ETIOPATHOLOGY AND TREATMENT-RELATED ASPECTS OF HIP FRACTURE

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Abstract

Hip fracture is a trauma with serious consequences, especially in the elderly. Etiological factors should be known better than nowadays to recognize the individuals at high risk. Also, the treatment of displaced femoral neck fractures has been controversial, and the factors leading to a functional outcome are not known well. The true impact of deep infection on the outcome after hip fracture surgery has also been insufficiently examined.

The thesis is based on two etiological studies. In the first study, the geometrical parameters of the upper femur and pelvis in postmenopausal women with hip fracture were (n = 70) compared to age-adjusted controls (n = 40). Measurements were made from position-standardized and calibrated pelvic plain x-rays. The differences between the two different types of hip fracture, femoral neck fractures (n = 46) and trochanteric fractures (n = 24) were also defined. High femoral neck/shaft angle (NSA), thin femoral cortices, low femoral shaft diameter (FSD) and trochanter width and the pelvic dimensions associate strongly with the hip fracture risk in postmenopausal women. Greater NSA, smallest outer pelvic diameter and acetabular width, narrower FSD and smaller femoral neck/shaft cortex ratio were associated with femoral neck fracture rather than trochanteric fracture in postmenopausal women. In the second study, lifetime factors, some bone metabolism markers and bone mineral density were analyzed from postmenopausal women (n = 74; 49 with femoral neck fracture, 25 with trochanteric fracture) and age-adjusted controls (n = 40). Impaired functional ability, use of loop diuretics, antidiabetic, antidepressant and neuroleptic drugs, some concurrent diseases, such as stroke, diabetes, malignancy, cardiovascular diseases, low bone mineral density of the upper femur, low serum calcium, low serum 25-hydroxyvitamin D and high serum calcitonin, seem to be related to the risk of hip fracture, while low bone mineral density and low serum calcitonin are related to the trochanteric type of fracture in postmenopausal women.

The treatment of displaced femoral fractures included two prospective case-control studies, and the first of these involved a comparison (357 matched pairs) of patients with osteosynthesis (OS) with two pins in Lund and patients with uncemented hemiarthroplasty (HA) in Oulu. The patients treated with OS had 4 months after fracture better ambulatory capacity, used walking aids less often and had less pain than the patients treated with HA. The other comparison (84 matched pairs) was made between OS with three screws and uncemented HA, and it revealed no significant differences between HA and OS in the short-term functional outcome. Both studies revealed a higher re-operation rate in OS patients than uncemented HA patients. The case-control study with 29 matched pairs showed that deep infection after a hip fracture operation impairs the short-term functional outcome and slightly increases mortality, with an attributable mortality rate of 10 %. In conclusion, this thesis suggests that the geometry of the upper femur and pelvis, the aforesaid lifetime factors, the aforesaid metabolism markers and bone mineral density are associated with the etiopathology and type of hip fracture in postmenopausal women. The short-term functional outcome was better in OS patients treated with two pins compared to uncemented HA, but the higher re-operation rate should be considered among the OS patients. Deep infection is a serious complication of hip fracture surgery, which impairs function and increases mortality.

Keywords: bone geometry, functional outcome, hemiarthroplasty, hip fracture, osteosynthesis

To Mirja, Henrietta and Herkko

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Abbreviations

ADL	Active daily living
AP	Anteroposterior
AW	Acetabular width
BMC	Bone mineral content
BMD	Bone mineral density
BMI	Body mass index
CFE	Calcar femorale
CV	Coefficient of variation
CV_{rms}	Root mean square coefficient of variation
CRP	C-reactive protein
DXA	Dual X-ray absorptiometry
DHS	Dynamic hip screw
FEBMD	Femoral neck bone mineral density
FNALa	Femoral neck axis length a
FNALb	Femoral neck axis length b
FNC	Femoral neck cortex
FSC	Femoral shaft cortex
FSD	Femoral shaft diameter
FX (and fx)	Fracture
HA	Hemiarthroplasty
HAL	Hip axis length
HD	Head diameter
LIPD	Largest inner pelvic diameter
ND	Neck diameter
NSA	Neck-shaft angle
OR	Odd`s ratio
OS	Osteosynthesis
PICP	Intact C-terminal of procollagen type I
QCT	Quantitative computed tomography
RR	Relative risk
s-ALP	Serum alkaline phosphatase
s-BAP	Serum bone specific alkaline phosphatase

s-Ca	Serum calcium
s-CT	Serum calcitonin
SD	Standard deviation
s-OC	Serum osteocalcin
s-25-(OH)-D	Serum 25-hydroxyvitamin D
SOPD	Smallest outer pelvic diameter
S-PINP	Serum intact N-terminal of procollagen type I
THA	Total hip arthroplasty
TRBMD	Trochanter bone mineral density
TW	Trochanter width
WABMD	Ward´s triangle femoral neck density

List of original articles

This thesis is based on the following articles and are referred to in the text by Roman numerals:

I Partanen J, Jämsä T & Jalovaara P (2001) Influence of the upper femur and pelvic geometry on the risk and type of hip fractures. J Bone Miner Res 16: 1540-1546.

II Partanen J, Heikkinen J, Jämsä T & Jalovaara P (2002) Characteristics of lifetime factors, bone metabolism and bone mineral density in patients with hip fracture. J Bone Miner Metab 20: 367-375.

III Partanen J, Saarenpää I, Heikkinen T, Wingstrand H, Thorngren K-G & Jalovaara P (2002) Functional outcome after displaced femoral neck fractures treated with osteosynthesis or hemiarthroplasty - A matched-pair study of 714 patients. Acta Orthop Scand 73 (5): 496-501.

IV Partanen J & Jalovaara P (2003) Functional comparison between uncemented Austin-Moore hemiarthroplasty and osteosynthesis with three screws in displaced femoral neck fractures -A matched-pair study of 168 patients. (submitted)

V Partanen J, Syrjälä H, Vähänikkilä H & Jalovaara P (2003) Impact of deep infection after hip fracture surgery on function and mortality. (submitted)

Contents

1 Introduction

Hip fracture is a serious condition that has been found to increase morbidity and mortality in elderly men and women, especially community-dwelling ones (Baudoin *et al.* 1996). Hip fractures also cause incremental cost, especially during the first year (De Laet *et al.* 1999). The majority of fractures occur in women, at least one in four being postmenopausal white women (Melton, III 1993). Worldwide, the number of hip fractures has been estimated to rise from 1.7 million in 1990 to 6.26 million by the year 2050 and this is mostly due to the increasing life expectancy and increasing size of the population in nearly all countries (Cooper *et al.* 1992). In Finland, the age-specific incidence rose from 273/100,000 in 1970 to 412/100,000 in 1991 among women aged 50 or over and from 108/100,000 to 194/100,000 among Finnish men, respectively (Parkkari *et al.* 1994).

The etiology of hip fractures is multifactorial, and many of the risk factors have been identified (Ribot *et al.* 1993, Cummings *et al.* 1995). A combination of several of these independent risk factors may help to define the intervention thresholds for treatment and improve the design of population-level screening policies, particularly in elderly women, who have the greatest risk of hip fracture (Kanis & McCloskey 1996). It has also been postulated that the etiologies of the two main hip fracture types, femoral neck and trochanteric fractures, are different (Mautalen *et al.* 1996). Knowledge of these differences would also help us to improve the targeting of hip fracture prevention (Michäelsson *et al.* 1999).

Also, the treatment of hip fractures must be optimal to ensure recovery of the patients. Controversial results have been reported concerning the treatment of femoral neck fractures with the main treatment methods, hemiarthoplasty and osteosynthesis (Lu-Yao *et al.* 1994). Especially functional recovery has been largely ignored at the cost of the successful healing of the fracture, although it is very important to consider how well the patient is able to resume his/her pre-fracture level of functioning (Koval & Zuckerman 1994).

Deep infection after the treatment of hip fracture is a rare but severe complication (Pietschmann *et al.* 1988, Mackay *et al.* 2000), which is associated with high mortality (Eastwood 1993), a prolonged need for hospital stay, a marked decline in mobility, a great increase in social dependency and additional costs for the hospital and for society

(Aagaard *et al.* 1994). However, the impact of deep infection on the true functional outcome and mortality of patients has been insufficiently examined.

This thesis focuses on hip fracture patients and the possible risk factors in Finnish postmenopausal women aged over 50 years, with special attention to the differences in the etiopathology of the two main hip fracture types, femoral neck and trochanteric fractures. The two main treatment modalities of femoral neck fracture, hemiarthroplasty and osteosynthesis, are also compared, with a special focus on short-term functional recovery. The determination of the true impact of deep infection after hip fracture surgery on function and mortality was the last topic of this work.

2 Review of the literature

This thesis focuses on hip fracture patients aged over 50 years who have sustained the fracture with “low-energy trauma”, which is a trauma associated falling on the standing height or less. This “low-energy trauma” must considered separately from the traumas of younger patients, who usually sustain hip fractures in traffic accidents and falls from height (Robinson *et al.* 1995, Hwang *et al.* 2001).

2.1 Anatomy of hip fracture

Hip fractures can be divided into four categories based on their anatomical location (Fig. 1): 1. femoral neck fracture. 2. basicervical fracture 3. trochanteric fracture and 4. subtrochanteric fracture.

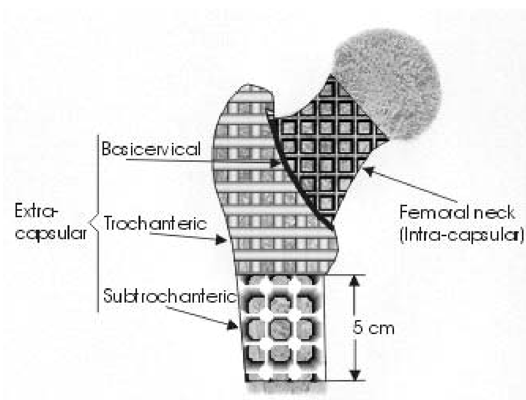

Fig. 1. Anatomical location of hip fracture, modification from Sobotta, Atlas of Human Anatomy, printed with permission from Urban & Fischer Verlag, drawn by Tauno Partanen.

Femoral neck fractures (46 % to 54 % of all hip fractures) and trochanteric fractures (34-46 %) are the most common types of hip fracture. Basicervical fractures (2-8 %) and subtrochanteric fractures (2-7%) are rare (Jalovaara *et al.* 1992, Berglund-Rödén *et al.* 1994). Femoral neck fractures are intra-capsular, but all the others are extra-capsular. Blood supply is more critical in femoral neck fractures, especially displaced ones, because the severity of the damage to the major blood supply depends on the extent of displacement of the fragments (Swiontkowski 1994).

2.2 Classification of the hip fractures

There are several classifications of *femoral neck fractures*, the Pauwels, AO and Garden classifications and the most widely used system is the Garden classification (Fig. 2) (Garden 1964, Müller *et al.* 1990, Bartonicek 2001).

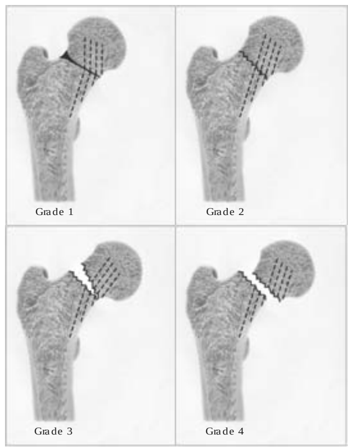

Fig. 2. Garden classification (Garden 1964), modification from Sobotta, Atlas of Human Anatomy, printed with permission from Urban & Fischer Verlag, drawn by Tauno Partanen.

The most important thing is to distinguish undisplaced (Garden I-II) and displaced (Garden III-IV) fractures from each other, because the rate of healing complications increases from 7 % in the case of undisplaced fractures to 36 % in the case of displaced fractures (Tidermark *et al.* 2002). The Pauwels and AO classifications have little clinical relevance (Parker *et al.* 1997).

Basicervical fractures are extracapsular two–part fractures, with the fracture plane running along the line of capsular insertion, just proximal to the lesser and greater trochanter (Parker *et al.* 1997). It is usually misdiagnosed as either a femoral neck fracture or a trochanteric fracture. It should be classified as a trochanteric fracture and treated as a trochanteric fracture (Saarenpää, I *et al.* 2002).

There are several classifications of *trochanteric fractures.* Evans started by classifying trochanteric fractures as stable and unstable fractures (Evans 1949). The most usable classification is the Jensen classification (Fig. 3), which is a modification of the Evans classification, with the types I and II being regarded as stable fractures and the types 3-5 as comminuted or unstable fractures (Jensen & Michaelsen 1975).

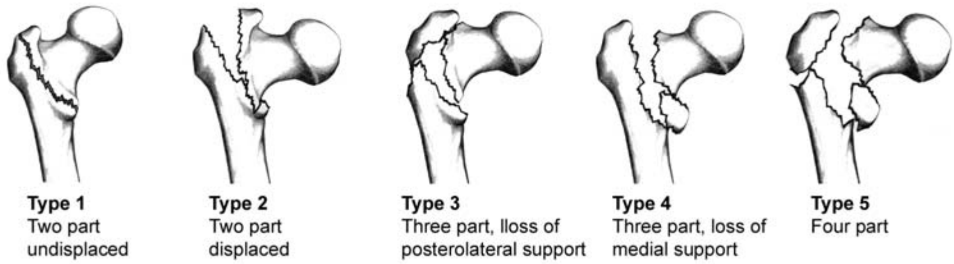

Fig. 3. Jensen classification of trochanteric fractures (Jensen & Michaelsen 1975), modification, drawn by Juho Vuolteenaho.

Subtrochanteric fractures can be subdivided into undisplaced, two-part and comminuted fractures, and the Seinsheimer classification (Fig. 4) is mostly used (Seinsheimer 1978).

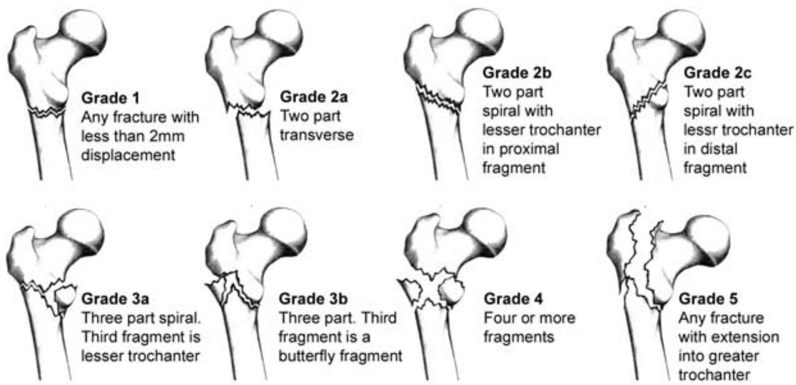

Fig. 4. Seinsheimer classification of subtrochanteric fractures (Seinsheimer 1978), modification, drawn by Juho Vuolteenaho.

2.3 Etiopathology of hip fractures

The etiopathology of hip fracture is multifactorial (Fig. 5) but there are three main causes that play an important role in the etiopathology of hip fractures: age, diseases and trauma (Alffram 1964).

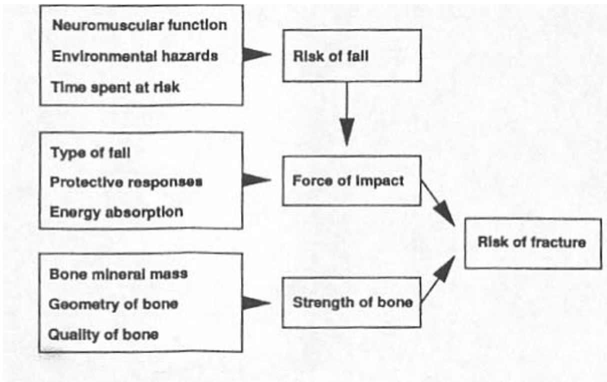

Fig. 5. Etiopathology of hip fractures (Kanis & McCloskey 1996) with permission from Blackwell Publishing.

Cummings and Nevitt (1989) proposed that hip fracture occurs in a cascade fashion with four conditions that need to be satisfied: the orientation of the fall causes the person to fall straight on his/her hip, the protective flexes fail, the local soft tissues do not absorb the energy, and bone strength is reduced. They also recognized the difference between simple falls by elderly persons and younger persons: the former usually fall laterally on their hip, while the latter fall forward, usually on their hands (Fig. 6).

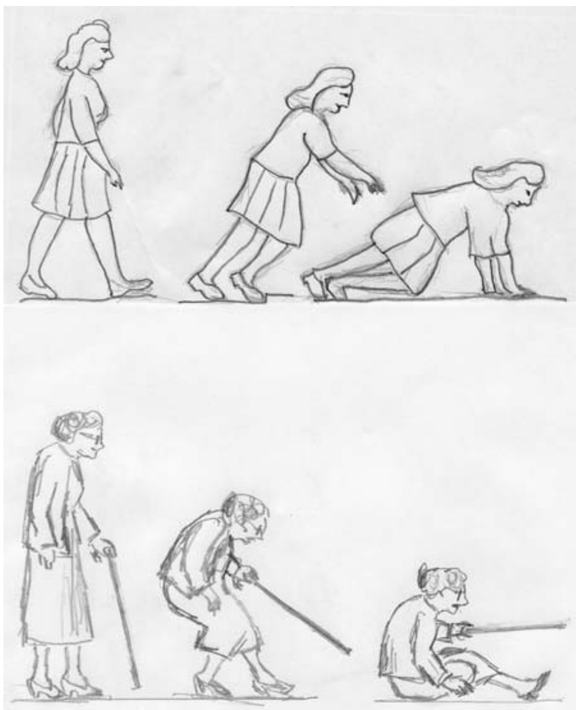

Fig. 6. Difference between a simple fall in a younger person (above) and in an elderly (below). Modification from Cummings & Nevitt 1989, drawn by Anja Partanen.

2.3.1 Age

The incidence of the hip fracture is closely related to age and increases almost exponentially, so that about 90 % of hip fractures occur after age 70 (Cummings *et al.* 1989, Melton, III 1996). The lifetime risk for a woman aged 50 years is 14-18 %, compared with 3-6 % for a man (Cooper 1998). It is estimated that 30 % of older adults will have a hip fracture by age 90. Normal postural stability deteriorates during aging because of changes in vision, vestibular function and the musculoskeletal system, and this contributes to the risk of falls as well as the types of falls (Birge *et al.* 1994). Bone loss affecting bone strength usually increases by aging (Cummings *et al.* 1990). Loss of weight during aging affects the local shock absorbers, reducing especially muscles and increasing the risk of fracture after the fall (Cummings & Nevitt 1989).

2.3.2 Sex

White women have a twofold risk compared to white men, while black women and men are at similar risk (Farmer *et al.* 1984). The cross-sectional geometry of the lower limb bones including the femur may play an important role in the differences of the hip fracture risk between women and men. Men undergo greater subperiosteal expansion upon aging than women and the cortical area remains almost constant in men, but decreases in women. Thus, age-related changes in bone cross-sectional geometry appear to compensate for age-related reductions in bone strength in men but not in women (Mow & Hayes 1991). The absence of a distinct equivalent of menopause with associated acceleration of bone loss in men, their shorter life expectancy, and their reduced propensity to fall, compared to elderly women, who fall two to four times more often than men, are other important factors explaining the difference in the risk of hip fracture between men and women. The risk factor patterns in osteoporosis are also partly different in men and women (Jackson J 1997).

2.3.3 Race

The risk of hip fracture in white Caucasian women is reported to be twofold compared to black women (Farmer *et al.* 1984). Cancellous bone density increases during a relatively short period in late puberty more in black women than in white women, and the authors conclude that metabolic and hormonal events related to the achievement of sexual maturity during adolescence may be important determinants of the racial differences in bone mass in women (Gilsanz *et al.* 1991). Body weight might also explain partly the lower incidence of hip fractures in black women than in white women, as the prevalence of obesity is higher in the older black female population (Pruzansky *et al.* 1989). Hip axis lengths vary between Caucasians, African-American and Asian women, with African and Asian women having significantly shorter hip axis lengths than their Caucasian counterparts, which may diminish the risk of hip fracture in African-American and Asian women and the possible ethnic differences in geometry are postulated to be due to genetic and/or nutritional differences (Cummings *et al.* 1994, Theobald *et al.* 1998). However, there are also controversial findings concerning the hip geometry and the risk of hip fracture between the different ethnic groups (Chin *et al.* 1997).

2.3.4 Anthropometric factors

Anthropometric factors may have an influence on the occurrence of hip fractures (Farmer *et al.* 1989). Maternal height and a slow rate of childhood growth are major determinants of the subsequent hip fracture risk according to a longitudinal study. Whether a reduced growth rate is a consequence of childhood lifestyle, genetic background or intrauterine hormonal programming remains unknown (Cooper *et al.* 2001). Tall individuals have been observed to have a higher risk of hip fracture than short individuals in many studies (Hemenway *et al.* 1995, Lau *et al.* 2001), although opposite findings have been also reported (Huopio *et al.* 2000). Height may contribute to the risk of hip fracture by increasing the force associated with falling (Hayes *et al.* 1993) and height may also influence the geometrical proportions of the hip, such as the hip axis length (Faulkner *et al.* 1993) or the femoral neck length (Nakamura *et al.* 1994). Low weight has been reported to be an independent predictor of hip fracture (McGrother *et al.* 2002). Low weight is also a powerful predictor of very low BMD (T-score $\leq$ -3.5), which might explain the high risk of hip fracture and another possible explanation for the high risk of hip fracture in low-weight individuals is that a low body weight may be a general marker of poor health and frailty (Dargent-Molina *et al.* 2000). Low body mass index (BMI) has been established as a risk factor for hip fracture (Hemenway *et al.* 1988), because low BMI is related to low bone mass (Edelstein & Barrett-Connor 1993).

2.3.5 Bone mineral density

Many studies have shown that low bone mineral density (BMD) or low bone mass in the hip region is associated with hip fractures in women and may predict a future hip fracture risk (Libanati *et al.* 1992, Marshall *et al.* 1996). Each SD decrease in femoral neck bone density increased the age-adjusted risk of hip fracture 2.6-fold, and in the lowest quartile of BMD the risk of hip fracture was 8.5-fold in a cohort study (Cummings *et al.* 1993). There are fewer studies on men, but one study showed that men had OR 1.98 for a non-traumatic fracture risk, including hip fracture, compared to women with OR 2.39 based on the measurement of femoral neck bone mineral density (Nguyen *et al.* 1993). Peak adult bone mass is attained in early adulthood after the end of linear skeletal growth, and it is influenced by genetic factors, hormones, nutrition and physical activity (Stevenson *et al.* 1989, Tylavsky *et al.* 1989). Thereafter, there is a period of bone loss, which is associated with age, menopause and various risk factors, such as low body weight, alcohol use and smoking, nulliparity and lack of regular exercise (Stevenson *et al.* 1989).

2.3.6 Geometry

The geometry of the hip may be an important predictor of a future fracture, because the strength of an object is also a function of its geometry according to the basic engineering principles (Karlsson *et al.* 1996). Other important principles are the mechanical properties of the material from which the structure is made and the location and direction of the loads to which the structure is subjected in service (Mow & Hayes 1991). Torsional strain on a loaded femur will cause it to break at its weakest point, which is the more horizontal femoral neck. This was first pointed out in case histories by Sir Astley Cooper over 150 years ago (Parker *et al.* 1997). Since then, the upper femoral skeletal geometry has been presented to contribute to the hip fracture risk in dual-energy X-ray absorptiometry and conventional pelvic radiography studies but the results have been partly conflicting (Faulkner *et al.* 1993, Glüer *et al.* 1994, Karlsson *et al.* 1996, Dretakis *et al.* 1999, Michelotti & Clark 1999, Alonso *et al.* 2000).

2.3.7 Fall

Over 90 % of hip fractures are due to a fall (Grisso *et al.* 1991), but only about 1 % of all falls of the elderly results in a hip fracture (Tinetti *et al.* 1988, Nevitt *et al.* 1991). A comparison between the predictions of the impact force of falling and the *in vitro* measures of femoral fracture strength postulates that any fall from standing height producing a direct, lateral impact on the greater trochanter may break the elderly hip, (Robinovitch *et al.* 1991) and the influence of the direction of falling on the fracture risk has also been proven in a clinical series (Greenspan *et al.* 1998, Parkkari *et al.* 1999).

The tendency of the elderly to fall is high, which may partly explain the dramatic age-related rise in the incidence of hip fractures (Hayes *et al.* 1993). Established factors for an increased risk of falls are a slower hand reaction time, decreased grip strength, falls while using stairs and steps, turning around or reaching (Nevitt *et al.* 1991), cognitive impairment (at least five errors on the short portable mental status questionnaire), disability of the lower extremities (problems with strength, sensation or balance), use of sedatives (benzodiazepines, phenotiazines and antidepressants), foot problems (moderate or severe bunions, toe deformities, ulcers or deformed nails) (Tinetti *et al.* 1988), neuromuscular impairments (inability to walk in a line with feet in a tandem position and by a slower walking speed), visual acuity (Cummings *et al.* 1995, Dargent-Molina *et al.* 1996) and overall impaired mobility (Greenspan *et al.* 1998). For recurrent non-syncopal falls, increased risk ratios have reported for persons who have difficulty standing up from a chair, difficulty performing tandem walk (heel to toe), arthritis, Parkinson´s disease, three or more falls during the previous year and a fall with injury during the previous year and for whites (Nevitt *et al.* 1989). Alcohol intake and physical factors in the environment, such as stairs, lighting and streets and walkways, have also been cited as important factors (Gregg *et al.* 2000).

2.3.8 Lifestyle factors

The lifestyle factors having an influence on the occurrence of hip fracture are described in table 1.

Table 1. Lifestyle factors and the risk of hip fracture in recent studies.

Study and year	Study design	Factor	Influence
Gregg *et al.* 2000	Prospective randomized study	Higher levels of leisure time physical activity	Reduces
Boonyaratavej *et al.* 2001	Prospective case-control study	Recent physical activity	Reduces
Michaëlsson *et al.* 1995	Prospective cohort study	High dietary iron, magnesium, vitamin C intake	Increases
Meyer *et al.* 1997	Prospective cohort study	High intake of protein in the presence of low calcium intake	Increases
Meyer *et al.* 1997	Prospective cohort study	Coffee intake 9 or more cups/ day	Increases
Sowers *et al.* 1991	Prospective case-control study	High water fluoridation	Increases
Danielson *et al.* 1992	Prospective ecological cohort	Low water fluoridation	Increases
Cauley *et al.* 1995	Prospective multicenter study	Exposition to water fluoridation 20 or more years in women	Decreases
Meyer *et al.* 1993	Prospective cohort study	Smoking 15 or more cigarettes/day	Increases
Law *et al.* 1997	Meta-analysis	Smoking	Increases
Baron *et al.* 2001	Prospective case- control study	Alcohol	Increases (weak inverse association with risk)

Physical activity in childhood and adolescence improves bone strength, while activity in adulthood seems merely to reduce bone loss (Frost 1999). Stair climbing and brisk walking are associated with increased bone mineral density at the hip and in the whole body in postmenopausal women (Coupland *et al.* 1999). One study indicated that women who could go out with walking did not have an increased risk of hip fracture and those who had to stay at home and use a gait aid had a 2-fold risk. The authors postulated that those who could go outside had greater muscle strength and better neuromuscular function, stability and visual acuity, which reduced their propensity to fall (Boonyaratavej *et al.* 2001). No load-bearing activity in the immediate past and no vigorous sport activities in early adulthood resulted in RRs for hip fracture 2.0 and 7.2, respectively, for women in the Asian Osteoporosis Study (Lau *et al.* 2001). A lack of physical activity has also been found to associate with the risk of hip fracture in European women (Johnell *et al.* 1995).

A high-magnesium diet in postmenopausal women has been found to increase urinary calcium excretion, and this may explain the increased risk of hip fracture (Nielsen 1990). High intake of iron was also related to an increased risk of hip fracture according to one study, but the mechanism was uncertain (Michaelsson *et al.* 1995). High intake of vitamin C might cause negative calcium balance (Allen 1982) and may reduce cancelleous and cortical bone (Thornton 1970) . Nondairy animal foods (meat, fish, and eggs) are low in calcium and high protein/low calcium may be harmful to skeletal health and may increase hip fracture risk (Meyer *et al.* 1997). An inverse relation between coffee intake and bone mass has been observed, which is due to the calciuric effect of caffeine, which may thus increase the hip fracture risk (Hasling *et al.* 1992). An increase in bone mass caused by fluoride may be associated with an increase in bone fragility (Lindsay 1990). The reported influence of the fluoridation of drinking water on the hip fracture risk is controversial, and the differences between these studies might be due to different study designs (Sowers *et al.* 1991, Danielson *et al.* 1992, Cauley *et al.* 1995). Calcium intake declines with age, because of a decrease in the consumption of dairy products. The intestinal absorption of calcium also decreases with age because of the reduced ability of the intestine to adapt to a low calcium intake (Meunier 1996). The poor vitamin D status is mainly due to low exposure to sunshine not compensated for by vitamin D supplementation (Lips *et al.* 1987). Aging also decreases the capacity of human skin to produce previtamin D_3 (MacLaughlin & Holick 1985). The cumulative response to a deficit in calcium intake and a low vitamin D status is a negative calcium balance, which induces secondary hyperparathyroidism and increases the risk of hip fractures (Parfitt *et al.* 1982, Meunier 1996).

Smoking has been reported as a risk factor for hip fracture among postmenopausal women (Meyer *et al.* 1993, Law & Hackshaw 1997) and the risk was decreased after cessation (Baron *et al.* 2001). There is also a report showing no association between cigarette smoking and the hip fracture risk (Johnell *et al.* 1995). The possible mechanisms through which cigarette smoking could affect the fracture risk are the lower body weight of smokers and lower levels of parathyroid hormone and 25-hydroxyvitamin and lower BMD and BMI (Mellström *et al.* 1993).

Excessive alcohol use may play an important role in the pathogenesis of osteoporosis and increase the risk of hip fracture (Moniz 1994). On the other hand, social drinking is associated with higher bone mineral density in men and postmenopausal women. The beneficial effect on bone might be due to elevated serum estradiol levels (Holbrook & Barrett-Connor 1993). Any use of alcohol, however, seems to suppress the function of osteoblasts, as evidenced by the low serum levels of osteocalcin, and prolonged moderate drinking elevates the serum levels of vitamin D metabolites with consequent malabsorption of calcium, hypocalcemia and hypocalciuria (Laitinen & Valimäki 1991).

2.3.9 Medication and concurrent diseases

Several medications and concurrent diseases are associated with the risk of hip fracture and the previous literature is described in Table 2.

Table 2. Medication and concurrent diseases and the risk of hip fracture in the recent literature.

Study and year	Study design	Medication/concurrent disease	Influence on the risk
Ray *et al.* 1987	Prospective case-control study	Use of psychotropic drugs	Increases
Heidrich *et al.* 1991	Prospective case-control study	Use of thiazide diuretics	+/-
Heidrich *et al.* 1991	Prospective case-control study	Use of loop diuretics	Increases
Solomon *et al.* 1993	Prospective case-control study	Use of thyroid hormone	+/-
Baltzan *et al.* 1999	Prospective cohort study	Use of oral corticosteroid	Increases
Solomon *et al.* 1993	Prospective study	Hyperthyroidism	+/-
Wejda *et al.* 1995	Prospective case-control study	Hyperthyroidism	Increases
Forsén *et al.* 1999	Prospective cohort study	Diabetes (Type 1)	Increases
Schwartz *et al.* 2001	Prospective multicenter study	Diabetes (Type II)	Increases
Kanis *et al.* 2001	Prospective study	Stroke	Increases
Lau *et al.* 2001	Prospective multicenter study	Cardiovascular disease	
Sato *et al.* 2001	Prospective study	Parkinson´s disease	Increases

Sedative and autonomic effects of *psychotropic drugs* increase the risk of falling in the elderly (Ray *et al.* 1987) and may increase the risk of hip fracture (Cummings *et al.* 1995).

Thiazides may increase the bone mineral content in postmenopausal women (Wasnich *et al.* 1986), but the use of thiazides seemed not to decrease the risk of hip fracture or osteoporosis (Adland-Davenport *et al.* 1985). Furosemide is a diuretic agent that promotes calcium excretion by the kidney (Suki *et al.* 1970). It may expose users to an increased risk for osteoporosis and osteoporotic fractures (Tromp *et al.* 2000) by reducing BMD (Ooms *et al.* 1993). On the other hand, thiazides and furosemide may increase the risk for syncope, producing a possible mechanism of action for the noted association between the use of diuretics and hip fracture (Heidrich *et al.* 1991).

The use of oral corticosteroids has been established as an independent risk factor for hip fracture (RR=2.1) (Baltzan *et al.* 1999) and for both nonvertebral fracture (RR=1.44) and vertebral fracture (RR=2.83) (van Staa *et al.* 2000). In the study by van Staa *et al.* (2000), a strong correlation was observed between the daily corticosteroid dose, rather than the cumulative dose, and the risk of fracture, with a higher risk in people using higher doses.

A weak relationship between the risk of hip fracture and cardiovascular diseases been reported earlier. The relationship was more prominent in women than in men (Lau *et al.* 2001).

Some new prospective studies have reported an increased risk of hip fracture in patients with diabetes. According to these studies, the relative risk of hip fracture was 6.9 in Type I (insulin dependent) diabetes (Forsén *et al.* 1999) and 1.8 in Type II (non-insulin-dependent) diabetes (Schwartz *et al.* 2001). The increased fracture risk could be due to altered bone status or complications of diabetes predisposing to trauma (e.g. retinopathy, peripheral neuropathy) (Meyer *et al.* 1993).

A history of stroke has been found as a risk factor for hip fracture (Ramnemark *et al.* 1998, Lau *et al.* 2001). The risk of hip fracture increases over 7-fold after hospitalization for stroke (Kanis *et al.* 2001). Hip fractures might be caused by the high incidence of accidental falls in stroke patients (Forster & Young 1995). Muscle weakness and an increased risk of developing osteoporosis on the paralyzed side might be other important factor predisposing to fractures in stroke patients (Hamdy *et al.* 1993).

The risk of hip fracture among patients with Parkinson´s disease was observed to be high in elderly women, and they had decreased BMI, lower BMD, and lower concentrations of serum ionized calcium and 25(OH)D with compensatory hyperparathyroidism (Sato *et al.* 2001). The increased risk of hip fracture in patients with Parkinson´s disease is probably due to their tendency to fall in specific ways (Johnell *et al.* 1992).

The frequency of hyperthyroidism has been suggested to be 2.5-fold in hip fracture patients compared to controls (Wejda *et al*. 1995). The increased risk of hip fracture associated with hyperthyroidism was not found in another study, and women with a history of hyperthyroidism and the use of thyroid hormone for a variety of thyroid disorders did not appear to have an enhanced prevalence of hip fracture (Solomon *et al.* 1993).

2.3.10 Gynaecological factors

Postmenopausal women with undetectable serum estradiol concentrations and high serum concentrations of sex hormone-binding globulin appear to have an increased risk of hip and vertebral fracture (Cummings *et al.* 1998). Estrogen deficiency results from declining ovarian function (Thomsen *et al.* 1986). The estrogen deficiency and bone loss might be caused by the higher prevalence of dead osteocytes (Tomkinson *et al.* 1997).

Bone turnover is altered during pregnancy and lactation, as demonstrated by a change in the markers of bone formation and resorption (Sowers 1996) and, in the case of lactation, even with measurement of bone mineral density (Holmberg-Marttila & Sievänen 1999). Despite this turnover activity, there appears to be little ultimate loss of mineral from the maternal skeleton during the pregnancy or lactation of well-nourished women if, during or after lactation, consistent menstrual cycling is re-established within a reasonable length of time (Sowers 1996). The actual net long-term effect of parity and lactation on the osteoporotic fracture risk is uncertain. Higher parity might be modestly associated with a reduced hip fracture risk, and this risk reduction seems partially attributable to weight gain with parity. According to the same authors, lactation is not associated with the hip fracture risk (Michaëlsson *et al.* 2001).

2.4 Differences in the etiopathology of femoral neck and trochanteric fractures

It has been postulated that the etiologies are different in femoral neck and trochanteric hip fracture patients (Backman 1957, Mautalen *et al.* 1996, Michaëlsson *et al.* 1999).

Women with trochanteric fractures are, on an average, 5 years older, have lower body weight about 6 kg, are about 3 cm shorter and have lower bone mineral density than women with femoral neck fracture (Bohr & Schaadt 1983, Eriksson & Widhe 1988, Vega *et al.* 1991b).

The size and architecture of the upper femur and pelvis are important in the pathogenesis of these two main hip fracture types. Decreased femoral shaft cortical thickness has been reported to predict trochanteric fractures and acetabular width and decreased femoral neck cortical thickness femoral neck fractures, which is compatible with the different mechanisms of these fracture types (Glüer *et al.* 1994). Hip axis length has also been found to be a predictor of femoral neck fracture. Differences in the compressive and tensile stress on the hip, which are related to differences in femoral neck length and shape, may partly explain these differences (Duboeuf *et al.* 1997).

No significant differences were found in the energy or characteristics of falls between femoral neck and trochanteric fracture patients (Greenspan *et al.* 1994).

Major differences in several lifetime factors between femoral neck and trochanteric fractures have been found, but these differences were age-dependent and not real risk factors after age adjustment (Sernbo & Johnell 1987). In another study, it was concluded that femoral neck fractures compared to trochanteric fractures are more strongly influenced by hormonal and environmental factors, such as smoking, the duration of menstrual cycling and exogenous estrogens (Michäelsson *et al.* 1999).

2.5 Methods for identifying the risk of hip fracture

The most commonly used method for the measurement of BMD or bone mineral content (BMC) is *dual X-ray absorptiometry* (*DXA)* or *quantitative computed tomography* (*QCT)*. QCT in clinical practice is too costly for screening large populations (Krischak *et al.* 1999). With the newest DXA machines, both the spine and the hip can be scanned in a few minutes, which reduces the cost. For screening purposes, however, DXA machines are too expensive and not portable (Raisz 1999). Careful repositioning of the foot and leg is essential, to reduce the effect of anteversion when measuring BMD by DXA (Cheng *et al.* 1997).

Ultrasonographic heel measurements have been found to predict the risk of hip fracture in elderly women living at home equally well as DXA of the hip (Hans *et al.* 1996). It has been suggested that *ultrasound* correlates better with the type of hip fracture than DXA, patients with trochanteric fractures having significantly lower ultrasound parameters than those with femoral neck fractures (Schott *et al.* 1995).

Assessment of the *Sing Index* on ordinary X-rays of the hip is an inexpensive and simple method and allows a rough estimation of the mechanical quality of the femur (Singh *et al.* 1970). However, due to its subjective character, its predictive value for the mechanical quality of bone in individual patients remains uncertain (Krischak *et al.* 1999).

Conventional *pelvic radiography* is widely available at low cost, and it offers sufficient spatial resolution and contrast to assess the macroscopic structure of the proximal femur (Glüer *et al.* 1994). Several studies using conventional pelvic radiography measurements have revealed an association between the pelvic and upper femur geometry and the risk of hip fracture in postmenopausal women (Glüer *et al.* 1994, Peacock *et al.* 1995, Karlsson *et al.* 1996, Michelotti & Clark 1999). On the other hand, linear and angular measurement parameters from pelvic radiography have been mutually conflicting in these studies (Table 3).

Table 3. Review on radiographic studies on pelvic and upper femur geometry in hip fracture patients.

Study and year	No. of patients	Assess-ment of magnifica-tion	Positioning	Digital image	Evaluation of repro-ducibility and accuracy	The risk is increased by
Gluër *et al.* 1994	162	No	Supine, feet taped at a 15-30º internal rotation	Yes	No	Reduced thickness of the femoral cortex
Peacock *et al.* 1995	22	No	Supine, feet at a 15º internal rotation	No	No	Long hip axis length, reduced lateral cortical thickness
Karlsson *et al.* 1996	92	No	Supine, feet in a resting position	No	No	Reduced thickness of the calcar femorale, increased NSA
Michelotti & Clark 1999	43	Yes	Supine, the toes touching	No	No	Reduced thickness of the femoral cortex, larger femoral head and neck diameter

Body habitus affects magnification in radiographic images (Clarke *et al.* 1976). It has been estimated that the average difference in buttock soft tissue thickness is 8.7 cm. All but one of the previous studies involved direct measurements from pelvic radiography without any calibration at the bone level to exclude the magnification error implicit in linear measurements (Pocock *et al.* 1997). On the other hand, the angular parameter called neck-shaft angle (NSA), defined as the angle between the femoral shaft and the femoral neck, is comparable between different measurement setups if the patient's position is similar. The subject's positioning also reflects the linear parameters, while abduction shortens the apparent hip axis length and external rotation shortens the apparent femoral neck length. Data concerning the error value for linear and angular measurements have generally been lacking in these previous studies (Michelotti & Clark 1999). A digital image analysis system has been found more accurate than the human eye but the measurements were made by digital imaging in only one study (Bould *et al.* 1999).

Linear and angular geometric parameters of the pelvis and upper femur and their relation to the hip fracture risk in postmenopausal women have been also measured from DXA scans in many previous works, and controversial results, especially as regards the predictive value of hip axis length and the risk of hip fracture, have been reported. Some studies have found increased hip axis length to be an independent risk factor for hip fracture in postmenopausal women (Faulkner *et al.* 1993, Boonen *et al.* 1995) while some others have not found any differences in hip axis length between the hip fracture patients and controls (Center *et al.* 1998, Dretakis *et al.* 1999, Alonso *et al.* 2000). Differences in the measurement setup might also explain partly the conflicting findings (Michelotti & Clark 1999).

The dramatic increase in the bone turnover rate, which results in an imbalance between bone formation and bone resorption, in the first years after the cessation of ovarial function is responsible for the accelerated rate of postmenopausal bone loss (Garnero *et al.* 1996).

Direct, region-specific measurements of bone formation and resorption in the femoral neck are hard to perform and have seldom been attempted (Eastell *et al.* 2001). Bone metabolism markers can be also measured indirectly by determining the markers for bone formation and bone resorption. It is postulated that a combination of baseline perimenopausal bone density and an assessment of biochemical markers may better predict the future hip fracture risk (Tromp *et al.* 2000), but they lack sufficient sensitivity and specificity to be very helpful in the day-to-day management of patients with osteoporosis (Adachi 1996).

Bone-specific alkaline phosphatase appears to be more sensitive than *total alkaline phosphatase* for clinical purposes. *Osteocalcin* is a vitamin D-dependent protein that has been estimated to represent up to 20 % of all noncollagenous protein in bone. It is only found in bone tissue and dentin. A proportion of newly synthesized osteocalcin is released into the circulation, where it can be measured by immunoassay. Thus, the serum level of osteocalcin is a very specific marker of the rate of bone formation. *Procollagen type I extension peptides, PICP* and *PINP* assays are measures of bone formation. Type I collagen is synthesized as procollagen precursor molecules. Before insertion into the existing extracellular matrix, the terminal propeptide extensions are proteolytically removed, and both PICP and PINP are released into the circulation (Adachi 1996). The immunoassays of osteocalcin and bone alkaline phosphatase have been established as the most effective markers of bone formation in osteoporosis (Garnero & Delmas 1996).

The measurement of pyridinium cross-links (urinary free pyridinoline, pyridinoline-containing type I collagen cross-linking peptides) and some of the related peptides is the most sensitive marker of bone resorption, and immunoassays are recommended valid techniques for their evaluation (Garnero & Delmas 1996).

On the other hand, metabolic changes in bone, other than osteoporosis, have been reported to be possible additional risk factors for hip fractures, while osteomalacia was present in 24 % and hyperparathyroid histological changes in 3 % of the hip fracture patients (Arnala *et al.* 1997). Histological osteomalacia was also diagnosed in 24 % of the patients with hip fracture in another report (Hoikka *et al.* 1982). Vitamin D metabolite, *25(OH)D*, is important in Europe at the end of the winter, due to a lack of sun exposure (Baker *et al.* 1979, Benhamou *et al.* 1995). 25(OH)D deficiency has been found in elderly people with hip fracture (Harju *et al.* 1985, Benhamou *et al.* 1995). *Parathyroid hormone* is associated with increased bone turnover resulting in net resorption, and the PTH effect is more marked on cortical than trabecular bone (Gupta & Rolla 1995, Lips 2001). Concerning the levels of PTH in hip fracture patients, controversial results have been found in the literature. Some studies have reported higher levels in hip fracture patients than non-hip fracture controls (Benhamou *et al.* 1995, Dubin *et al.* 1999) and one found no increase in PTH levels after hip fracture (Johansen *et al.* 1997).

Low serum *calcium* concentrations in hip fracture patients have been reported, although no changes in total calcium levels were found in one study (Benhamou *et al.* 1995, Boonen *et al.* 1997). The normal serum calcium concentration can be maintained by mobilization of calcium from bone in the case of osteoporosis (Harju *et al.* 1985).

Calcitonin is a peptide from the parafollicular cells of the thyroid regulated by serum calcium levels (Dubin *et al.* 1999). It inhibits bone resorption (Benhamou *et al.* 1995). Higher levels of serum calcitonin have been observed in hip fracture patients (Prince *et al.* 1989) but contrary to this, no increase in serum calcitonin levels was found in some other reports (Reginster *et al.* 1992, Boonen *et al.* 1997).

2.6 Treatment of femoral neck fractures

Speed introduced intra-capsular femoral neck fracture as the “unsolved fracture” about 70 years ago (Speed 1935). Even today, there are a number of controversies concerning the methods of treating displaced fractures of the femoral neck and the main problem is whether to reduce the fracture and to use internal fixation or to perform total or partial hip replacement arthroplasty (Lu-Yao *et al.* 1994).

The surgeon Nicholas Senn first reported the importance of reduction and nailing of hip fracture on the basis of animal experiments. He also reported that femoral neck fractures involve two main indications: (1) immediate reduction and (2) permanent fixation. He used immediate reduction, a specific external compression screw and a plaster-of-Paris dressing in the treatment of femoral neck fractures (Senn 1889).

In the early 20th century, Murphy began to nail femoral heads (Speed 1935). Since then, more than a hundred devices have been used in the treatment of femoral neck fractures (Swiontkowski 1994). Nowadays, the osteosynthesis (OS) modality to treat femoral neck fractures consists of either reduction and fixation with one or more hook pins, nails (Strömqvist *et al.* 1987), or screws (Kuokkanen *et al.* 1991), or reduction and fixation with a sliding screw and plate (Elmerson *et al.* 1995).

The prospective comparisons between different types or numbers of pins, screws, or nails have not reported any significant differences in the main results (Sernbo *et al.* 1990, Herngren *et al.* 1992, Lagerby *et al.* 1998).

Osteosynthesis with one or more hook pins, screws or nails did not basically differ from the use of a sliding screw and plate in one of the prospective studies (Elmerson *et al.* 1995), while another study was in favour of a sliding screw and plate due to the lower failure rate (Sorensen *et al.* 1992) and two were in favour of screws due to the better union of the fracture (Madsen *et al.* 1987) and the lower infection rate (Christie *et al.* 1988).

In 1940, the self-locking metal hip prosthesis, called Austin-Moore prosthesis, was introduced as the first vitallium prosthesis to replace the upper portion of the femur (Moore 1957). Since then, the Austin-Moore prosthesis has undergone much development and has been the most commonly utilized mode of uncemented *hemiarthoplasty (HA)* along with the cemented Thompson hemiarthroplasty in the treatment of displaced femoral neck fractures (Thompson 1954, Lindholm *et al.* 1976, Kwock & Cruess 1982, Jalovaara & Virkkunen 1991). Many designs of hemiarthroplasty have been used in the treatment of femoral neck fractures (Lausten & Vedel 1982, Lo *et al.* 1994). The main difference between the different hemiarthroplasties is the design of the stem, the use of cement, and whether a second articulating joint is included within the prosthesis (Parker & Rajan 2001).

Concerns about the possible lower effects on the cardiopulmonary system and technically easier revision are the main factors in favour of an uncemented implant. Early loosening with associated pain and poor function with an uncemented implant may motivate the surgeon to choose a cemented implant (Khan *et al.* 2002). According to the previous prospective studies, fixation of the prosthesis with cement might improve the outcome, resulting in better pain relief and better gait than fixation of the prosthesis without cement (Emery *et al.* 1991, Godsiff *et al.* 1992, Khan *et al.* 2002). Consequently, cemented prostheses may give a better outcome, but because of the under-reporting of outcomes and the small number of patients involved, no definitive conclusions can be made based on a Cochrane Database of systematic Reviews (Parker & Rajan 2001).

The results of prospective randomized trials comparing the use of unipolar and bipolar prosthesis suggest that the less expensive unipolar prosthesis for hemiarthoplasty may be justified in the elderly. These previous studies demonstrated a greater range of hip motion in rotation and abduction and faster walking speed when the bipolar prosthesis was used (Cornell *et al.* 1998), while the degree of return to the pre-injury state was better when the unipolar prosthesis was used (Calder *et al.* 1996). On the other hand, one study found no significant differences between the use of unipolar and bipolar prostheses (Wathne *et al.* 1995).

Total hip arthroplasty (THA) in selective cases of acute femoral neck fracture may provide consistent pain relief and a good functional outcome without any increase in complications (Coates & Armour 1979, Taine & Armour 1985). THA should be considered in the case of acute displaced femoral neck fractures in previously active elderly individuals with acetabular articular cartilage changes. Other indications may include rheumatoid arthritis, Paget´s disease, mentally deficient patients and short life expectancy in otherwise active individuals (Delamarter & Moreland 1987).

For centuries, femoral neck fractures have been treated conservatively by some kind of extension and imperfect immobilization (Senn 1889). *Non-operative management* still remains a feasible option for truly non-ambulatory, demented, aged patients with proximal femoral fracture. It has been suggested that the decision concerning treatment should be made in the chronic care institution by professionals who know the individual (Winter 1987).

2.6.1 Comparative studies

The treatment of femoral neck fractures, especially displaced femoral neck fractures, is controversial, and the results of the previous prospective studies concerning the treatment with *osteosynthesis or hemiarthroplasty* (Table 4) have been inconsistent (Söreide *et al.* 1979, Söreide *et al.* 1980, Sikorski & Barrington 1981, Parker 1992, van Vugt *et al.* 1993, Lu-Yao *et al.* 1994, Parker & Pryor 2000, Puolakka *et al.* 2001).

Table 4. Prospective comparative studies on HA and OS in the treatment of displaced femoral neck fractures.

Study and year	Study design and number of patients	Follow-up	Main results	Re-operation rate	Mortality at one year
Söreide *et al.* 1979	Prospective randomised (104)	1-year	Mobilization better in HA patients	HA 5.7 % OS 17.6 %	HA 21 % OS 18 %
Söreide *et al.* 1980	Prospective randomised (104)	1-year	Cost of the treatment lower in OS patients	HA 5.7 % OS 17.6 %	HA 21 % OS 18 %
Sikorski & Barrington 1981	Prospective randomised (218)	2-year	Mobilisation better in HA patients	HA (posterior approach) 6% HA (anterior approach) 13 % OS 38 %	HA (posterior approach) 41 % HA (anterior approach) 23 % OS 35 %
Parker *et al.* 1992	Prospective (200)	1-year	Less wound infections in OS patients	HA 7 % OS 22 %	HA 33 % OS 36 %
Van Vugt *et. al.* 1993	Prospective randomised (43)	2-year	Better clinical results in OS patients	HA 27.1 % OS 22.7 %	HA 31.3 % OS 11.1 %
Parker *et al.* 2000	Prospective randomised (208)	3-year	Less wound infections in OS patients	HA 3.8 % OS 35 %	HA 29.4 % OS 26.8 %
Puolakka *et al.* 2001	Prospective randomised (32)	2-year	Lower re-operation rate in HA patients	HA 0 % OS 44 %	HA 46.7 % (2-year mortality) OS 47.1 % (2-year mortality)

Many studies favour OS and report fewer postoperative infections (Parker 1992, Parker & Pryor 2000), lower costs (Parker 1992), lower morbidity and mortality (Raine 1973, Bracey 1977, Rodriguez *et al.* 1987) and better long-term outcome (van Vugt *et al.* 1993). Some studies have failed to indicate any differences between HA and OS (Stewart 1984). The remaining studies recommend HA as more suitable for the treatment of femoral neck fracture because of less pain (Broos *et al.* 1987), more satisfactory results (Johnson & Crothers 1975), lower re-intervention rates (Parker *et al.* 2000, Puolakka *et al.* 2001), better walking ability and functional condition (Bray *et al.* 1988, Rogmark *et al.* 2002) and better postoperative mobilization (Söreide *et al.* 1979, Sikorski & Barrington 1981).

There are few studies comparing *OS and THA*. One study reported that patients, which were treated with THA, used less outdoor walking aids, and were more likely to do their own shopping than patients treated with OS (Jónsson *et al.* 1996). In another prospective, randomized study, the THA group performed better than the OS group concerning weight change over time, locomotion and pain, and the authors concluded that THA could be safely performed on the elderly without increased postoperative mortality (Bachrach-Lindström *et al.* 2000). THA has been also recommended to patients with normal functional capacity and high functional demands after a comparison between OS and THA (Johansson *et al.* 2000).

According to Smrke *et al.* (2000) *HA* gives a better range of motion compared to *THA* patients (Smrke *et al.* 2000). On the other hand, younger patients treated with THA was found to have a better outcome than patients treated with HA (Gebhard *et al.* 1992).

The patients treated with THA had the least pain and the best mobility in both short- and long-term outcome assessment and also had a lower revision rate compared to OS and HA. Skinner *et al.* (1989) found that HA had the worst outcome, and both OS and HA resulted in the poorest outcome in the study by Ravikumar *et al.* (2000). The high dislocation rate following THA, 12.5-20 %, should be noted (Skinner *et al.* 1989, Ravikumar & Marsh 2000).

2.6.2 Functional outcome after femoral neck fracture

Functional outcome has received less attention than more frequently reviewed aspects, such as mortality, re-operation rate, bone healing, complications, and cost. It is also very important to know how well patients are able to regain their pre-injury level of function and independence, because this is a good indicator of the efficacy of the treatment with regard to the socioeconomic aspects (Koval & Zuckerman 1994, Young *et al.* 1996). Functional status on admission predicts the occurrence of a hospital-acquired complication, (Becker *et al.* 1987) and functional recovery has also been used to determine the effect of geriatric rehabilitation of hip fracture patients (Huusko *et al.* 2002). Most previous studies concerning the functional outcome of OS and HA have revealed no significant differences (Söreide *et al.* 1979, Young *et al.* 1996, Parker & Pryor 2000).

2.7 Deep infection after hip fracture surgery

Deep infection is a rare, but serious complication after hip fracture surgery (Pietschmann *et al.* 1988, Dávid *et al.* 1995) often leading to prolonged hospitalization, reduced activity level, poor quality of life, and additional costs for the hospital and for society (Aagaard *et al.* 1994). It also increases morbidity, mortality and social dependency (Eastwood 1993).

Only one study was found in the literature comparing hip fracture patients with deep infection to patients without deep infection (Eastwood 1993). However, some studies have given special attention to deep infection by focusing on the monitoring of infective complications and undertaking prophylactic measures to lower infection rates (Enstone & Humphreys 1998, Mackay *et al.* 2000).

2.7.1 Definition, risk factors and incidence

The criteria for deep infection have been defined as follows: A major infection extending through the deep fascia (Hedström *et al.* 1998) with purulent discharge complicated by spreading cellulites, systemic upset (Mackay *et al.* 2000), positive or negative cultures from the deep tissues (McQueen *et al.* 1990), pockets of pus or wound breakdown (Eastwood 1993).

Patient-related risk factors for deep postoperative infection include previous surgery of the joint, rheumatoid arthritis, corticosteroid therapy, diabetes mellitus, poor nutritional state, obesity and advanced age (Brause 1986, Enstone & Humphreys 1998). Perioperative risk factors include a break in sterility during the operation, postoperative wound infection, postoperative urinary tract infection and an unhealed wound at discharge (Enstone & Humphreys 1998).

The deep infection rate after hip fracture surgery is varies from 0.8 to 2.8 % (Chiu *et al.* 1993, Lu-Yao *et al.* 1994, Meissner 1994, Mackay *et al.* 2000). Older studies generally have higher infection rates ranging within 2.2-16.9 % (Boyd *et al.* 1973, Tengve & Kjellander 1978, McQueen *et al.* 1990). The decreased incidence is mostly due to advances in theatre design, surgical techniques, antibiotic prophylaxis, wound care, and special attention to detail and good practice (Mackay *et al.* 2000).

3 Aims

1. To clarify if the simple radiographical geometry of the upper femur and pelvis is related to the hip fracture risk and fracture type.
2. To find out the relation of lifetime factors, parameters of bone metabolism and bone mineral density with the hip fracture risk and fracture type.
3. To investigate which one, osteosynthesis or uncemented hemiarthroplasty is better in the treatment of femoral neck fractures in terms of functional outcome.
4. To determine the impact of deep infection after hip fracture surgery on functional outcome and mortality.

4 Patients and methods

4.1 Upper femur and pelvic geometry and the risk of hip fracture and fracture type

The basic study series consisted of 93 consecutive postmenopausal women with non-pathological femoral neck fractures or trochanteric fractures without previous hip fractures or hip surgery. They were admitted to Oulu University Hospital between January 1998 and October 1998. Inclusion criterias and the ambulation were assessed by a trained nurse at admission. The radiographs were inadequate in 9 cases (missing calibration scale or inability to maintain the required position on the x-ray table), and they were excluded from the study. Further 14 patients were excluded because of a failure to find suitable controls with regard to age (patients aged over 85 years were excluded). Thus, 70 patients (fracture group, mean age 74.9 years, range 53–85 years) constituted the final study group. Forty-six of them had a femoral neck fracture (femoral neck group, mean age 73.7 range 53–85) and 24 a trochanteric fracture (trochanteric group, mean age 77.3, range 60–85). 67 % of the patients were fully ambulatory (able to walk outdoors without help) and all were ambulatory indoors with or without support. 55 % of the patients did not use any walking aids.

The control subjects (40 women, mean age 73.7 years, range 63–84 years) were recruited in 1998–1999 from a private clinic´s densitometry series, excluding women with previous hip fracture, metabolic bone disease, or treatment with sex hormones, calcitonin, or bisphosphonates. All but one was fully ambulatory and 90 % did not use any walking aids.

Anteroposterior pelvic *radiographs* of the fracture patients were taken within a few days postoperatively, and those of the controls were taken using the same x-ray equipment. A standard position was used in all cases: supine with the pelvis and both legs straight forward and the big toes touching each other, resulting slight internal rotation of the femur. The beam was centered on symphysis pubis in the midline, and the focus-to-film distance was always 1 meter. The 43 cm x 38 cm cassette was placed under the patient. A calibration scale was fixed at the level of the greater trochanter of the noninvolved hip for calibrating the dimension measurements (Fig. 7).

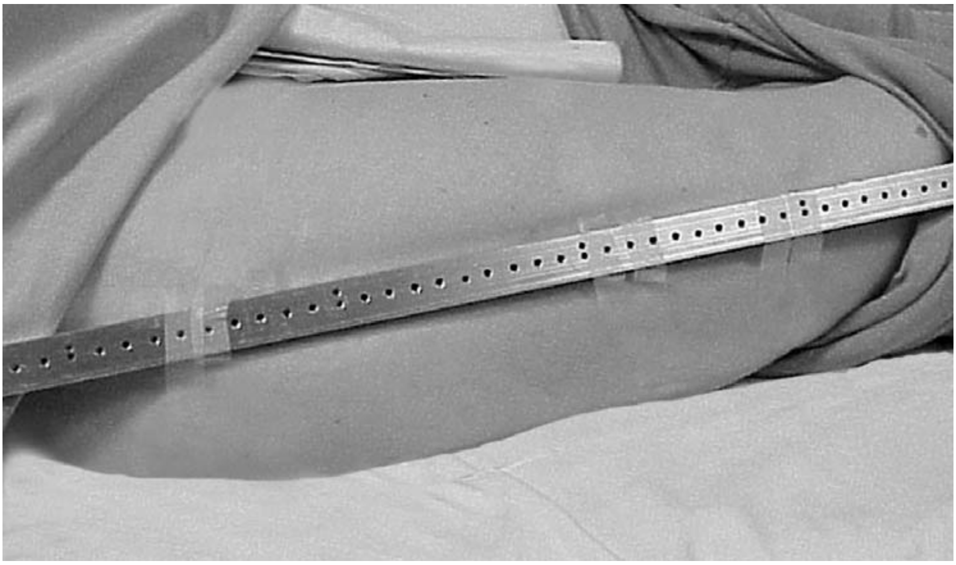

Fig. 7. Calibration scale fixed at the trochanteric level.

The X-rays were digitized with a ccd camera (Dage MTI 72E, Dage, USA) on a light table (Northern Light Desktop Illuminator, Imaging Research Inc., Canada), using an objective Canon CI-TV 16 mm lens, and digitally stored in a PC computer. The images were calibrated using the calibration scale, and the dimensions were measured by a digital image analysis system MCID M4 with software version 3.0, rev. 1.1 (Imaging Research Inc., Canada). Several dimensions of the uninjured hip and pelvis were measured (Fig. 8).

All the measurements were made by a single observer.

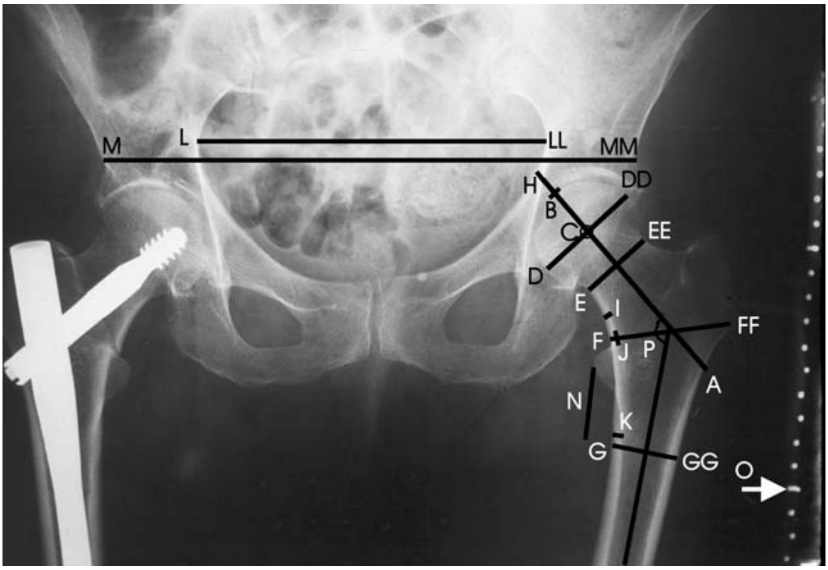

Fig. 8. Definition of the parameters measured from the ap roentgenograms of the pelvis and the upper femur. L-LL= largest inner pelvic diameter (LIPD), M-MM=smallest outer pelvic diameter (SOPD), A-H= hip axis length (HAL), A-B and A-C= femoral neck axis length (FNALa and FNALb, respectively, measured in two ways), B-H= acetabular width (AW), D-DD= femoral head diameter (HD), E-EE= femoral neck diameter (ND), F-FF= trochanteric width (TW), G-GG= femoral shaft diameter (FSD), I= femoral neck cortex width (FNC), J= medial calcar femoral width (CFE), K= femoral shaft cortex width (FSC) and P= neck/shaft angle (NSA). O shows the calibration scale and N is a 3 cm bar generated with the software.

The *reproducibility* of the measurements was evaluated by three blind repeat measurements of the geometrical parameters from 10 radiographs. The root mean square coefficient of variation (CV_{rms}) was used as a measure of reproducibility, being 0.9 %, 1.5 %, 2.5 %, 2.5 %, 3.3%, 1.5 %, 0.7 %, 1.2 %, 1.1 %, 1.2 %, 1.5 %, 5.2 % and 9.9 % for FNALa, FNALb, FSD, TW, AW, ND, HD, HAL, NSA, SOPD, LIPD, FSC and FNC. These values indicate that the method was highly reproducible for all the other parameters except cortical thickness.

The *accuracy* of dimension measurements was evaluated from the radiographs of 18 patients with a hip prosthesis (Austin Moore). The diameter of the spherical head of the prosthesis was measured from the radiographs with image analysis and compared with the known head size of the prosthesis. The root mean square accuracy error was 2.3 %.

4.2 Lifetime factors, bone metabolism and bone mineral density in patients with hip fracture

The *study subjects* consisted of 102 consecutive postmenopausal women with nonpathological femoral neck fractures or trochanteric hip fractures in 1998 without previous hip fracture or surgery. 28 patients aged over 84 years were excluded because of a failure to find suitable controls with regard to age. Thus, 74 patients (fracture group, mean age 74.2 years, range 53–84 years) constituted the study group. 49 had a femoral neck fracture [cervical group, mean age 73.1 (53–84) years] and 25 a trochanteric fracture [trochanteric group, mean age 76.3 (61–84) years]. There was no significant difference in age between the femoral neck and trochanteric fracture patients.

The *control group* [40 women, mean age 73.7 (63–84) years] was the same control group as described in the chapter 4.3.1.

Thirty-seven patients and 19 controls were excluded from the statistical comparison of BMD and the biochemical measurements of bone metabolism because they had had treatments with calcium, D-vitamin, biphosphonates, estrogens, calcitonin or corticosteroids, and one fracture patient was excluded for primary hyperparathyroidism.

BMD of the upper femur was measured by two different equally tested and calibrated scanners (Lunar DPX, Lunar Radiation Corporation, Madison, WI, USA) using equal measurement routines. Before the measurements, a control phantom was scanned daily, and the same measurement program was used in both similar Lunar DPX densitometries. The coefficient variation of the femoral neck *in vivo* reported by the manufacturer was 0.6–1.7 %. The measurement of the patients was performed 2–4 days after the fracture. Three parts of the hip (nonfracture side of the fracture patients and left side of the controls) were measured at sites of femoral neck (FEBMD), Ward`s triangle (WABMD) and trochanter (TRBMD).

Blood samples for *measurements of bone metabolism markers* from the patients (on the first or second postoperative day) and controls were obtained in the morning after an overnight fast. Serum was separated and the samples were analyzed immediately, with the exception of the samples for s-CT and serum osteocalcin (s-OC), which were stored at –20° C for 1–2 months until assayed. All assays were performed in clinical laboratory according to good clinical practise.

Serum (s)-Intact N-terminal of procollagen type 1 (s-PINP) was measured using a radioimmunoassay test kit (Orion Diagnostica, ISO9001, Orion Corporation, Orion Diagnostica, Espoo, Finland, sensitivity 3.0 μg/l, intra-assay CV 5.5%, interassay CV 5.6 %) (Tähtelä *et al.* 1997). S-25-hydroxyvitamin D (s-25-(OH)-D) was measured using a commercial radioimmunoassay test kit (25-hydroxyvitamin D H^3 RIA, DiaSorin, Catalog No./REF./KAT.-NR.: 68100E, Stillwater, Minnesota, sensitivity 4.0 nmol/l, intra-assay CV 8.8 %) (Hollis *et al.* 1993). S-Parathyroid hormone (s-PTH) was assayed using a commercial radioimmunoassay (Intact PTH Parathyroid Hormone 100T Kit-Catalog n:o 40–2170, Nichols Institute Diagnostics, San Juan Capistrano, California, USA, sensitivity 7.5 ng/l, intra-assay CV 2.6 %, interassay CV 5.9 %) according to the manufacturer´s instruction. S-Alkaline phosphatase (s-ALP) was analyzed by the method recommended by the Committee on Enzymes of Scandinavian Society for Clinical Chemistry and Clinical Physiology (Reagents: Oy Reagena Ltd, Finland, Analyzer: BM/ Hitachi 911 Automatic Analyzer, sensitivity $3.7 \cdot 10^{-4} \Delta A$/min per U/l, intra-assay CV 0.8%, interassay CV 2.9%). S-Bone specific alkaline phosphatase isoenzyme (s-BAP) was measured by the REP Electrophoresis kit (Helena Bio-Sciences, Cat No. 3200, Sunderland, Tyne & Wear, SR5 3XB. U.K.). Total s-calcium (s-Ca) was analysed by flamephotometry (Eppendorf AFIX 5055, Eppendorf-Netheler-Hinz GmbH, Hamburg, sensitivity $2.4 \cdot 10^{-1} \Delta A$ per mmol/l, intra-assay CV 0.7%, interassay CV 3.3%) (Robertson & Marshall 1979). S-Calcitonin (s-CT) was assayed by a radioimmunoassay test kit (Calcitonin, Diagnostic system laboratories, INC catalog. No: DSL-1200, Webster, Texas, 77598–4217, USA, sensitivity 4.0 pmol/l, intra-assay CV 5.0 %, interassay CV 12.4 %) (Erdogan *et al.* 1997). S-Osteocalcin (s-OC) was measured by an immunoradiometric assay test kit (Human Osteocalcin Kit, immunoradiometric assay (IRMA), 40–2248, Nichols Institute Diagnostics, San Juan Capistrano, CA, 92679 USA, sensitivity 4.0 μg/l, intra-assay CV 5.2 %, interassay CV 8.3 %).

The data were recorded on a special form by the same interviewer, a trained nurse, who interviewed both the fracture patients at admission and the controls. The following lifetime data were collected: body weight, height, body mass index (BMI), menarcheal age, age at menopause, parity, ovarian surgery, independence, walking ability, femoral muscle strength, vision, current medication, and concurrent diseases. "The lifestyle factors", including diet, use of alcohol and coffee, smoking and physical activity, were also recorded.

4.3 Uncemented Austin-Moore hemiarthroplasty versus two hook pins

In 1989–1996, all femoral neck fractures were prospectively registered at the University Hospitals of Oulu, Finland and Lund, Sweden (Jalovaara *et al.* 1992, Berglund-Rödén *et al.* 1994, Parker *et al.* 1998). In Lund, the main treatment method was OS with two hook pins (n=1277). In Oulu, the commonest treatment method was uncemented Austin-Moore HA (n=546).

Cross-matching of these patients was performed by a statistician for age (±2 years), sex, preoperative residence, walking capacity and displacement of the fracture. 357 pairs of displaced femoral neck fractures were found (Table 5).

Standardized forms were prospectively filled in with data concerning the patients' background, hospital stay, resource demands and quality of life, i.e. information concerning their place of residence, need for institutional care as well as pre- and postoperative ADL functions (the patients were asked if they were able to dress and undress themselves without any help) and locomotor ability. Follow-up was continued for four months by recording the re-operation rate, mortality and the same functional parameters that were recorded preoperatively. Mortality and re-operation rate were also recorded at one year after the fracture.

OS with two hook pins in Lund was performed using atraumatic insertion and firm intracapital fixation (Strömqvist *et al.* 1992) (Fig. 9).

Table 5. Cross-matched data of patients with femoral neck fracture treated with hemiarthroplasty (HA) in Oulu and osteosynthesis with two hook pins (OS) in Lund.

Operation type	HA (%)	OS (%)
Male	70	70
Female	287	287
All	357	357
Mean age (years) and range	82 (63–98)	82 (63–98)
Female mean age and range	82 (63–98)	82 (63–98)
Male mean age and range	81 (64–97)	81 (64–97)
Admitted from		
Own home	232 (65)	232 (65)
Convalescent home	7 (2)	0
Fullservice unit	92 (26)	99 (28)
Geriatric department, nursing home	24 (6)	24 (6)
Other	2 (1)	2 (1)
Acute hospital	0	0
Walking capacity before the fracture		
could walk alone outdoors	192 (54)	192 (54)
could walk outdoors only supported by another person	48 (13)	48 (13)
could walk alone indoors but not outdoors	92 (26)	92 (26)
could walk indoors only supported by another person	23 (6)	23 (6)
could sit on a chair but not walk	2 (1)	2 (1)
bedridden	0	0

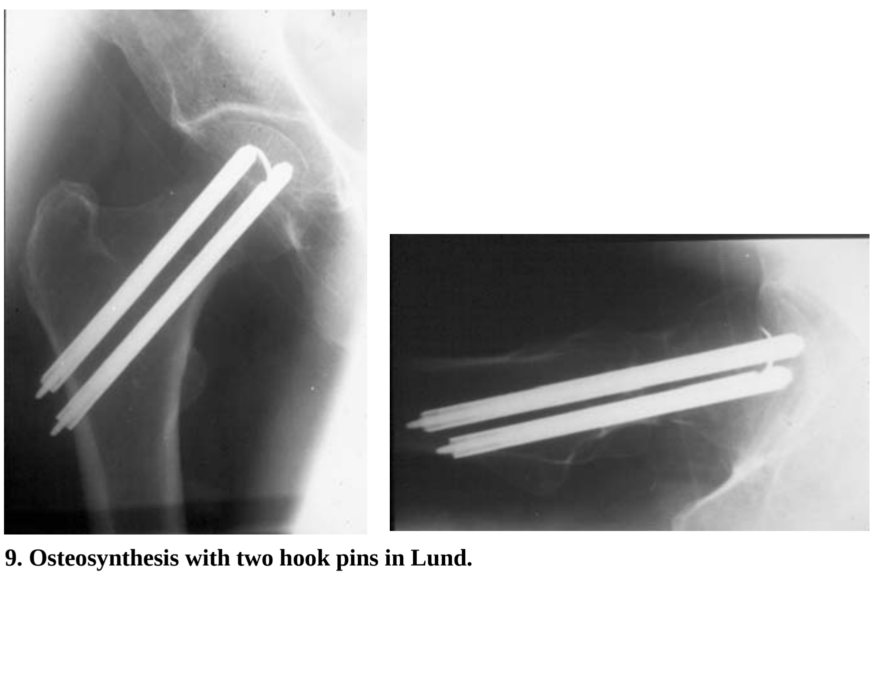

Fig. 9. Osteosynthesis with two hook pins in Lund.

HA in Oulu was always performed through a posterior approach using an uncemented Austin-Moore prosthesis (Fig. 10).

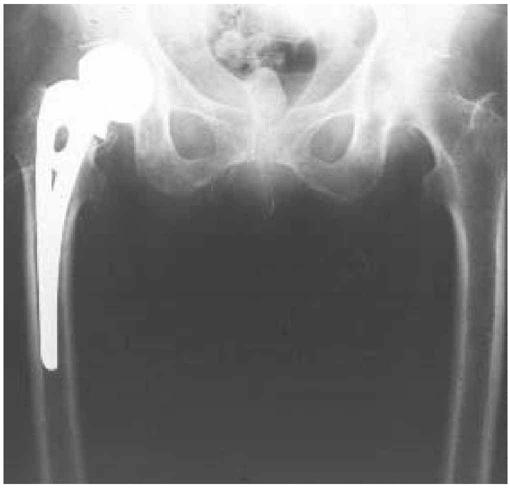

Fig. 10. Austin Moore hemiarthroplasty in Oulu.

Full weight bearing was allowed on the first postoperative day for both OS and HA patients. The patients were encouraged to walk as soon as possible.

The after-care policies were different in Lund and Oulu. In Lund, the policy was to treat the patients in the primary hospital until they were able to return to their original residence, but in Oulu, nearly all patients including the OS and HA patients, were discharged into health care centre hospitals or rehabilitation units as soon as possible.

4.4 Uncemented Austin-Moore hemiarthroplasty versus osteosynthesis with three screws

During 1989–1999, all hip fractures treated in Oulu University Hospital were prospectively registered (Jalovaara *et al.* 1992, Berglund-Rödén *et al.* 1994, Parker *et al.* 1998). There were 1055 femoral neck fractures. 161 patients with displaced femoral neck fractures (Garden III–IV) underwent OS with three hip screws and 711 uncemented Austin-Moore HA.

These patients were also cross-matched for age (±2 years), sex, preoperative residence, walking capacity and displacement of the fracture, and 84 pairs with displaced femoral neck fractures were found (Table 6).

Table 6. Cross-matched data of patients with femoral neck fracture treated with hemiarthroplasty (HA) and osteosynthesis with three screws (OS).

Operation type	HA (%)	OS (%)
N:o of patients	84	84
Mean age (years) and range	75 (63–92)	75 (62–92)
Male	29	29
mean age (range)	75 (63–87)	74 (62–86)
Female	55	55
mean age (range)	75 (62–86)	75 (63–92)
Residental status at fracture		
own home	70 (83)	70 (83)
convalescent home or fullservice unit with meals	12 (14)	12 (14)
geriatric department, rehabilitation or long term care	2 (3)	2 (3)
Walking capacity		
walked alone or accompanied out of doors	64 (76)	64 (76)
Walked alone indoors but not out of doors	17 (20)	17(20)
walked indoors only accompanied	3 (4)	3 (4)
unable to walk, able to sit	0	0
Use of walking aids		
can walk without aids	49 (59)	59 (70)
one stick	17 (20)	13 (16)
two sticks	2 (2)	1 (1)
rollator/walking frame	16 (19)	11 (13)
wheelchair	0	0
ADL-functions		
yes	65 (77)	68 (81)
no	19 (23)	16 (19)

The same standardized forms were prospectively filled in with data as in the study III and follow-up was continued for four months by recording the re-operation rate, mortality and the same functional parameters that were recorded preoperatively. Mortality and re-operation rate were also recorded at one year after the fracture.

OS with three screws in Oulu was performed through a lateral incision after closed reduction and fixation (Fig. 11). HA in Oulu was always performed through a posterior approach using an uncemented Austin-Moore prosthesis (Fig. 10).

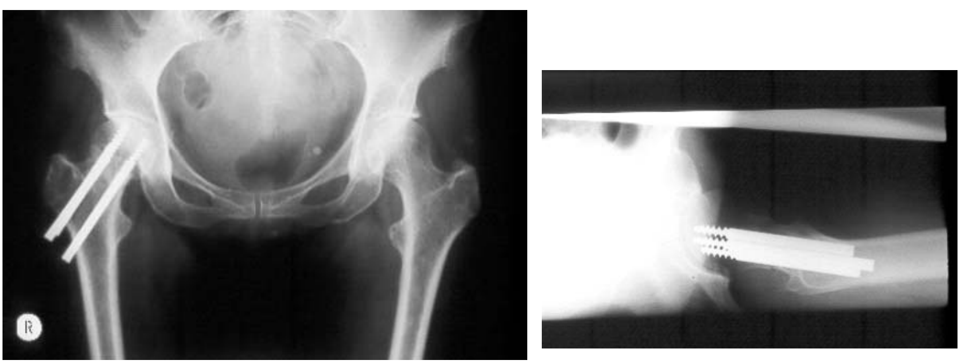

Fig. 11. Osteosynthesis with three screws in Oulu.

Full weight bearing was allowed on the first postoperative day for both OS and HA patients. The patients were encouraged to walk as soon as possible.

4.5 Deep infection after hip fracture surgery

2299 patients with non-pathological hip fractures aged over 50 years (mean age 78.2 years, 1718 female, and 583 male) were admitted into the Oulu University Hospital during 1989–1999. 287 had undisplaced femoral neck fractures (13 %), 1027 displaced femoral neck fractures (45 %), 55 basicervical fractures (2 %), 371 trochanteric two-fragment fractures (16 %), 460 trochanteric multi-fragment fractures (20 %) and 99 subtrochanteric fractures (4 %).

437 patients were treated with two or three screws (19 %), 814 patients with HA (Austin-Moore, 35 %), 70 patients with THA (3 %), 291 patients with dynamic hip screw (DHS, 13 %), two patients with AO plate (0.1 %), 657 patients with Gamma nail (29 %), 5 patients with girdlestone (0.2 %) and 23 patients conservatively (1 %).

A control group was formed by a statistician. Matching was performed for age, sex, fracture type, operative method, place of residence and walking ability (Table 7).

Table 7. Cross-matched data in patients with and without deep infection after hip fracture surgery.

	Patients with deep infection (%)	Patients without deep infection (%)
N:o of patients	29	29
Residental status		
own home	14 (48)	14 (48)
convalescent home or fullservice with meals	14 (48)	14 (48)
geriatric department, rehabilitation or long term care	1 (2)	1 (2)
Walking Ability		
walked alone out of doors	12 (42)	12 (42)
walked out of doors only accompanied	5 (17)	5 (17)
walked alone indoors but not out of doors	10 (35)	10 (35)
walked indoors only accompanied	1 (3)	1 (3)
unable to walk	1 (3)	1 (3)
Use of walking aids		
can walk without aids	13 (45)	14 (48)
one stick	10 (34)	4 (14)
two sticks		1 (3)
rollator/walking frame	4 (14)	9 (31)
wheelchair	2 (7)	1 (4)

Standardized forms were prospectively filled in with data concerning the same data as in the studies III and IV and follow-up was also continued for four months by recording the same functional parameters that were recorded preoperatively. Mortality and re-operation rate were recorded up till December 2000.

4.6 Ethical considerations

Written informed consent was obtained from all the patients and controls, and the study protocols were approved by the institutional ethical committee.

4.7 Classification of fractures

The femoral neck fractures were classified according to Garden, the trochanteric fractures according to Jensen and the subtrochanteric fractures according to Seinsheimer (Garden 1964, Jensen & Michaelsen 1975, Seinsheimer 1978). Basicervical fractures were classified here as a two-fragment undisplaced trochanteric fractures (Jensen & Michaelsen 1975).

4.8 Statistical analyses

The data organization and statistical analyses were performed by a statistician using the SPSS statistical software: version 8.0, version 9.0, and version 10.0; SPSS, Inc., Chicago, IL, USA. Pearson´s linear correlation coefficients were calculated in the study I and II. Student's t-test and the Mann-Whitney U-test were used to compare the differences for significance. The Mann-Whitney U-test was used whenever the material was not normally distributed. The Chi-square test and Fisher's exact test (2 x 2 table) were used to compare the dichotomous variables and the Chi-square and exact tests in the analysis of multiple categorical variables. $P<0.05$ was considered significant.

Statistical analyses in the studies with cross-matched data were performed as described by Breslow and Day (1980) for matched-pair studies III, IV and V, comparing the pair members to each other with McNemar's test for dichotomous variables and with marginal homogeneity for multiple categorical variables. Only the pairs with complete data were considered in the statistical analyses (Breslow & Day 1980). This explains the great variation in the numbers of observations. $P< 0.05$ was considered significant.

The sample power test (power=0.80, alpha=0.05) was used to find the number of pairs reaching the level of significant difference in the analysed parameters in the study IV and Kaplan-Meier analysis was used for survival analysis in the study V.

5 Results

5.1 Geometrical measures

The fracture group had a higher NSA than the controls (Fig. 12). The cortical thickness values were significantly lower in the fracture group (Fig. 13). FSD ($p<0.001$) and TW ($p<0.01$) were also significantly lower in the fracture group than in the control group. The pelvic dimensions SOPD and LIPD were smaller in the fracture group than in the control group ($p<0.01$ and $p<0.05$, respectively).

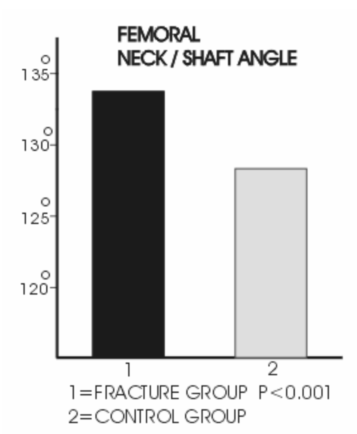

Fig. 12. NSA in fracture patients and controls.

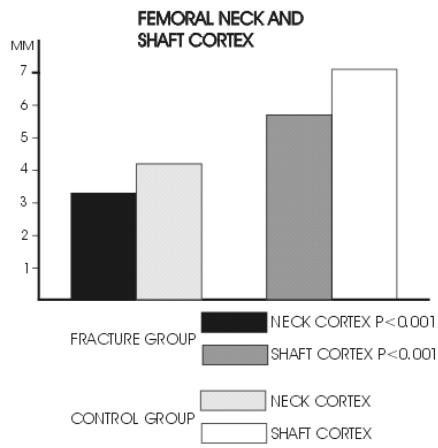

Fig. 13. Femoral cortices in fracture patients and controls.

The ratio FNC/FSC was significantly lower in the femoral neck fracture patients ($p<0.05$). NSA was significantly greater in the femoral neck fracture patients (Fig. 14). SOPD and AW were significantly wider in the femoral neck fracture patients ($p<0.01$ and $p<0.05$, respectively). FSD was significantly narrower in the femoral neck fracture group than in the trochanteric group ($p<0.05$).

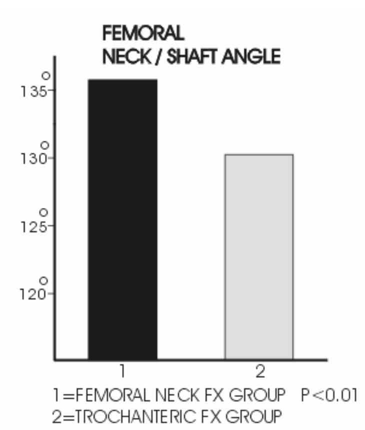

Fig. 14. NSA between femoral neck fracture patients and trochanteric fracture patients.

5.2 Bone mineral density, parameters of bone metabolism, and lifetime factors

Body weight and BMI (p=0.004) were significantly lower in the fracture group compared to the control group. The BMD in the upper femur differed significantly between the fracture and the control group (Table 8).

Body weight, BMD of the upper femur and BMI (p=0.021) were higher in the femoral neck fracture patients compared to the trochanteric fracture patients (Table 8).

Table 8. Weight, height and bone mineral density (BMD) measured at femoral neck (FEBMD), Ward`s triangle (WABMD) and trochanter region (TRBMD) in postmenopausal hip fracture patients and controls.

Group	n	Weight kg	N	Height cm	n	FEBMD *g/* cm^2	n	WABMD *g/* cm^2	n	TRBMD *g/* cm^2
Fracture (mean and SD)	74	61 (13)[6*]	74	159 (6)	36	0.68 (0.13)[7*]	36	0.57 (0.16)[5*]	36	0.62 (0.15)[7*]
Control	40	68 (9)	40	160 (4)	21	0.84 (0.09)	21	0.68 (0.1)	21	0.78 (0.09)
Femoral neck fx	49	63 (13)[3*]	49	160 (5)	24	0.73 (0.12)[2*]	24	0.62 (0.15)[4*]	24	0.67 (0.14)[1*]
Trochanteric fx	25	55 (11)	25	158 (6)	12	0.61 (0.12)	12	0.46 (0.12)	12	0.55 (0.13)

[1]* p= 0.022, [2]* p= 0.011, [3]* p=0.005, [4]* p= 0.003, [5]* p= 0.002, [6]* p= 0.001, [7]* p< 0.001

The s-Ca and s-25-(OH)-D levels were significantly lower in the fracture group than in the control group. The level of s-CT was significantly higher in the fracture group than in the control group.

There were no significant differences between the trochanteric and femoral neck fracture groups in any other biochemical measurements except s-CT, which was higher in the femoral neck fracture group than in the trochanteric fracture group (Table 9).

Table 9. Biochemical measurements associated with bone and calcium metabolism in postmenopausal hip fracture patients and controls.

Group	n	S-ALP U/L	S-CA mmol/L	S-CT pmol/L	S-25-(OH)-D nmol/L	Fs-PTH ng/L	S-PINP µg/L	S-BAP U/L	S-OC µg/L
Fracture (mean and SD)	36	160.6 (60.8)	***2.1 (0.2)	**7.4 (5.2)	***24.7 (12.9)	54.7 (33)	49.1 (39)	61.4 (27.7)	27 (26)
Controls	21	148.5 (50.1)	2.3 (0.2)	4.9 (2.3)	56.9 (27.1)	41.4 (14.3)	38.9 (20)	64.6 (37)	24.2 (8.6)
Femoral neck fx	24	162.4 (61.6)	2.1 (0.1)	*8.3 (5.9)	26 (13.9)	57 (36.5)	48.6 (39.3)	58.1 (25.8)	28 (30.4)
Trochanteric fx	12	156.7 (61.9)	2.2 (0.2)	5.4 (2.5)	22 (10.5)	50 (25.1)	50.2 (40.1)	68.3 (31.4)	25 (12.7)

* p=0.044, ** p=0.022, *** p<0.001

The fracture group included more users of loop diuretics, i.e. furosemid, insulin, oral antidiabetics, neuroleptics and antidepressants, than the control group. Asthma drugs (inhaled cortison, inhaled decongestants) and thyroid hormone were more often used in the control group (Table 10).

Table 10. Main differences between postmenopausal women with hip fracture compared to controls regarding to medication, concurrent diseases and gynaecological and lifestyle factors.

Parameter	Results	p-value
Loop diuretics	More used in fracture patients	p<0.001
Insulin and antidiabetics	More used in fracture patients	p=0.029
Neuroleptics	More used in fracture patients	p=0.049
Antidepressants	More used in fracture patients	p=0.005
Astma drugs	More used in controls	p=0.032
Thyroid drugs	More used in controls	p=0.021
Cardiovascular diseases	More in fracture patients	p=0.011
Stroke	More in fracture patients	p=0.002
Diabetes	More in fracture patients	p=0.002
Malignancies	More in fracture patients	p=0.031
Physical activity	Fracture patients less active	p<0.001
The use of alcohol	More used in controls	p=0.006
Deliveries	More in fracture patients	p=0.036

Cardiovascular diseases (coronary disease, hypertension, heart failure, valvular diseases) and stroke (ischemic brain disorders) were significantly more frequent in the fracture group compared to the control group. Type I and type II diabetes mellitus and malignancies were also significantly more common in the fracture group than in the control group (Table 10).

Use of alcohol was more frequent in the control group than in the fracture group. The fracture group was less active physically compared to the controls (Table 10).

The fracture group included more women who had had one or more deliveries (Table 10).

More of the controls lived independently (p<0.001), their walking ability was better (p<0.001), and they used walking aids less often (p=0.002) than the fracture patients. Femoral muscle strength and vision were also better in the control group than in the fracture group (p<0.001).

No significant differences were seen in any medication, concurrent diseases, gynaecological and lifestyle factors, femoral muscular strength, independency, walking ability or use of walking aids between the femoral neck and trochanteric fracture groups.

5.3 Functional outcome after uncemented Austin-Moore hemiarthroplasty and osteosynthesis with two hook pins

The median duration of hospitalization after the first admission into a primary hospital was significantly longer for OS patients in Lund than for HA patients in Oulu (p=0.001). On the other hand, more of OS patients were discharged directly into their own home from the primary hospital (p=0.001).

Table 11. Outcome after comparison between uncemented HA in Oulu and OS with two hook pins in Lund.

Parameter	Results	p-value
Walking capacity	OS patients better ambulatory capacity	0.001
Use of walking aids	OS patients less use of walking aids	0.001
Pain	OS patients less pain	0.007
Re-operation rate	OS patients higher re-operation rate at one year	0.005

More OS patients than HA patients were able to manage in their own home or lived semi-independently in a convalescent home or full-service unit at four months (p=0.025).

71 % of the HA patients and 87 % of the OS patients who had been living in their own homes at the time of the fracture had returned to their own home at four months.

OS patients had better ambulatory capacity. OS patients also used less walking aids than HA patients (Table 11). When asked if they could walk equally well at four months as before the fracture, OS patients reported better walking capacity (p=0.002).

OS patients were able to manage better in ADL skills, but this was the case also at fracture. OS patients also had less pain in the involved hip than HA patients (Table 11).

Mortality was 4 % higher at four months and 5 % higher at one year among HA patients than among OS patients.

The re-operation rates were of the same magnitude in both HA and OS patients at 4 months, while at one year, OS patients had a higher re-operation rate (17 %) than HA patients (10 %) (Table 11).

5.4 Functional outcome after uncemented Austin Moore hemiarthroplasty and osteosynthesis with three screws

There were no significant differences between the study groups in Oulu concerning functional outcome.

Significantly more of the OS patients than the HA patients had been re-operated by four months and one year (re-operation rates at 4 months 19 % and 4 % and those at one year 20 % and 6 %, p=0.004 and p=0.012, respectively). Mortality was of the same magnitude among both HA and OS patients (at four months 7 % and 10 %, at one year 17 % and 14 %, respectively).

5.5 Deep infection after hip fracture surgery

Twenty-nine patients (mean age 80, range 56-92 years) out of the 2276 treated surgically developed deep infection (rate 1.3 %), and all of them had revision surgery in accordance with our treatment policy. Eight patients were men (mean age 74 range 56-89 years) and 21 were women (mean age 82, range 60-92 years). The infection appeared after the primary operation in 25 cases and after a re-operation in 4 cases. The mean delay of the revision for infection was 84 (range 5-300) days. Bacteriological culture was positive in 27 of the patients and negative in two cases. One or more concurrent diseases were present in 93 % of the patients and in 92 % of the controls. The cases had more often diabetes than the controls (41 % vs. 14 %, p=0.038). The corresponding figures for cardiovascular diseases (coronary heart disease, chronic heart failure, valvular heart disease, hypertension) were 76 % and 59 %, respectively (p=0.213).

Infection impaired the functioning of the patients as evaluated at 4 months after primary surgery. Their walking ability was poorer and they used more walking aids, but the place of residence was not affected (Table 12).

Table 12. Outcome data after comparison between patients with and without deep infection after hip fracture surgery.

Parameter	Patients with deep infection (%)	Patients without deep infection (%)	p-value
Residental status			0.785
own home	6 (21)	10 (34)	
convalescent home or fullservice with meals	5 (17)	8 (28)	
geriatric department, rehabilitation or long term care, acute hospital	14 (48)	6 (21)	
unknown or dead	4 (14)	5 (17)	
Walking Ability			0.039
walked alone out of doors	4 (16)	7 (29)	
walked out of doors only accompanied		2 (8)	
walked alone indoors but not out of doors	5 (20)	7 (29)	
walked indoors only accompanied	5 (20)	3 (13)	
unable to walk	11 (44)	5 (21)	
Use of walking aids			0.022
can walk without aids		1 (4)	
one stick	3 (12)	2 (8)	
two sticks		3 (13)	
rollator/walking frame	10 (40)	13 (54)	
wheelchair	12 (48)	5 (21)	
Mortality			
at four months	4 (14)	4 (14)	1.000
at one year	10 (35)	7 (24)	0.508

In the infection group, one-year mortality was 34 %, while the corresponding figure for the control group was 24 %, giving attributable mortality of 10 % for deep infection. The highest mortality at one year was seen in the patients who had undergone removal of an Austin-Moore prosthesis (67 %). Infection seemed to increase mortality over the first three postoperative years, but the difference in comparison with the patients without infection was not significant (p=0.1594, Fig. 15).

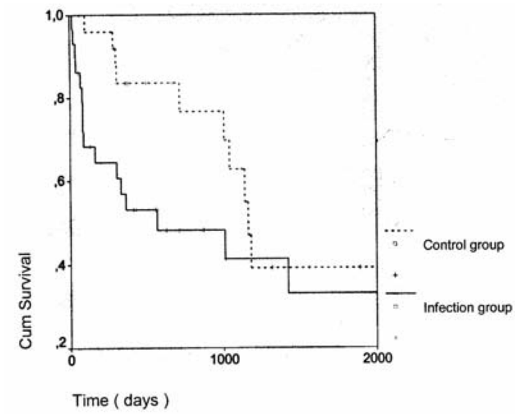

Fig. 15. Survival analysis.

The operations for infection could be divided into two categories: Removal of the whole osteosynthesis or prosthesis and salvaging of the implant or prosthesis. One-year mortality tended to be higher after the removal procedures (8 patients at one year, 44 %) than after the salvage procedures (2 patients at one year, 18 %, p=0.234). When the revision surgery for infection was done more than 1.5 months after the primary operation, significantly more patients needed removal of the osteosynthesis or prosthesis compared to those with less than 1.5 months' delay (p=0.0078). However, the delay had no significant effect on mortality (< 1.5 months vs. >1.5 months, p=0.449).

Staphylococcus aureus was the most common causative micro-organism either alone, in 14 cases (48 %), or as a mixed infection, in 3 cases (10 %), and it was recovered from blood in four cases, giving a bacteremia rate of 24 %. *Staphylococcus aureus* infection seemed to be associated with higher mortality at one year (p=0.014) than the other bacteria. The course of *Staphylococcus epidermidis* infection seemed to be milder and did not increase mortality.

6 Discussion

6.1 Upper femur and pelvic geometry and hip fracture risk

The geometrical parameters of the pelvis and the proximal femur were measured from plain pelvic radiographs. To reduce the variability of the data, the patients' position was standardized and the dimension measurements calibrated. The method appeared to be highly reproducible for all the other parameters except cortical thickness. The root mean square accuracy error was also quite low, 2.3 %. No relevant comparison could be made, because of no error values have been reported by any other authors. Accuracy and reproducibility were also improved by using digital image analysis, which has been shown to be more accurate than the human eye (Bould *et al.* 1999). Digital analysis was seldom used in other conventional pelvic x-ray studies (Glüer *et al.* 1994).

We found that women with thin cortices have an increased risk to sustain a hip fracture, which is in good accordance with the other studies (Glüer *et al.* 1994, Peacock *et al.* 1995). The neck-shaft angle was larger in the fracture group compared to the control group in our study. This finding has been inconsistent in previous studies: some studies have found NSA to be larger in the fracture group (Glüer *et al.* 1994, Karlsson *et al.* 1996), while others have failed to reveal any differences (Peacock *et al.* 1995, Michelotti & Clark 1999). It has been reported that the medial cortex becomes thinner when the NSA increases (Putz 1993). We found a correlation in hip fracture patients between thin cortices in the upper femur and NSA, which is in agreement with this previous finding of individual cases. A high neck/shaft angle seems to increase more the risk of femoral neck fracture (Fig. 16).

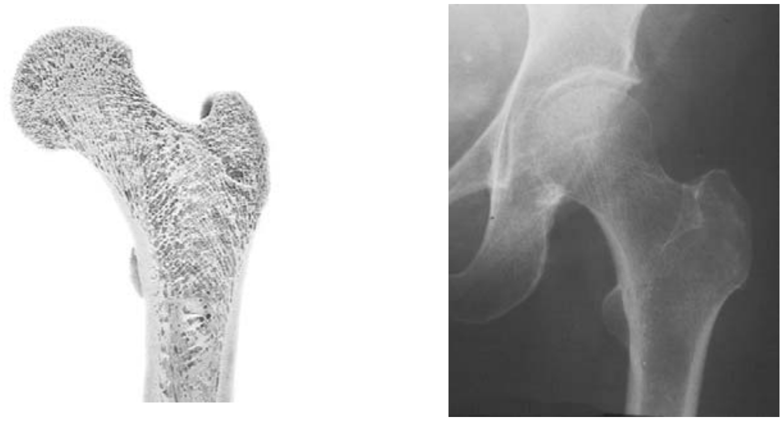

Fig. 16. High NSA, strong trabeculae in the head of the femur, thin cortices in the medial side of the upper femur (printed with permission from Urban & Fischer Verlag).

The risk of hip fracture might be lower if the NSA value is low (Fig. 17). In patients with severe osteoporosis, the trochanteric area might be exposed to the highest risk of fracture, whenever the person sustains a typical fall on the lateral aspect of the hip (Parkkari *et al.* 1999).

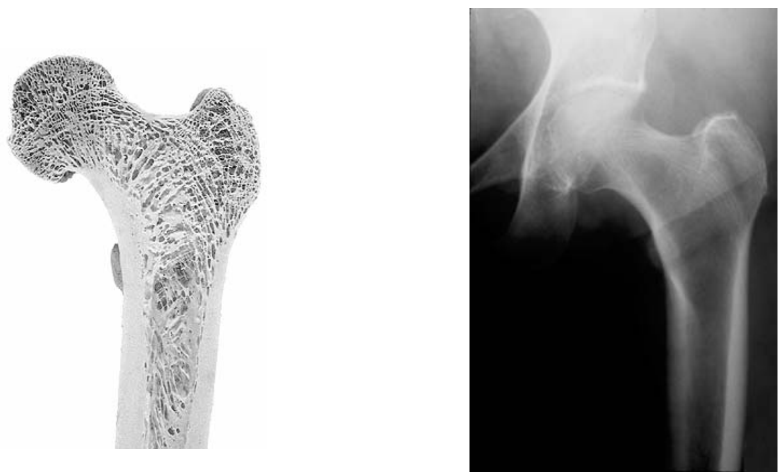

Fig. 17. Low NSA, strong cortices in the medial side of the upper femur (printed with permission from Urban & Fischer Verlag).

The lower TW and FSD in our hip fracture patients compared to the controls may indicate that the bone breaks more easily because of the smaller cross-sectional area due to the basic biomechanical properties of cortical and trabecular bone (Mow & Hayes 1991). Contrary to our findings, smaller pelvic diameters in hip fracture patients compared to controls were not found by Karlsson *et al.* (Karlsson *et al.* 1996). The significance of this controversy is uncertain.

6.2 Lifetime factors, markers of bone metabolism and a risk of hip fracture

The fact that our control group was obtained from a private outpatient clinic with strict exclusion criteria may cause some bias: the controls were probably more health-oriented and vital. However, we do not consider this crucial because public health care centers also refer patients for DEXA measurements in this private clinic. We therefore we believe that the control group, by and large, represents an average and comparable population in our area. There were some limitations in our study: the study was cross-sectional, the group sizes, especially the size of the trochanteric fracture group, were relatively small, and we did not measure bone resorption markers.

The body weight and BMI of the controls turned out to be higher than those of the fracture patients, which difference is in line with earlier reports (Eriksson & Widhe 1988, Karlsson *et al.* 1993). We did not see any differences in body height, as previously reported (Hemenway *et al.* 1995, Farahmand *et al.* 2000, Lau *et al.* 2001).

It is generally known that hip fracture patients have lower BMD than non-fracture controls or the average population (Nakamura *et al.* 1992, Sugimoto *et al.* 1994, Tromp *et al.* 2000), which was also shown in our study. But one third of our fracture patients did not fully meet the criteria of osteoporosis as defined by WHO (<–2,5 SD) (WHO Study Group 1994), and a minor part of them even had almost normal bone density. The important roles of the falling mechanism and bone geometry in the pathogenesis of hip fractures might explain the occurrence of hip fractures among these patients (Hayes *et al.* 1993, Glüer *et al.* 1994, Duboeuf *et al.* 1997). The geometry was also shown to be important by our findings.

Hip fracture patients had lower levels of total calcium and lower levels of 25(OH)D in serum than the controls in line with the findings reported earlier (Arnala *et al.* 1997),(Hoikka *et al.* 1982, Harju *et al.* 1985, Punnonen *et al.* 1986) and there was a significant inverse correlation between s-25-(OH)-D and s-PTH. This might imply subsequent secondary hyperparathyreoidism, which is postulated to be largely responsible for the excessive bone loss (Parfitt *et al.* 1982).

Our fracture patients were less healthy than the controls, as a greater proportion of them had had heart diseases, strokes, diabetes and malignant diseases. Diabetes has been reported to be associated with hip fractures (Forsén *et al.* 1999), and heart diseases also appear to associate with the occurrence of hip fractures (Lau *et al.* 2001). Whether the increased risk should be attributed to a reduced bone mass or to factors associated with the falling has not yet been determined (Forsén *et al.* 1999). A history of stroke is a major risk factor for hip fracture (Ramnemark *et al.* 1998, Lau *et al.* 2001), and this was also true in our study.

The use of loop diuretics was markedly higher in fracture patients than in controls. The lower BMD in the fracture patients might be partly explained by their more abundant use of loop diuretics. It must be emphasized that loop diuretics are in common use worldwide, and this might explain partly the increased incidence of hip fractures in many countries.

The functional ability of the fracture patients was poor when evaluated in terms of independence, walking ability, physical activity, use of walking aids, vision and femoral muscle strength. Similar findings have been reported by other authors (Tromp *et al.* 2000, Boonyaratavej *et al.* 2001). The lesser mobility of the elderly enhances bone resorption (Lips *et al.* 1990) and might also partly explain the lower BMD values in the fracture group.

6.3 Etiopathology of femoral neck and trochanteric fracture

The main geometrical differences between the features of femoral neck and trochanteric fractures were the greater NSA, SOPD and AW, the narrower FSD and the smaller FNC/FSC in femoral neck fracture patients. Similar findings have been reported by Glüer *et al.* for FNC/FSC and AW, but they did not measure the pelvic diameters or FSD. However, we did not find any significant difference in HD or cortical thickness, as Glüer *et al.* did (Glüer *et al.* 1994). Ferris *et al.* reported a shorter femoral neck length in patients with trochanteric fractures, but no differences in HD, FSD or NSA. However, they did not differentiate between women and men, their cervical fracture patients were significantly younger than those with a trochanteric fracture, and the group size (n=10) was relatively small (Ferris *et al.* 1989). Our findings support the postulation that differences in geometry play a role in the etiopathology of these two common hip fracture types.

Other important difference between patients with trochanteric hip fracture and femoral neck fracture is the fact that trochanteric fracture patients are more osteoporotic than femoral neck fracture patients (Eriksson & Widhe 1988, Vega *et al.* 1991a). This was also observed here.

We also found the body weight of the women with femoral neck fractures to be higher than those with trochanteric fractures, which is also in line with the previous reports (Eriksson & Widhe 1988, Karlsson *et al.* 1993). This difference may be related to the lower BMD observed in patients with trochanteric hip fractures compared with patients with the femoral neck fractures.

The increased calcitonin level seen in fracture patients, especially ones with femoral neck fractures, might be the result of a feedback mechanism in osteoporotics with increased bone resorption tending to increase the calcium level. Calcitonin antagonizes this mechanism. The mechanism might be more closely related to patients with femoral neck fractures than patients with trochanteric fractures.

We found no significant differences in the lifetime factors between the femoral neck and trochanteric fracture groups, although the groups were quite small in size. This is in agreement with the study of Sernbo *et al.* (1987), who found differences in several lifetime factors, but these were age-dependent and not real risk factors after age adjustment (Sernbo & Johnell 1987).

6.4 Osteosynthesis or hemiarthroplasty in the treatment of displaced femoral neck fractures?

The groups were were drawn from an extensive prospective series, which made it possible to match them for several parameters. This makes the comparison fairly reliable, and we believe that our method is nearly as adequate as randomization.

We were also able to perform cross-matching for walking ability, which reflects the patient's general condition and concurrent diseases. In view of the fact that there were no significant differences in any other background factors, the pairs should be reliably matched and comparable. We did not find any controlled comparison between OS and HA at this level of matching in the literature, which made adequate comparison with other published results difficult. However, the results previously reported on functional outcome have been very inconsistent.

In the study comparing osteosynthesis with two pins and uncemented hemiarthroplasty, the patients were drawn from two hospitals in different countries. Both hospitals were university hospitals in Scandinavia, where the climate, housing conditions, social welfare system and care facilities are fairly similar. Thus, the quality and results of treatment should be similar. It should also be emphasized that both hospitals were very familiar with their respective methods of treating femoral neck fractures. There were some missing data at the 4-month follow-up, more so in Lund. This may be due to the fact that Lund used mainly mailed forms filled in by the patients, while in Oulu the patients who did not return the follow-up forms were contacted for a telephone interview. This should not significantly influence the results, since only the complete pairs of patients were considered in the statistical tests.

The patients of the study comparing osteosynthesis with three screws and uncemented hemiarthroplasty were drawn from another participating hospital, Oulu University Hospital, and the same parameters as in the above-mentioned study were comparatively assessed.

The duration of treatment after the primary admission was longer for OS patients in Lund, but this reflects the different after-care policies in Lund and Oulu. Oulu has numerous local hospitals in the vicinity, that can admit the patients almost immediately after surgery, but in Lund, rehabilitation begins in the primary hospital.

Ambulatory capacity was better among our OS patients than among our HA patients, although the differences were not significant between the study groups, OS and HA, in Oulu. The better functioning of OS patients may be partially explained by the less pain associated with OS, as reported earlier (Skinner *et al.* 1989, Ravikumar & Marsh 2000). One prospective and randomized study (Dorr *et al.* 1986) reported that the patients with uncemented HA had increased pain and decreased ambulation compared to the patients with THA and cemented HA, which might partly explain the better functional outcome and residential status in our study because OS patients had less pain compared to uncemented HA patients. However, we did not compare cemented HA to osteosynthesis, and it remains unclear if the patients with cemented HA would have had an equal or better functional outcome compared to OS. In their prospective and randomized study, (Bray *et al.* 1988) concluded that the two-year functional results were better in the cemented HA group than in the OS group, but the number of patients was small, and the differences were not statistically significant. On the other hand, many authors have reported similar functional outcomes in HA and OS patients (Söreide *et al.* 1979, Berglund-Rödén *et al.* 1994, Young *et al.* 1996, Parker & Pryor 2000b). The discrepancy between our paper and the previous studies may be explained by the facts that no randomization or matching was used in some of them, and that the number of patients in all these studies was markedly smaller than in our study groups in Lund and Oulu. The difference in functional capacity seems to be small and does not reach the level of significance in small series, as it was also seen in the comparison between the study groups in Oulu.

Mortality has mostly been reported to be lower in OS patients than in HA patients (Bracey 1977, Raine 1973, Rodriguez *et al.* 1987). On the other hand, some prospective trials (Söreide *et al.* 1979, Parker & Pryor 2000) have not revealed any difference in mortality following OS or HA. We found no significant differences in mortality between the study groups.

At four months, there no were differences in the re-operation rates between Oulu and Lund, but the OS group in Oulu had a higher re-operation rate than the HA group in Oulu. At one year, the re-operation rate was significantly higher in the OS groups in Lund and Oulu compared to the HA group in Oulu. The re-operation rate has been found to be higher in OS than HA patients in most earlier studies (Lu-Yao *et al.* 1994).

6.5 Deep infection

Our results showed that deep infection after hip fracture surgery impaired the patients' functional ability in the assessment of short-term outcome and also tended to increase mortality. This is partly in harmony with an earlier case-control study, where deep infection after hip fracture impaired mobility, increased social dependency and prolonged the inpatient period. In that study (Eastwood 1993), however, mortality was much higher (62% at 6 months) than in our study (35 % at one year). This difference might be partly due to the higher mean age of the patients (86 years) in that study than in ours (80 years).

Underlying diseases, especially diabetes, have been shown to be risk factors for deep infection after hip fracture surgery (Enstone & Humphreys 1998). This was also seen in our study, where 41 % of the cases but only 14 % of the controls had diabetes. The most frequent bacterial specimen isolated from the wound area or from blood was *Staphylococcus aureus*, which is in agreement with previous studies (McQueen *et al.* 1990, Aagaard *et al.* 1994). *Staphylococcus aureus* infections also involved higher mortality than other micro-organisms, which can be explained by the generally known severity of *Staphylococcus aureus* infections and especially septicemia (Lowy 1998, Jensen *et al.* 2002). Actually, one fourth of our patients with *Staphylococcus aureus* infection had bacteremia.

6.6 Future

Falling mechanics, low hip bone mineral density (BMD) and impaired mobility have all been identified as independent risk factors for hip fracture (Robinovitch *et al.* 1991, Hayes *et al.* 1993, Greenspan *et al.* 1998). In the future, it would be useful to combine geometric measurements with an analysis of falling mechanics, BMD and mobility.

The effectiveness of bone geometry as measured from plain pelvic x-ray images, BMD, markers of bone metabolism and lifetime factors in the risk of hip fracture and type could be tested in a longitudinal study.

7 Conclusions

1. The radiographical geometry of the upper femur, especially high neck/shaft angle, thin cortices and low femoral shaft diameter and trochanter widht, and the pelvic dimensions associated strongly with the hip fracture risk in postmenopausal women. Greater neck/shaft angle, smaller outer pelvic diameter and acetabular widht, narrower femoral shaft diameter and smaller femoral neck/shaft cortex ratio were associated with femoral neck fractures rather than trochanteric fractures in postmenopausal women.
2. Impaired functional ability, use of loop diuretics, antidiabetic, antidepressant and neuroleptic drugs, some concurrent diseases, such as strokes, diabetes, malignant diseases and cardiovascular diseases, low bone mineral density of the upper femur, low serum calcium, low serum 25-hydroxyvitamin D and high serum calcitonin, seemed to be related to the risk of hip fracture, while low bone mineral density and low serum calcitonin were related to the trochanteric fracture type in postmenopausal women.
3. Short-term functional outcome was better after osteosynthesis with two pins compared to uncemented Austin-Moore hemiarthroplasty with regard to more frequent return to the previous place of residence, better ambulatory capacity, less use of walking aids and less pain. Osteosynthesis with three screws was equally good as Austin Moore hemiarthroplasty with regard to short-term functional outcome. On the other hand, Osteosynthesis was associated with a higher re-operation rate than uncemented Austin-Moore hemiarthroplasty.
4. Deep infection after hip fracture surgery impaired the short-term functional outcome and slightly increased mortality, with an attributable mortality rate of 10 %.

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