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On the diagnosis and treatment of femoral neck fractures

Frede Frihagen

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Thesis

Frede Frihagen

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Contact address

Frede Frihagen, MD
Orthopaedic Centre
Ullevål University Hospital
Kirkeveien 166
0407 Oslo
Norway
e-mail: j.f.frihagen@medisin.uio.no
tel: +47-22118080

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Sofiemyr June 2nd 2008

Frede Frihagen

List of papers with brief summary

Paper 1

Frihagen F, Nordsletten L, Tariq R, Madsen JE. MRI diagnosis of occult hip fractures. Acta Orthop 2005; 76(4): 524-30.

100 patients with a clinical suspicion of a hip fracture and negative or unequivocal radiographs were examined with magnetic resonance imaging (MRI). Almost half had a hip fracture, and a quarter had a fracture in another location, like the pelvis. In nearly all cases a diagnosis was found that explained the patient's problems and directed treatment. An interobserver analysis showed fairly good accordance in the interpretation of the images between three radiologists. We concluded that MRI is a useful tool when there is a clinical suspicion of a hip fracture and a negative or inconclusive plain radiograph.

Paper 2

Frihagen F, Madsen JE, Reinholt FP, Nordsletten L. Screw augmentation in displaced femoral neck fractures. Clinical and histological results using a new composite. Injury 2007; 38(7): 797-805.

21 patients with displaced femoral neck fractures were operated with two parallel Olmed screws augmented with about 2ml of a bis-GMA-based composite injected into the femoral head around the screws. The procedure of augmenting was fast and technically feasible. Half the patients were reoperated due to healing complications within two years. Histological examination of 4 extracted femoral heads showed fragmentation of the composite into small particles with foreign-body response with giant cells and macrophages along with granulation tissue formation and low grade inflammation. The method of augmentation was easy, but the failure rate was high and the fragmentation of the composite with inflammatory response found on histology is noteworthy.

Paper 3

Frihagen F, Madsen JE, Aksnes E, Bakken HN, Maehlum T, Walløe A, Nordsletten L. Comparison of re-operation rates following primary and secondary hemiarthroplasty of the hip. Injury 2007; 38(7): 815-9.

282 hemiarthroplasty procedures for an acute femoral neck fracture and 149 hemiarthroplasty procedures after failed internal fixation with two parallel screws were studied retrospectively. The objective was to examine the rate of reoperations occurring after the hemiarthroplasty surgery. The risk of a reoperation was about twice as high for the patients receiving a secondary hemiarthroplasty. In addition, the risk of a rare but especially poor outcome, an excision arthroplasty, was about ten times higher after a secondary arthroplasty. The higher risk of a reoperation after a salvage hemiarthroplasty favours the use of a hemiarthroplasty as primary procedure after displaced femoral neck fractures.

Paper 4

Frihagen F, Nordsletten L, Madsen JE. Hemiarthroplasty or internal fixation for intracapsular displaced femoral neck fractures: randomised controlled trial. BMJ 2007; 335(7632): 1251-4.

222 patients with displaced femoral neck fractures were randomised to surgical treatment with either internal fixation (two parallel Olmed screws) or a bipolar hemiarthroplasty (Charnley/Hastings). The patients were followed for two years. The functional results measured with Harris hip score, Barthel Index and Eq-5d were better in the hemiarthroplasty group and the complication rate was four times higher in the internal fixation group. The mortality and morbidity were the same in both groups after two years. One third of the patients were dead. A subgroup analysis of the patients

with uncomplicated healing of the fracture in the internal fixations revealed no functional advantage in keeping the native hip joint, as the results in this subgroup also were poorer than in the hemiarthroplasty group. The conclusion from this study was that most patients with femoral neck fractures should be treated with a hemiarthroplasty rather than internal fixation.

Paper 5

Frihagen F, Grotle M, Madsen JE, Wyller TB, Mowinckel P. Nordsletten L. Outcome after femoral neck fractures: A comparison of Harris Hip Score, Eq5d and Barthel Index. Injury 2008; 39(10): 1147-56.

The outcome measures (Harris hip score, Barthel Index and Eq-5d) used for the 222 patients in paper 4 were examined for discriminatory ability, responsiveness, ceiling effect and response rate when comparing a group of patients with an early major complication and a group with no complications. All scales were useful for the purpose, but Harris hip score ranked top on all accounts, and should be included when measuring function after a hip fracture.

Hip fractures – definition, epidemiology and diagnosis

What is a hip fracture?

The bony components of the hip joint are the acetabulum on the proximal side of the joint and the femoral head and femoral neck on the distal side (Figure 1). The term hip fracture has, however, come to mean either a fracture of the femoral neck or a fracture in the trochanteric area of the proximal femur. Often, subtrochanteric fractures are also included in this term.

One could have expected fractures of the acetabulum and the femoral head also to be included in the term hip fracture, but most often they are not. The usefulness of the term hip fracture comes from the many common features in epidemiology, mechanism of injury, clinical presentation, diagnosis, perioperative conditions and rehabilitation of patients with these fractures.

The injury is almost always a low energy one, i.e. a simple fall from standing height (or lower). Impact on the greater trochanter is common, landing on a well padded buttock seems to protect from fracture. Most often the fracture occurs in bone with mineral density below normal, even though in the majority of cases the criteria for the diagnosis osteoporosis are not met.[2] In some cases there is virtually no trauma as in a stress fracture or in a pathological fracture (fracture through bone with pathology other than osteoporosis, such as metastatic malignant disease).[3] Rarely there may be more energy involved and the fracture may thus occur in bone with normal mineral density. The clinical presentation usually consists of pain, inability to bear weight, and shortening and external rotation of the affected extremity according to the degree of displacement (Text box 1).[1]

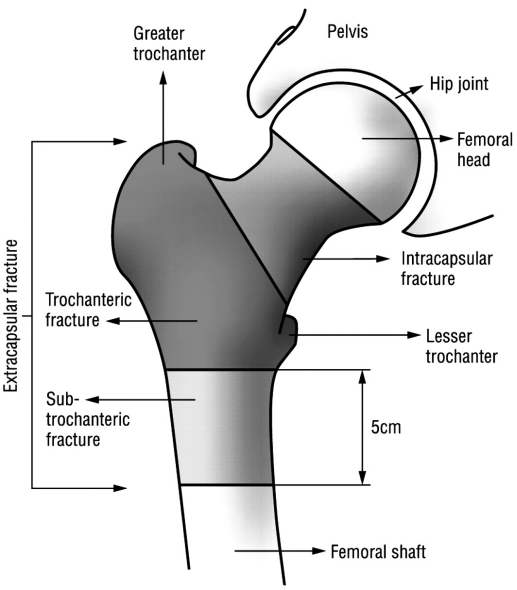

Figure 1. The hip joint and the proximal femur. Reprinted with permission from the BMJ.[1]

Text box 1. Signs and symptoms of a hip fracture

Shortening and external rotation of affected leg
Inability to bear weight on affected leg
Inability to move affected leg
Pain on passive movement
Groin pain
Pain on palpation of trochanter major
Inability to raise leg straight while supine
(sensitive sign in less obvious cases)

What is a trochanteric fracture?

A fracture in the area of the trochanter major and trochanter minor of the proximal femur (Figure 1) is named intertrochanteric, pertrochanteric, or a trochanteric fracture. These fractures should be treated surgically with a sliding screw device or an intramedullary nail. Fractures through the base of the femoral neck (laterally) are sometimes included in the term trochanteric because the treatment, prognosis and the pattern of surgical complications are the same. The prognosis for healing of the fracture is good.[4] A subtrochanteric fracture is sometimes considered together with the trochanteric fractures, but is a rarer type of fracture, and more often occurs as a result of high energy trauma. More bleeding, soft tissue problems and a more extensive fracture pattern may be expected

Text box 2. Different hip fractures and their treatment

Fracture	Recommended treatment	Good alternative (e.g. for some fractures/ some patients)	Probably inferior alternative(s) in most cases
Undisplaced femoral neck fracture[6;7]	Internal fixation with parallel screws	Hemiarthroplasty or total hip arthroplasty	Sliding screw/plate device
Displaced femoral neck fracture[5;8;9]	Hemiarthroplasty	Total hip arthroplasty	Internal fixation
Trochanteric fractures[4;10-12]	Sliding screw/plate device		Intramedullary nail
Subtrochanteric fractures[4]	Intramedullary nail	Sliding screw/plate device	

with subtrochanteric fractures. Isolated fractures of the greater trochanter are usually treated conservatively.

What is a femoral neck fracture?

A fracture through the intraarticular part of the femoral neck is usually referred to by the term femoral neck fracture. Another term is intracapsular proximal femoral fracture. About 80% of these fractures are displaced.[5]

Epidemiology

Geographical variations and variations between different populations in the epidemiology of hip fractures are large. The Scandinavian countries and the United States have the highest incidences, further south and east in Europe the incidences are lower, and the Mediterranean countries, Asia and South America have the lowest incidences. There seems to be a gradient of incidence from north to south, and to some extent from west to east. The variation is 15-fold from Norway with the highest risk to Chile with the lowest.[13-15] The number of fractures in a region will vary substantially with the age distribution because of the exponential rise of incidence with age. All the randomised studies of the treatment of femoral neck fractures have been performed in countries with a high or very high incidence rate. In Norway the age-adjusted fracture rates per 10,000 for the age group above 50 years were 118.0 in women and 44.0 in men in 1996/97.[16] The tendency towards an increase in incidence rate has stopped in several high-incidence countries, including Norway and an increase in femoral neck fractures in those countries now will be due to the fact that the population still is ageing.[17;18] 75% of patients with femoral neck fractures are women, and most are old. The average age in Oslo is 81 years, and 59% of the patients are more than 80 years old. Only 4% are below 60, and many chronologically young patients appear biologically old.[16;19] In reports from other countries similar numbers have been found. There are some variations according to geography and population, and the largest dominance of women and the highest ages are found in high-incidence countries, but similar patterns of age and sex distribution have been found almost everywhere.[20-25] There may be a tendency that the proportion of men and the average age of the patients will increase in the future. The variation in physical and cognitive health is large, ranging from bedridden patients with severe cognitive deficits to healthy and independent patients.[26-29] The percentage reported with cognitive failure varies from 10 to 50%.[5;30-33] The large variation depends somewhat on selection criteria, but also on diagnostic criteria used. In our study we found that 31% had a previously recognised cognitive failure. When tested at 4 months post fracture the proportion with cognitive failure was 50%. In addition, 52% of the patients with displaced femoral neck fractures had a concurrent symptomatic medical disease.[5]

Diagnosis

The diagnosis of a hip fracture is usually straightforward. A strong clinical suspicion is often recognized by the patient herself. The classical signs and symptoms of a hip fracture are given in Text box 1. This suspicion is usually easily confirmed by a standard radiograph in two planes. Several other

Text box 3. Choices of internal fixation or arthroplasty[9]

Method	Potential problem/advantage
Arthroplasty[41]	
Hemiarthroplasty or total hip arthroplasty	Higher dislocation rates in total hip arthroplasty. Total hip arthroplasty may give better function in the healthiest patients.[9;42,43] Total hip arthroplasty is more extensive surgery.
Cemented or uncemented arthroplasty[44]	Cemented arthroplasty may give faster rehabilitation, especially when compared to non-anatomical uncemented arthroplasties.[41] Acute cement toxicity may be fatal.[45] Cemented arthroplasty may be more difficult to remove if needed.
Bipolar or unipolar hemiarthroplasty	Bipolar may give better range of motion, and less acetabular wear, but more potential for dislocations as the device is more complicated.[46]
Internal fixation[47]	
Sliding screw with plate, or screws or nails	Sliding screw with plate gives more wound problems, but may be more stable.[48;49] Screws may be more stable than nails.[50]
Two or more screws or nails	More than two screws may increase stability, but take longer to insert and may invite complications.[47;51]

methods for imaging may be used if there still is doubt after a conventional radiograph, such as scintigraphy, CT-scan, magnetic resonance imaging (MRI), conventional planigraphy and various clinical procedures.[34-40] It is furthermore important to clarify whether the patient broke her hip and fell or fell and broke her hip. The latter is the normally occurring sequence, but if the former is the case one must suspect a pathological fracture, such as a fracture through a metastasis of malignant disease.[3] Furthermore, it may be of value to map the reasons for the patient's falling. If she fainted and fell instead of stumbled and fell, one should look closely for medical comorbidities such as cardiac disease, an infection (most often a respiratory or urinary tract infection), a cerebrovascular event, or poorly regulated diabetes mellitus.

The treatment of femoral neck fractures

In femoral neck fractures with no displacement, internal fixation with parallel screws or nails is the treatment of choice for most surgeons, gaining a success rate of 85-95% [1;6;7] In displaced femoral neck fractures, however, the choice between arthroplasty and internal fixation has been the topic of a long-standing debate in orthopaedic surgery. Internal fixation was historically the mainstay of treatment, but arthroplasty has been gaining territory the past years.[52;53] Despite more than 100 publications comparing treatment with internal fixation and arthroplasty, including several randomised controlled trials (RCTs), no clear consensus on which treatment produces the best functional results has been reached.[5;8;9;42;43;54-70] Accordingly, there is no consensus on how to treat specific subgroups of patients, with a few exceptions such as the treatment of pathological fractures with arthroplasty, and young and healthy patients with internal fixation.[1;71] In addition, not enough is known on what kind of internal fixation to use when internal fixation is chosen, and there is not enough evidence as to what kind of arthroplasty to use when arthroplasty is preferred.[9;47;50] The available meta-analyses have concluded that the reoperation rate is higher after internal fixation, but no difference in post-operative pain, hip function or quality of life has been found.[8;9;54;70] The choice between internal fixation and arthroplasty as the treatment for displaced femoral neck fractures has thus been based on criteria other than knowledge on what treatment gives the best functional results. An argument in favour of arthroplasty has been lower reoperation and complication rates. Arguments in favour of internal fixation have been that it is a shorter operation and a smaller surgical trauma with less blood loss. It has further been maintained that it is an advantage to preserve the native hip joint and it has been claimed that the complications after internal fixation have been less serious than after arthroplasty. Also, it has been claimed that a reoperation to arthroplasty after failed internal fixation is not a major complicating event for these patients. These latter beliefs have had no scientific foundation. Local medical culture and tradition probably have played a large role in the decisions. The reoperation rate after internal fixation seems to have increased during the past years.[9] This may be due to better follow-up, so that more patients who need a reoperation actually get one. It may also be due to improvements in peri- and postoperative care so that it is conceived as safe to offer more patients a reoperation with arthroplasty after failed internal fixation.

History

The first historically documented person who died of the consequences of a fracture of the femoral neck was Charles IV, German king and Holy Roman Emperor. He suffered a femoral neck fracture, and – as has been the case with countless patients with a femoral neck fracture after him – subsequently fell ill with a pneumonia leading to his death in 1378.[72] In 1935 Speed called the femoral neck fracture "the unsolved fracture" due to the high failure rate and he complained about the lack of progress in the treatment of femoral neck fractures which in his mind lagged behind the general progress of fracture treatment of the first decades of the 20th century.[73] The treatment before the surgical era consisted of traction, plaster, or simply some kind of bed rest, sometimes with a closed manipulation of the fracture to achieve reduction.[74] Bernhard R. K. von Langenbeck (1810-1887) was the first to propose operative treatment of a fracture of the femoral neck and he actually did one operation, but the patient died. The first successful internal fixation of a proximal femoral fracture was done in 1875 by Franz König.[75] In 1897 and 1899, Professor Nicolaysen at the National Hospital in Oslo published his technique, and the results of closed nailing of fractures of the femoral neck in 21 patients. He performed his first operation in July 1894.[76] Both from Finland and Sweden early reports on the treatment of hip fractures were published,[77;78] but most fractures were still

treated conservatively. Technological and medical advances such as asepsis, stainless steel implants, radiology, and reduction techniques led the Norwegian born Marius Nygaard Smith-Petersen and colleagues to develop a flanged nail in 1921. Their method became widely used and was the start of the true surgical era in the treatment of femoral neck fractures.[75] The advent of intraoperative fluoroscopy was another important improvement of the method of internal fixation. Even though failure rates remained high, internal fixation remained the most common treatment for decades. Moore and Bohlman reported the use of a hemiarthroplasty in 1943.[79] And Garden noted in 1961 that "some – in despair – have resorted to removal of the head and replacement with a prosthesis".[80] Despite Garden's dislike of the practice, arthroplasty kept gaining territory. The "unsolved fracture" is now being solved, but not by improving union rates as Speed foresaw, but rather by changing the focus from fixing these fractures to replacing them.

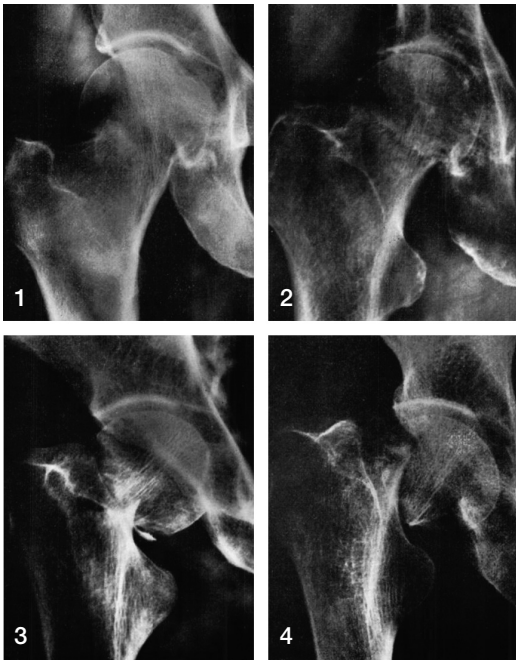

Figure 2. Garden's classification. Garden stages 1–4. Reproduced with permission and copyright © of the British Editorial Society of Bone and Joint Surgery [80;85]

Classification

The most widely referred classification systems of femoral neck fractures are Garden's, [80] AO [81;82] and Pauwell's.[83;84] The function of a classification system is to provide a basis for clinical decision making and prognosis, and facilitate research and comparison of treatment results. In femoral neck fractures a classification system that could give a prognosis on healing with internal fixation would be of particular value, but the most widely used classification systems can not do this, and other attempts of defining radiological prognostic signs of healing have not been successful.[82;86-89] The division in displaced and non-displaced fractures has been the only one that is both reproducible and related to prognosis of healing complications in internal fixation. Currently this dichotomy is the one used in most studies and clinically by many orthopaedic surgeons.[8;9;58;90] A clear definition of a displaced fracture is, however, missing. Several studies do not define what is meant by a displaced fracture. Some studies use the Garden stage III and IV as definition of a displaced fracture.[9] One study stated that the fracture had to be clearly displaced on both the anteroposterior and lateral radiographs in order to be defined as displaced.[58] In this thesis a fracture with an angular displacement in either radiographic plane qualifies as a displaced fracture.[5] The lateral radiograph is not described as a part of Garden's classification system. This may be because it often is of poor quality, and may be even more difficult to interpret than the anterioposterior radiograph. Another potential problem are the recently introduced terms "slightly" or "minimally" displaced, as they are poorly defined and not validated.[58;84;89]

Surgical treatment

Almost all femoral neck fractures are treated surgically. Conservative treatment may be used in exceptional cases only. The prolonged bed rest of conservative treatment has so many dangers (e.g. medical complications such as pneumonia, urinary tract infection, pressure sores, thromboembolic disease) that it should be avoided. The risk of a secondary displacement in undisplaced fractures is high (20 to 60%) when conservative treatment

is attempted.[7;91-94] A displaced fracture left without surgery will – in the event of patient survival – with high probability lead to a painful and useless limb.[1,95]

Internal fixation

The surgical results after internal fixation of undisplaced fractures are good with high union rates (95%) and surgical complication rates of 10-15%, and this treatment is recommended by most surgeons.[6;7;93-96] Fractures in young and healthy patients are equally treated with internal fixation.[7;71;97;98] Young in this context is probably below 60–70 years. Many of the young patients will, however, be biologically old, i.e. have significant comorbidities and/or drug abuse and often short life expectancy, and be most suited for a hemiarthroplasty.[19] In the presence of symptomatic arthritis or other diseases affecting the hip joint an arthroplasty would be preferred treatment, even in young patients or patients with undisplaced fractures, as the prognosis for healing is poorer and a painful hip with reduced function is a likely result even with a healed fracture. Some recommend internal fixation for the very frail elderly due to fear of a higher mortality in this group,[58] but there is limited evidence to support this view, and no evidence that the results with internal fixation are better in the very old. More than 100 different types of internal fixations have been identified. In theory, a sliding screw/plate device may be more stable mechanically compared with screws, but it also requires more extensive surgery with a higher risk of infection and higher blood loss. Whether a screw/plate-device, or two or three or even four screws or nails is better, remains uncertain. [1;9;47;50;99;100]

Arthroplasty

This thesis and most of the recent publications conclude that most patients with displaced femoral neck fractures should be treated with a hip replacement.[5;8;9;42;43;54;101] There are several alternatives for arthroplasty: The most important choice is between a hemiarthroplasty and a total hip arthroplasty. In a hemiarthroplasty the acetabulum is left untouched, whereas in a total hip arthroplasty the acetabulum is replaced by a prosthetic cup. There is some evidence that the relatively younger and fitter benefit from a total hip arthroplasty. This is more extensive surgery, however, and more prone to complications, and in some studies the risk of a prosthetic dislocation is as high as around 20%.[59] In some studies, however, the rate of complications is acceptably low, especially when selecting the relatively healthiest patients, with dislocation rates of 2–4%.[8;9;42;43;101;102] Another important choice in arthroplasty is between components that are cemented in place or components that require bony ingrowth. Existing evidence suggest that cemented prostheses perform better, but there are few studies where modern cementless implants that do well in osteoarthritis have been used for femoral neck fractures.[9;41;44;103;104] The last major division in arthroplasty is between a bipolar hemiarthroplasty and a unipolar hemiarthroplasty. In this thesis a bipolar hemiarthroplasty has been used. The theory is that the range of motion will improve and especially that the wear of the acetabulum will be reduced. There is, however, little evidence that there is any advantage with a bipolar solution over a simpler unipolar hemiarthroplasty, and indeed the bipolar mechanism carries a risk of complications as the prosthesis may dislocate internally.[46;105-107]

Cost

The studies comparing cost vary somewhat in terms of the factors included. The cost of surgery, all hospital costs, other health care system costs and costs for the community are included to a varying degree. Regarding the cost of the implant itself, any internal fixation device is cheaper than any arthroplasty. Hemiarthroplasty is less expensive than a total arthroplasty. This is also true for the primary operation, as the duration of surgery is shorter for internal fixation and the longest for total hip arthroplasty. However, when the costs of readmissions and reoperations are included, the differences in cost are at least levelled.[31;42;108-110]

Consequences of a hip fracture

The most immediate and obvious consequence of a hip fracture is hospitalisation of the patient and a subsequent operation. This has an impact on both the individual with the fracture and on the society in which she lives. This is also the case for the time period after the surgery. The need for an acute

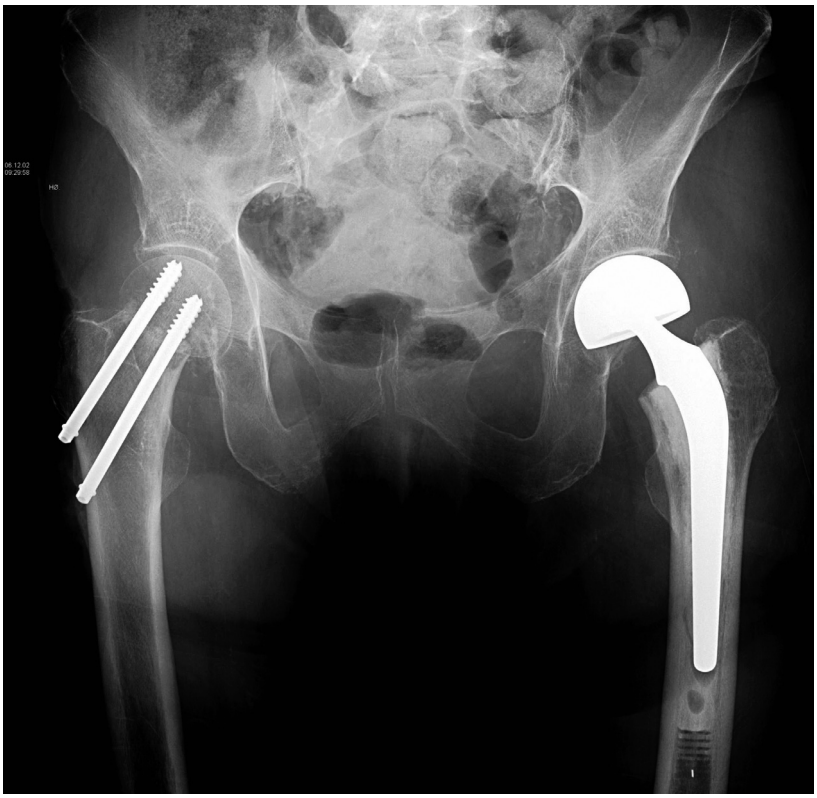

Figure 3. Anterioposterior pelvic radiograph of a patient who has suffered femoral neck fractures on both sides, only a few weeks apart. On the right side she was operated with two parallel screws and on the left side with a hemiarthroplasty.

hospital admission and surgery is a major event in anybody's life; A hip fracture implies a 1 year mortality of about 25% and a substantial risk of becoming more dependent in everyday tasks, and for some patients it means that they no longer can live independently.[1;5;31;111-113]

The injury is usually sustained in an everyday situation, perceived to be low-risk, and the psychological effect of this sudden reminder of one's fragility leads to a fear of a new fall, and may lead to anxiety and depression following a hip fracture.[114;115] A proximal femoral or hip fracture is the most common reason for admission to an acute orthopaedic ward, and among the most common reasons for admission in a nursing home. The cost of the surgical treatment and the hospital stay is high, and added to that comes the cost of rehabilitation, nursing home and increased use of home-based services.[116-118] Potential savings are large, both in individual suffering and economic cost for society, by avoiding a hip fracture and by providing the best possible surgical treatment when a fracture occurs.

Aim of the studies

The aim of the present studies has been to elucidate some aspects of the diagnosis and treatment of femoral neck fracures by:

1) evaluating the use of magnetic resonance imaging in occult hip fractures;
2) examining a new technique of delivering a composite intended for screw augmentation in the internal fixation of femoral neck fractures;
3) comparing the role of internal fixation and hemiarthroplasty in the treatment of displaced femoral neck fractures;
4) evaluating the use of three assessment scales in elderly patients after femoral neck fractures.

Patients and methods

Patients

The patients in all the papers were recruited from the Orthopaedic Centre at Ullevål University Hospital. In **paper 1,** 100 consecutive patients who were examined with magnetic resonance imaging (MRI) on suspicion of a hip fracture were registered prospectively from November 1998 to December 2001. The charts were examined retrospectively at least one year after the initial radiographic examination. The interobserver analysis was performed on a random selection of 23 MRI series. **Paper 2** describes 21 consecutive patients with displaced femoral neck fractures recruited during October and November 2001 and followed prospectively at 1, 3, 6 and 12 months, and with a telephone consultation after 24 months. In **paper 3,** a prospective registration of all hemiarthroplasties performed between January 1998 and March 2002 in our department was performed. 480 hemiarthroplasties were registered in all but for 12 patients the charts could not be obtained. A further 5 were excluded because they were living outside the hospital's area, 24 because they had a fracture due to cancer metastases and 8 because they had symptomatic osteoarthritis. 431 hemiarthroplasties after femoral neck fractures could thus be studied. The follow-up data were extracted retrospectively from the medical records between June 2003 and June 2004. In **papers 4 and 5,** 222 patients with a displaced femoral neck fracture were recruited consecutively from September 2002 to March 2004 and randomised either to treatment with two parallel screws or hemiarthroplasty. The inclusion criteria included age above 60 years, prefracture ability to walk, no previous serious hip pathology, judged by anaesthesiologist to be fit enough for arthroplasty surgery. The patients were excluded if they lived outside the hospital's area, had a pathological fracture and a delay of > 96 hours from fracture to operation. The patients were followed at 4, 12 and 24 months postoperatively.

Methods

Treatment

The patients in **papers 2 to 5** were either operated with a Charnley-Hastings bipolar cemented hemiarthroplasty (DePuy/Johnson and Johnson, United Kingdom) or closed reduction and internal fixation with two parallel cannulated screws (Olmed, DePuy/Johnson and Johnson, Sweden). Arthroplasty was performed through a direct lateral approach with the patient in a lateral decubitus position with a third-generation cementing technique.[119;120] The treatment is described in detail in **paper 4.** The patients in **paper 1** were treated operatively or non-operatively according to their findings on MRI, usually with two parallel cannulated screws when a femoral neck fracture was found and a sliding screw/plate device in the trochanteric fractures. Early mobilisation with full weight bearing/weight bearing as tolerated was department routine and practiced for all patients in **papers 2, 4 and 5.** Occasionally, the surgeon would order partial weight bearing in cases with young patients or other special circumstances in **papers 1 and 3.**

Objectives and outcomes

In **paper 1** the objective was to evaluate the use of MRI in the diagnosis of suspected hip fractures. In **papers 2 to 5** the main objective was to compare and describe different surgical treatments for femoral neck fractures, albeit **paper 2** was mainly a feasibility study testing the screw augmentation method, and **paper 5** was evaluating the assessment scales used in **paper 4**. **Paper 4** was a randomised controlled trial (RCT) with 222 patients and **paper 5** analysed the same patients. **Paper 2** was a prospective series of 21 patients. **Papers 1 and 3** were retrospective studies based on chart data, but the registration of patients was prospective.

In **paper 1** the primary outcome was the findings of the MRI examinations. Secondary outcomes were the diagnoses' implications for treatment and the analysis of interobserver agreement. **Paper 2**

was primarily a feasibility study with perioperative results as the most important outcomes. Further outcomes were Harris hip score,[121] surgical failures and histological results. In **paper 3** the main outcome was the number of reoperations and the secondary outcomes were the reason for a reoperation and the final surgical result in the two groups treated either with primary or secondary hemiarthroplasty. In **paper 4** the main outcome measure was Harris hip score.[121] Secondary outcomes were Eq-5d,[122] Barthel Index,[123] surgical complications and reoperations. In **paper 5** we evaluated the measurement scales from **paper 4**.

Statistical methods

We used Pearson's chi square for dichotomous or dichotomised variables and t-tests for Harris hip score, Eq-5d index score, and analyses of continuous variables. Dependent samples t-test was used when appropriate (**paper 5**). Kappa values were calculated for interobserver agreement (**paper 1**). Logistic regression, standardised response mean (SRM) and receiver operator characteristics (ROC) curves was used to evaluate the assessment scales (**paper 5**). For all papers various versions of SPSS (SPSS Inc, Chicago, IL; http://www.spss.com/) were used for all calculations, except for kappa statistics in **paper 1** and SRM statistics in **paper 5**.

Ethical considerations

Paper 1 was not an ethical challenge as no study-related intervention was performed. The same is true for **paper 3**. For the procedure in **paper 2** we had animal data and some human clinical data that implied that the substance used to augment the screws would do no harm, and potentially make a more stable implant construct. We considered the worst case scenario to be that the substance did nothing at all, neither harm nor benefit the patients. The strong inflammatory response seen in some of the histological samples may have proven us wrong, but the lack of a control group renders the matter unresolved. With further use of this substance, or any new substance, we will certainly be aware of the possibility of doing harm, even if it seems unlikely. **Paper 4** was ethically a limited challenge because we aimed to compare two at the time well established and widely accepted surgical methods, and our main aims were to make a methodologically sound study as close as possible to the daily clinical life of the department. At the time of study planning and study start for **papers 2 and 4** both internal fixation and hemiarthroplasty were routine treatments of displaced femoral neck fractures in the department.

Main results

Paper 1 supports the use of MRI when there is a continued suspicion of proximal femoral fracture after negative or equivocal plain radiograph. We also demonstrated that in the absence of a fracture of the proximal femur, another explanation for the symptoms will often be found, directing further patient treatment. In **paper 2** we found that the technique developed for augmenting the screw purchase in the femoral head was easy and safe to perform. A high reoperation rate, fragmentation of the composite and the inflammatory response on the histological examinations of the retrieved femoral heads gave, however, reasons for concern. In **paper 3** the reoperation rate was higher in the secondary hemiarthroplasty group than in the group who were operated with a hemiarthroplasty as a primary treatment; the risk of a reoperation was about twice as high for the patients receiving a secondary hemiarthroplasty (11% vs. 5%); p=0.04). In addition, the risk of an excision arthroplasty as final result was about ten times higher after a secondary arthroplasty (4% vs. 0.4%; p=0.004). In **paper 4** there was a tendency towards the same results and the patients in the internal fixation group more often needed several reoperations.

The most important finding in this thesis, however, was that the functional results were better after hemiarthroplasty than after internal fixation in **paper 4**. Harris hip score, Eq-5d and Barthel Index all showed better results in the hemiarthroplasty groups at one or more of the scheduled follow-up points at 4, 12 and 24 months (Table 3 in **paper 4**). As expected, the reoperation rate and complication rate were much higher in the internal fixation group (Table 6 and 7 in **paper 4**). A subgroup analysis indicated also that the results in patients with internal fixation that healed uneventfully were poorer than the hemiarthroplasty group (Table 4 in **paper 4**). The findings in **paper 5** support the use of the assessment scales in **paper 4**, and found an advantage of Harris hip score over Eq-5d and Barthel Index.

Discussion

Methods

The methodology of the papers varies from prospective registrations with retrospective chart evaluations in **papers 1 and 3,** via a small prospective patients series in **paper 2**, to a randomised controlled trial (RCT) with power analysis, pre-defined primary outcome, high follow-up and intention to treat analysis in **papers 4 and 5**. Hence the level of evidence (http://www.cebm.net/) produced by the papers varies, too. The evidence in **papers 1 and 2** would be of ***level 4,*** as they report patient series with no comparison possible. The evidence of the findings of **paper 3** is probably of ***level 3***, as it is a comparative study, albeit retrospective. The evidence produced by the findings in **paper 4** would be ***level 1***, as it is an RCT with a low risk of bias. The nature of the question asked, however, may limit the use of methodology leading to higher levels of evidence. In **paper 3**, the large number of secondary hemiarthroplasties is a great strength and it would require a large RCT to gather such a high number of failures, and still an analysis of secondary complications would not be straightforward within the framework of an RCT. The same may be said about **paper 1.** A randomisation between patients who were to be observed without magnetic resonance imaging (MRI) and patients to be examined with MRI would be ethically challenging, and at least difficult to recruit patients for. The strength of the conclusions from **paper 1** is, however, weaker than if a randomisation could have been performed. The quality of the methodology of both **papers 1 and 3** would nevertheless have been better if a structured prospective registration of data had taken place, instead of a retrospective chart-based data registration. For **paper 3** this would have lifted the evidence-level from ***3*** to ***2***. **Paper 2** is a case series mainly testing the feasibility of a new method, and any clinical question raised should subsequently be tested in a randomised trial.

General discussion

In **Paper 1** it seemed that magnetic resonance imaging (MRI) is a useful tool, and the results of the interobserver analysis also implied that it is reliable. There is, however, a lack of comparison with other diagnostic modalities and methods. Computed tomography and repeated conventional radiographs are among the image modalities that may be compared with MRI.[36-39] Comparison with better defined clinical management routines and/or a better description of management of these patients without the use of MRI are also lacking. In our department however, no further studies are planned on this topic; we will continue the current routine use of MRI in cases with a suspected occult hip fracture.

Paper 2 should be followed by an RCT comparing the new method of screw augmentation with the standard of care, i.e. hemiarthroplasty. If looked upon as a pilot study for an upcoming RCT it was a success because the new technique of augmenting the screws was found easy to perform. We have

Figure 4. Example of screw voids in the femoral head after reversing the screws. The whiter appearance of the bone on the right hand side of the femoral head indicates that the bone density is higher in the femoral head near the joint space than it is towards the femoral neck. The better screw purchase provided by this bone is one of the reasons that the recommended screw placement is as near to the joint line as possible. The screws are only partially threaded to allow for compression over the fracture.

not proceeded with a larger RCT, in part because the histological findings were worrying, and in part because the – perhaps unscientific – impression was that the method didn't offer a substantial improvement. Maybe a return to square one with biomechanical testing and laboratory work followed by clinical studies on other patient groups is a better path to follow studying augmentation of internal fixation. Eligible patients could be patients with non-displaced femoral neck fractures, or trochanteric fractures. Compelling new arguments in favour of augmented screws must be found before patients with displaced femoral neck fractures should be included. Other substances and composites intended for screw augmentation in low quality bone exist. The calcium phosphate cements are best studied, even in a number of randomised trials, and have shown good results in reducing pain and helping to maintain fracture reduction.[124-128] Their role in femoral neck fractures, however, remains unclear.[125;127-132]

In **paper 3** we found that a hemiarthroplasty operated after a failure of internal fixation has twice the risk of a further reoperation compared to a primary hemiarthroplasty. This refutes the old claim that a reoperation with arthroplasty after internal fixation is low-risk surgery, and also the claim that a reoperation even may be an advantage because it can be done as elective or semi-elective surgery with the patient in better shape than in the acute setting with a fracture. The limited existing data on the topic support the findings of **paper 3**.[133-135] **Paper 3** indirectly supports the conclusion that hemiarthroplasty is a better treatment than internal fixation.

Paper 4 may be perceived as just another in a series of randomised controlled trials (RCT) comparing internal fixation and arthroplasty in patients with displaced femoral neck fractures. Due to the recruitment of all patients with displaced femoral neck fractures above 60 years of age irrespective of comorbidities, cognitive function and high age, **paper 4** has a high level of generalisability of the results. Due to the high methodological quality, the results are trustworthy. The use of modern and well defined implants and surgical methods makes the study relevant to orthopaedic surgeons. The study produced statistically significant and, more importantly, clinically relevant results. In some countries, the potential for clinical change, and thus the paper's ability to influence clinical practice was limited, because hemiarthroplasty already was the primary choice in the treatment of displaced femoral neck fractures. In other countries (e.g. Norway) the shift to arthroplasty as primary treatment will be – and already has been – influenced by our findings. An added bonus is that the sub group analysis weakens the unsubstantiated belief that there is an advantage for the patient to keep the native hip joint. **Paper 4** could also influence the choice of hemiarthroplasty as it provides indirect evidence that the bipolar Charnley/Hastings performs better than some other hemiarthroplasties, most notably the Austin Moore hemiarthroplasty, that have failed to show better functional results than internal fixation in previous studies.[9;55;58;101]

Some of the previous studies were of poor quality and some included only subgroups of patients, and up to now it has been difficult to draw clear evidence-based conclusions. Few studies, however, have shown any advantage for internal fixation, and the much larger complications and reoperation rates for internal fixation have been consistent through all studies, including non-randomised trials.[8;9;70;101] Several recent studies have shown a functional benefit of arthroplasty, but these studies have mainly compared internal fixation with total hip arthroplasty in the relatively healthiest patients.[42;43;54] The finding that this patient group benefits from a (total hip) arthroplasty is interesting. Hemiarthroplasty is, however, still a better documented and a more common treatment for the majority of patients with femoral neck fractures.[52;53]

Paper 5 demonstrated that the use of the assessment scales from **paper 4** was prudent and the selection of Harris hip score as primary outcome measure was justified. All scales were found to be useful, but Harris hip score performed better than the other assessment scales. Functional outcomes are of utmost importance when studying the treatment of hip fractures. No consensus exists, however, as to which functional outcome(s) should be used in clinical trials. There is a need for further validation research. Emphasis should also be placed on ease of administration, response rate and the wide variety of functional levels that these patients represent. The scoring of health-related

quality of life (e.g. Eq-5d) has become important in clinical studies partly because of its ability to fit in with analyses of health economics and the possibility to make comparisons between different studies and even different diagnoses. The main weakness we found with the Eq-5d was the low response rate. In a relatively fitter subgroup of patients with femoral neck fractures studied by Jan Tidermark and his group in Stockholm this has not been a problem.[43;102;136;137] The main problem with the Barthel Index was its ceiling effect, with more than half the patients scoring either 19 or 20 points of 20 possible. On a more theoretical level both scales measuring health-related quality of life and activities of daily life are vulnerable to "noise" from other causes of reduced function in these elderly and often multimorbid patients. Both types of scales must contain items that are not relevant to a hip fracture, or at least be more influenced by other physical or cognitive problems that the patients might have.

Conclusions

1. Hemiarthroplasty is a better treatment than internal fixation with two parallel screws for displaced femoral neck fractures in patients above 60 years of age.
   a. Functional results are better with hemiarthroplasty
   b. Reoperation and complication rates are lower with hemiarthroplasty. Secondary hemiarthroplasties have a higher risk of a further reoperation.
   c. There is no difference in mortality and morbidity
2. The role of the new composites intended for augmenting screw purchase in poor bone in the treatment of femoral neck fractures remains unclear. Attention must be paid to the risk of eliciting an inflammatory response.
3. Harris hip score, Barthel Index and Eq-5d may all be used for the evaluation of the surgical result in patients with displaced femoral neck fractures. Harris hip score has some advantages over the other scales.
4. Magnetic resonance imaging is a useful and reliable tool for discovering occult hip fractures, and in the absence of a hip fracture other explanations for the patient's pain and reduced function will most often direct further treatment.

Suggestions for further research

There are several potential ways to improve the surgical treatment of displaced femoral neck fractures:

1) Trials comparing different kinds of arthroplasties, most importantly hemiarthroplasty and total hip arthroplasty. Other factors of interest are cemented versus un-cemented prostheses, and unipolar hemiarthroplasty vs. bipolar hemiarthroplasty.
   – Subgroups of patients who may benefit from a specific kind of arthroplasty should be sought.
2) To identify subgroups of patients with displaced femoral neck fractures who may do well with internal fixation. It is important to stress that outcome measures for this research would have to include not only rates of surgical complications and reoperations, but also – and more importantly – functional endpoints.
3) Several previous studies have failed to demonstrate differences between different implants for internal fixation of femoral neck fractures. Subgroups of patients may benefit from internal fixation, e.g. patients with undisplaced fractures or the youngest and fittest. A trial designed to show an advantage of one implant for internal fixation over another in these subgroups would have to be well planned and conducted, and probably very large. Still it would carry a substantial risk of not being conclusive. If such an endeavour were to be undertaken, two designs that may have a reasonable chance of leading to a useful result would be:
   – a comparison of a screw/plate-device and two or three parallel screws;
   – internal fixation with or without augmentation.
4) Trials comparing computed tomography and magnetic resonance imaging (MRI) in diagnosing occult hip fractures and trials with well defined routines for the clinical management of patients with suspected occult hip fractures may improve a rational use of diagnostic resources and increase the diagnostic accuracy of these injuries.

Plain language summary

This thesis deals mainly with the diagnosis and treatment of femoral neck fractures (See Figure 1, page 5). A fracture of the femoral neck usually occurs in elderly patients, the average age is around 80 years. The majority of the patients (75–80%) are women. **Papers 2 to 5** deal with the treatment of patients with displaced femoral neck fractures. The main treatment alternatives are either to preserve the femoral head by realigning the fracture fragments and fixing the fracture with screws (internal fixation), or replacing the fracture with an artificial hip joint. In this thesis the type of artificial hip joint used is a hemiarthroplasty which is a replacement of the upper part of the thigh bone, i.e. the head and neck of the femur, with no surgery done on the acetabulum (Figure 1, page 5).

Paper 1 showed that the use of MRI is useful to diagnose hip fractures when the patients have signs and symptoms of a hip fracture, but standard radiographs are normal or difficult to interpret. The paper also showed that if a hip fracture is not found on MRI, another explanation for the patient's problems is usually found.

In **paper 2** we operated 21 patients with displaced femoral neck fractures with internal fixation and added a new composite "synthetic bone" to augment the screw purchase in the head of the thigh bone. We demonstrated that the technique of delivering the "synthetic bone" was fast and easy to perform. 11 patients had to be reoperated because of later healing complications, and although this seems a lot, it is not more than expected after traditional internal fixation. In bone samples examined by microscope we found signs of the composite breaking up in very small particles and causing inflammation in the bone.

In **paper 3** we compared patients operated acutely with hemiarthroplasty because of a femoral neck fracture with patients operated with hemiarthroplasty as a subsequent surgery due to failure of internal fixation. About twice as many patients operated with hemiarthroplasty as a secondary procedure needed at least one further reoperation. We also found that the number of patients who in the end had their prosthesis removed without any replacement, which usually means a poor functional result, was higher in the group receiving their hemiarthroplasty as a secondary operation.

Paper 4 is the paper of the highest scientific quality. It demonstrated that among 222 patients with displaced femoral neck fractures, there were much fewer reoperations and complications in the group operated with a hemiarthroplasty compared to the group operated with internal fixation. More importantly, the patients operated with hemiarthroplasty had better hip function, better ability to perform everyday tasks, and better health-related quality of life, even when compared to the subgroup of patients with internal fixation who had no complications. There was no difference in mortality between the groups.

The last paper (**5**) describes the different assessment scales that were used in paper 4 to describe hip function (Harris hip score), the ability to perform everyday tasks (Barthel Index) and health-related quality of life (Eq-5d). We found that all three scales were useful, but that Harris hip score had some advantages over the other scales.

The main conclusions of the thesis are:

- Most patients with displaced femoral neck fractures should be treated with a hemiarthroplasty.
- More research is needed about the new substances intended to reinforce screw hold in bone, and special attention should be given to inflammation of the bone.
- Harris hip score, Barthel Index and Eq-5d may all be used to evaluate patients with femoral neck fractures, but Harris hip score has some advantages over the others.
- Magnetic resonance imaging (MRI) is a useful tool for diagnosing a hip fracture when ordinary x-rays are inconclusive.

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