and 2 percent in three separate studies with 283 patients (Klemm and Börner 1986), 112 patients (Wiss et al. 1986), and eighty-four patients (Brumback et al. 1988b) having comminuted fractures that were treated by interlocking nailing. In a recent prospective series including eighty-three patients treated by reamed femoral nailing, all fractures united within 115 days, the average time to union being eighty days (Tornetta and Tiburzi 2000). The incidence seems to be lowest in specialized units maintaining a strict and uniform management regimen.

The occurrence of technical faults during primary nailing can, in part, be explained by the nature of the teaching hospital. Most of the operations were performed by senior residents, some of whom were still in the beginning of their learning curve for the more demanding intramedullary nailings. Avoidance of increased comminution during intramedullary nailing as well as static interlocking in diastasis should be pointed out in the training of junior residents. A previous report also paid attention to the adverse effect of opening the fracture site during the nailing procedure (Rokkanen, Slätis, Vankka 1969). In contrast to several earlier reports (Curylo and Lindsey 1994; Kelly 1984; Klemm and Börner

1986), infection did not play an important role in the development of nonunion in the study IV.

In the epidemiologic study on 201 fractures (I), Type B1 fractures, which represent the fractures with a large butterfly fragment, amounted to 10.5 percent. In the study IV, a large butterfly fragment was present in 34 percent of the nonunions. This seems to indicate a significant role of large butterfly fragments and a possible concomitant muscle interposition in the development of failed union. In the study IV, due to the designation of the hospital as a referral center for the catchment area, no patients were missing from the follow-up, and the development of truly recalcitrant nonunions was avoided as well.

The time interval between the primary nailing procedure and the correct identification of a disturbance in the union process showed unexpected variation. In several cases, especially in those with broken intramedullary nails, the delay before operative procedures were undertaken was unacceptably long. Expectancy is seldom warranted when a diagnosis of failed consolidation has been made. The problems associated with broken nails and the importance of avoiding nail breakages have been stressed by some previous authors, too (Bucholz, Ross, Lawrence 1987; Franklin et al. 1988). The conventional division of the radiographic appearance of nonunion into atrophic and hypertrophic did not seem to offer any value in the femoral shaft fractures after intramedullary nailing.

One third of the cases of the study IV required two or three reoperations before union could be achieved. It is difficult to compare this finding to prior documentation with varying initial treatment of patients, including those with fractures of the subtrochanteric and supracondylar regions of the femur, or even fixation of osteotomies and tibial fractures (Christensen 1970; Solheim and Vaage 1973; Oh et al. 1975; Okhotsky and Souvalyan 1978; Kempf, Grosse, Rigaut 1986; Webb, Winquist, Hansen 1986; Wu and Shih 1992; Curylo and Lindsey 1994; Cove et al. 1997; Ring, Barrick, Jupiter 1997; Kempf and Leung 2002). Nonunion after plate fixation requires a different policy of treatment of failed consolidation, because direct surgery on the fracture site is necessary for removal of the hardware (Webb, Winquist, Hansen 1986; Böstman et al. 1989). In light of the results of the study IV, autogenous bone grafting from the iliac crest to the fracture site without any additional measures, such as exchange intramedullary nailing or dynamization, seemed to be useless, whereas exchange intramedullary nailing was an effective method without any serious complications. Bony consolidation was likewise accomplished by dynamization, without a need for additional reoperations, in cases where the fracture gap was the principal problem. However, according to a previous report, significant axial femoral shortening may result from dynamization (Wu 1997). The findings of the study IV confirmed the practical value of the previously presented concept of exchange nailing without supplemental external bone grafting as the preferred treatment method of femoral diaphyseal nonunion (Christensen 1970; Wu and Chen 1997; Furlong et al. 1999; Wu and Chen 2002; Yu, Wu , Chen 2002). Nevertheless, in a recent series of nineteen patients with ununited femoral shaft fracture treated by exchange nailing, nine required one or more additional procedures before solid union was achieved, and no factors of predictive value could be identified (Weresh et al. 2000). Classifying nonunions into atrophic and hypertrophic was not applicable to consolidation failures after intramedullary nailing.

6.6. Prevention of femoral shaft fractures

Preventive measures against femoral shaft fractures should focus on the active and passive protection of automobile drivers, especially young men (I), and on the prevention and treatment of osteoporosis in elderly women (I, II).

Displacement is a rare, undesirable consequence of fatigue osteopathy of the femoral shaft among young conscripts during basic military training (III). Internal fixation is required in all displaced femoral shaft fatigue fractures. Preventive methods should focus on an early, effective detection of these fatigue fractures to avoid fracture displacement with a subsequent prolonged morbidity. The conclusions may be applicable beyond the circumstances of military service, since freetime training has increased among people to a considerable degree. So far, however, only a few sports-related cases of displaced femoral shaft fatigue fractures have been reported (Orava 1980; Luchini, Sarokhan, Micheli 1983; Dugowson, Drinkwater, Clark 1990; Clement et al. 1993). The preventive methods include training appropriate to individual physiology, and early recognition of fatigue osteopathy with radiographic, scintigraphic, or preferably MRI examinations. Above all, conscripts, even the most ambitious, should be taught to seek medical attention as soon as symptoms indicative of fatigue osteopathy emerge.

7. SUMMARY AND CONCLUSIONS

7.1. Demography of femoral shaft fractures in adults

Based on the data of the epidemiologic study (I), one-third of traumatic fresh femoral shaft fractures occurred during the third quadrant of the year. The distribution of males sustaining a femoral shaft fracture at that time was noteworthy. The amount of fresh femoral shaft fractures in women was highest during the fourth quadrant of the year. Even if 75% of the femoral shaft fractures were caused by high energy trauma, the number of low energy fractures was remarkable. The main group sustaining high energy trauma were automobile drivers in road traffic accidents. The occurrence of concomitant injuries was, expectedly, related to high energy trauma, whereas no significant associated injuries were seen in patients with a low energy femoral shaft fracture. The most common cause of a diaphyseal fracture in the elderly was low energy trauma. This observation together with the excess of female patients indicates that osteoporosis can be a major causative factor among the older age group. Femoral shaft fractures caused by low energy violence mainly occur in patients suffering from a chronic disease or a condition causing osteopenia of the femur. The study (I) showed that the patients with spiral fractures were older than those with other types of fractures.

With regard to their incidence features, femoral shaft fractures caused by different injury mechanisms vary (I, II, III). The study of femoral shaft fractures caused by low energy injuries (II) showed that spiral fractures are typical low energy injuries. Summarizing the results of the study II, it appears that a fracture of the femoral shaft is only seldom caused by low energy trauma without some predisposing factor that has weakened the mechanical strength of the bone. The incidence of traumatic fractures of the adult femoral diaphysis was 9.9:100 000 person-years, with higher age- and gender-specific incidences among young men aged 15 to 24 years and elderly women 75 years old or older (I). The incidence of femoral shaft fractures caused by low energy injuries was 2.5:100 000 person-years, and was higher for people aged 60 years or older (II). The incidence in conscripts to sustain a displaced femoral shaft fatigue fracture was 1.5:100 000 person-years in military service (III).

Displacement of a femoral shaft fatigue fracture can occur even without preceding symptoms. Despite unclear knee or thigh pain for 1 to 6 weeks, femoral shaft fatigue fractures in otherwise healthy conscripts were diagnosed only after fracture displacement.

7.2. Morphology of femoral shaft fractures in adults

The study of femoral shaft fractures caused by low energy injuries (II) showed that spiral fractures are typical low energy injuries. Summarizing the results of the study II, it seems that a fracture of the femoral shaft is only seldom caused by low energy trauma without some predisposing factor that has weakened the mechanical strength of the bone.

Regarding the morphologic features, femoral shaft fractures caused by different injury mechanisms vary (I, II, III). Most traumatic femoral shaft fractures were isolated without concomitant injuries (I). The most common traumatic fracture type of the femoral shaft was a simple AO Type A, non-comminuted, purely transverse, and located in the middle third of the femur (I). The patients with spiral fractures and with fractures located in the distal third of the femoral shaft were older than those with other types of fractures (I). The most common fracture pattern related to low energy trauma was a simple AO Type A spiral fracture, with minimal or no comminution, in the middle third of the femoral shaft (II). Femoral shaft fractures caused by low energy trauma were morphologically different from displaced fatigue fractures, which were mainly of simple AO Type A, noncomminuted oblique, or oblique-transverse, located in the distal third of the femoral shaft (III). A displaced fatigue fracture of the femoral diaphysis can be primarily comminuted (III).

7.3. Treatment of femoral shaft fractures in adults, and nonunions after intramedullary nailing

Based on the data from the epidemiologic study (I), most of the femoral shaft fractures in the community can be treated adequately with conventional intramedullary nails rather than interlocking nails, with the stability of fixation and fracture alignment maintained.

The complication rate in fractures caused by low energy trauma is high (II). The treatment of these seemingly simple fractures requires careful planning and a meticulous operative technique (II).

Factors that predispose traumatic fresh femoral shaft fractures to nonunion after intramedullary nailing are related to severe fracture comminution and concomitant injuries. Without convincing signs of progressive consolidation of a femoral shaft fracture, reoperation should be performed within six months of the primary nailing to minimize the risk of nail breakage. Exchange nailing seems to be the method of choice for the treatment of a disturbed union. In some selected cases with primary static interlocking nailing, dynamization alone can be considered. Bone grafting alone as a treatment of a failed union of a femoral shaft fracture cannot be recommended (IV).

7.4. Prevention of femoral shaft fractures in adults

Based on the data of the epidemiologic study (I), preventive measures against femoral shaft fractures should generally focus on the protection of automobile drivers, especially young men, and on the effective treatment of osteoporosis in elderly women.

Furthermore, preventive methods should focus on an early, effective detection of fatigue fractures to avoid fracture displacement with subsequent prolonged morbidity, including training appropriate to individual physiology, and early recognition of fatigue osteopathy with radiographic, MRI, and scintigraphic examinations. Above all, conscripts, even the most ambitious, should be taught to seek medical attention as soon as symptoms indicative of fatigue osteopathy emerge.

On the basis of the present results, the following conclusions can be drawn:

Femoral shaft fractures in adults are not exclusively results of high energy trauma. Low energy trauma causes 25% of the fractures (I). Femoral shaft fractures caused by low energy mechanism mainly occur in patients suffering from a chronic disease or a condition causing osteopenia of the femur (II). Concerning displaced femoral shaft fatigue fractures, even in symptomatic fractures, the diagnosis was delayed until displacement, which can also occur without preceding symptoms (III).

With regard to their incidence and morphologic features, femoral shaft fractures caused by different injury mechanisms vary (I, II, III). The incidence of traumatic fractures of the adult femoral diaphysis was 9.9:100 000 person-years, with higher age- and gender-specific incidences among young men aged 15 to 24 years and elderly women 75 years old or older (I). The incidence of femoral shaft fractures caused by low energy injuries was 2.5:100 000 person-years, and was higher for people aged 60 years or older (II). The incidence in conscripts to sustain a displaced femoral shaft fatigue fracture was 1.5:100 000 person-years in military service (III).

Most traumatic femoral shaft fractures are isolated without concomitant injuries (I). The most common fracture type of the femoral shaft is a non-comminuted simple AO Type A, most of which in traumatic fractures are purely transverse and located in the middle third of the femur (I), in fractures related to low energy trauma spiral in the middle third of the femur (II), and in displaced fatigue fractures oblique or oblique-transverse located in the distal third of the femoral shaft (III). In traumatic fractures, the patients with spiral fractures, and with fractures located in the distal third of the femoral shaft, are older than those with other types of fractures (I). Femoral shaft fractures caused by low energy trauma are morphologically different from displaced fatigue fractures, which can also be primarily comminuted (III).

Despite the low energy mechanism and seemingly simple morphology of fractures, treatment of femoral shaft fractures caused by low energy trauma is not devoid of complications, and requires careful planning and a meticulous operative technique (II). In displaced femoral shaft fatigue fractures, gentle handling of the bone during the fracture fixation is imperative due to the extraordinary brittleness of the fracture fragments (III). Despite the additional comminution intraoperatively, the complication rate seems to be low (III).

Preventive methods against traumatic femoral shaft fractures should be focused on the protection of automobile drivers, especially young men, and on preventing low energy injuries in elderly women (I, II). Preventive methods against femoral shaft fatigue fractures should focus on an early, effective detection of these fractures to avoid fracture displacement with a subsequent prolonged morbidity (III).

Factors that predispose traumatic fresh femoral shaft fractures to nonunion after intramedullary nailing are related to severe fracture comminution and concomitant injuries. Without convincing signs of consolidation in progress among traumatic femoral shaft fractures treated with intramedullary nailing, reoperation should be performed within six months after primary nailing to minimize the risk of nail breakage. Exchange nailing seems to be the method of choice for the treatment of a disturbed union. In some selected cases, with primary static interlocking nailing, dynamization alone can be considered. Bone grafting alone as a treatment of a failed union of a femoral shaft fracture cannot be recommended (IV).

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Notation of references according to the recommendation of the Medical Faculty of the University of Helsinki.