The bridging nail in periprosthetic fractures of the hip. Incidence, biomechanics, histology and clinical outcomes
Zuurmond, Rutger Gerard

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CHAPTER 7

Retrograde Bridging nailing of periprosthetic femoral fractures.

Zuurmond RG, Pilot P, Verburg AD

Injury 2007;38:958-64
Abstract

A retrograde femoral nail was designed to slide over the tip of the femoral stem. Eighteen patients (4♂, 14♀) were treated with this retrograde nail between 1995 and 2003. The mean age was 81.4 years (range 61-96) with a mean follow-up of 21 months (range 4-61 months). Eight patients suffered from severe comorbidity. Mean surgical time was 91 min. Fourteen patients regained their preoperative functional level. Six patients died within the first post-operative year of natural causes. Their knee- and hip-function were reasonable considering the age group and co-morbidity. One revision was required and one patient had a protruding nail. In all patients radiological union of the fracture was seen between 4 and 12 months after surgery. Retrograde bridging nailing of the periprosthetic fractured femur is a therapeutic option in geriatric or impaired patients and can serve as a definitive implant.
Introduction

Periprosthetic fractures (PPF) of the hip are a complex problem for patient and surgeon. The general condition of geriatric patients often prohibits extensive surgery. High morbidity and mortality up to 20% is seen in this population.\textsuperscript{12} The incidence of PPF is rising due to aging of the population and an increasing incidence of total hip arthroplasty (THA). Important risk factors for developing PPF include osteoporosis, osteopenia, neuromuscular disorders, previous hip surgery, revision arthroplasty and loosening of the stem.\textsuperscript{5} In addition, young age at time of hip fracture surgery and design of the stem have recently been identified as risk factors by a Finnish study group.\textsuperscript{21}

The active patient with displaced PPF is best served by revision arthroplasty. Besides revision arthroplasty, several methods of internal fixation have been described for the treatment of well fixed implants. Classic AO plates, LISS plates, cerclages (e.g. Partridge) with or without cortical allograft struts and various systems of cable-plate fixation.\textsuperscript{4,20,22} Late problems associated with internal fixation techniques are stress concentration and the forthcoming possibility of refracture. However to achieve a stable fixation can be technically demanding.

A practical well-known classification of PPF is the Vancouver classification. (Fig. 1) Recently, several treatment strategies based on the Vancouver classification have been proposed.\textsuperscript{3,9,11,17} In type B3 fractures with poor bone stock proximal femoral replacement is suggested. However, patients with B3 type fractures are often compromised, suffering from severe co-morbidity. Surgery with extensive dissection is a high risk procedure in these patients making less invasive surgery preferable. Besides high mortality,\textsuperscript{12} the treatment is associated with high failure rates. A Swedish study showed a failure rate of 23\% after fracture treatment.\textsuperscript{10} Factors that significantly contributed failure were type B1 fractures, other treatment than long stem revision and initial treatment consisting of plate-osteosynthesis and cerclages.\textsuperscript{10}

Closed retrograde nailing is a common solution for femoral fractures in poly-trauma patients for its minimal invasive aspects. The retrograde intramedullary approach of PPF has a long history. The first reported retrograde intramedullary implants for the treatment of PPF were Endernails.\textsuperscript{16} In 1996 an Austrian study group reported a retrograde nail for the treatment of a periprosthetic fracture\textsuperscript{13} and Ponzer et al. reported a series of patients treated with retrograde nailing below a Moore prosthesis.\textsuperscript{18} However, retrograde nailing below a hip stem leaves a possible stress-rising zone between the ends of the implants. Creating a rigid fixation between the intramedullary implant and the stem would solve this problem. The use of custom made lengthened implants has previously been reported\textsuperscript{27,28} although these are antegrade solutions.

These reports and results\textsuperscript{14,18,27,28} initiated retrograde Bridging nailing in periprosthetic fractures of the femur.\textsuperscript{25} The first patients were treated with an adapted intramedullary femoral nail that was driven over the tip of the prosthesis and thus providing stable fixation. This evolved to a new fabricated device, the Bridging nail.
Materials & Methods

An adapted retrograde femoral nail is used to perform the osteosynthesis. The length and diameter are estimated using an image intensifier and a sterile measuring staff during operation. The patient is positioned supine on a radiolucent table with a bolster to flex the knee 60º and align the fracture. In the first phase a universal antegrade femoral nail was shortened with a sterilised industrial hand-saw and polished with a file under aseptic conditions. In a later phase a complete set of nail sizes was available. Through a short medial parapatellar incision the medullary canal of the distal femur is opened percutaneously under radiographic control. Limited reaming of the isthmus is usually necessary. Alignment of stem and nail is more difficult in patients with contractures (Parkinson’s disease) and proximal long spiral fractures. A small direct lateral vastus splitting approach to the tip of the stem is advisable to guide the nail in these cases or to remove interfering cement.

When a rigid fixation is achieved by hammering the nail over the tip of the stem, the nail is locked in the distal femur. For fractures reaching the

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supracondylar area, locking around the knee is best performed with thick bolts. For this purpose the Bridging nail has two holes, with a six millimetre diameter. At least three centimetres overlap of stem and nail was pursued. This was believed to provide a stable fixation.

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**Type A** # of major or minor trochanter

**Type B** # of diafysis, at the level of the stem
- B1 fixed stem, adequate bone stock
- B2 loose stem, adequate bone stock
- B3 loose stem, loss of bone stock

**Type C** # distal of stem

*Figure 1. Vancouver classification of periprosthetic fractures*
Results

Between 1995 and 2004, 18 patients, (4♂, 14♀) were treated with retrograde nailing of the hip stem. Mean age was 81.4 years (range 61-96). 13 patients had a type C fracture and 5 type B. One of these patients (type B) suffered from high-energy trauma.

Eight patients had severe co-morbidity (e.g. Parkinson’s disease, melanoma and mammacarcinoma). The youngest patient (61 years of age) had trisomy 21. The femur was fractured below a primary total hip stem in twelve patients. One of these patients suffered from an interprosthetic fracture with a total knee arthroplasty in situ. Three patients had a femoral fracture below a revision stem and three below a hemiprostheses (Table 1).

Mean clinical follow-up was 21 months range from 4-61 months. Four patients died within six months after surgery. Two patients deceased just within one year post-operative of a natural cause without hip or knee complaints. Two patients died after more than 3 years of cardiac failure. Their knee and hip functions were painless. 14 patients regained their preoperative functional level. Two needed one crutch and two patients became wheelchair dependent. Fracture union in all surviving patients was seen after 6–12 months. The surviving ten patients showed a painless hip and knee function without long term complications at recent follow up.
Complications

Surgical re-interventions were needed in two patients. One patient needed revision surgery, two weeks after initial surgery, for protrusion of the nail into the knee joint after inadequate distal locking. The nail was inserted deeper in the distal femur. The second patient needed revision surgery for the treatment of a fracture between a hip and knee prosthesis. In this case primary stability could not be achieved. It was impossible to pass the wide AO outrigger through the condyles of the prosthesis resulting in a failed junction of the nail and the hipstem. Ten days after primary surgery the fracture was treated with allograft struts. Follow up after 12 months showed unlimited walking and good knee function.

One patient with Parkinson’s disease and flexion contracture of the hip the proximal femur was split. This occurred in an attempt to achieve a closed reduction and fixation. Post-operatively three-centimetres shortening were seen on clinical and X-ray examination as a result of the stem sinking into the nail. No complementary surgical intervention was needed. Nevertheless a painless hip and knee motion was reported at the postoperative controls at three and six months. The shortened leg was compensated with a shoe raise. Gait was acceptable with cane. Callus formation was seen after 3 months with further consolidation at six months.

One patient with pre-existent osteoarthritis had slight protrusion of the nail in the knee joint. She suffered from mild pain. This patient had no surgical re-intervention.

Discussion

Nowadays retrograde nailing is common practice in the treatment of femoral fractures and multiple studies demonstrate its safety. We presented a series of 18 compromised patients with a periprosthetic fracture (PPF) treated with a retrograde Bridging nail. Satisfactory functional results were achieved and slow but reliable union of all femoral fractures has been observed with the intramedullary nail in situ.

The compromised geriatric patient has often a poor physical condition not suitable for extensive surgery. This group benefits from reduced duration of surgery with minimal dissection that enables early postoperative mobilisation. The phenomenon of femoral widening of the diaphysis is seen in osteoporosis and geriatric patients. As a result the diameter of the medullary cavity is usually large enough for the nail to be inserted with only minimal reaming. Early postoperative mortality was not observed in this patient group.

Healthy patients with femoral fractures near implants benefit from revision arthroplasty. High re-operation rates are common after reconstructive surgery. Re-operation rate for the primary PPF treatment is 23% of which
44.5% takes place in the first year after fracture surgery.\(^{10}\) The Bridging nail can provide retrograde fixation of the hip stem in low demand patients. In geriatric patients the expected strain on the femur is limited and the retrograde nail can serve as a definitive implant. In younger active patients the nail should be reserved for selected cases. These patients might benefit from the Bridging nail in cases without classic treatment options. The nail can also serve as a salvage option in failed fracture treatment as well in our opinion. Long term effects of fracture treatment with the Bridging nail in younger more active patients are unknown.

Elimination of stress risers, contributing to re-fracturing, is desirable. Overlapping implants tolerate the highest loads. When it is impossible to achieve overlapping a minimum distance between implants of twice the diameter of the shaft is advised in literature based on biomechanical testing.\(^{6,7,15}\) This is not always feasible in plate-osteosynthesis of Vancouver type C fractures. Besides the minimal invasive aspects, elimination of a stress rising zone initiated the development of the Bridging nail. The concept of lengthening of a hip stem was described before. Voggenreiter et al.\(^{26}\) presented a therapeutic option for pathological femoral fractures. A hemiprosthesis was lengthened with a slotted nail. This construction was cemented in the compromised femur to achieve rigid fracture fixation in a palliative setting. Wroblewski lengthened a hip stem with a Küntscher nail in order to treat a femoral shaft fracture.\(^{28}\) These constructions proved their value in selected patients. The Bridging nail combines stem lengthening with minimal invasive surgery creating conditions for fracture healing without extensive soft tissue damage.

In this type of retrograde nailing femoral shortening up to 1 1/2 centimetres is common. The demands of the patient group and the goals of treatment make leg shortening a less important clinical issue. In one patient with Parkinson’s disease and flexion contracture of the hip the proximal femur was split. This occurred in an attempt to achieve a closed reduction and fixation. Open fracture reduction might have prevented this complication. Two re-interventions were necessary during a follow up period of 1.5-61 months. Both patients were surgically treated within two weeks after primary surgery. Failure of distal locking is a common problem in osteoporotic bone. Preferably at least two thick condylar compression bolts are used.\(^{2}\)

In our series minor knee problems in the initial post-operative period were seen, although these problems were not interfering with mobilisation. The morbidity of an arthrotomy of the knee joint has been evaluated. In a prospective study Ricci et al. found similar clinical results of antegrade and retrograde nailing in femoral fractures. However, antegrade nailing was associated with problems related to the hip, whereas retrograde nailing was associated with problems of the knee.\(^{19}\) Although, this finding was not supported by Tornetta et al. who found no difference in knee pain with retrograde nailing after union when compared to antegrade nailing.\(^{24}\)
LISS plating for PPF treatment combines the principles of rigid fixation and minimal invasive surgery. Besides, arthrotomy of the knee is avoided. In PPF callus formation is uniformly slow and bridging of the fracture usually takes several months. Weight bearing after LISS plating is delayed to avoid plate breakage while early loading is possible after intramedullary nailing.\textsuperscript{8,26} In geriatric patients this early load bearing makes rapid ambulation possible which is desirable to prevent complications due to inactivity.

Loosening of the stem is frequently seen in the geriatric age group and is considered a risk factor for periprosthetic fractures.\textsuperscript{1} In Vancouver type B fractures with prosthetic loosening the Bridging nail can slide over the remains of the cement and fits between cement and cortical bone providing rigid fixation. A small amount of cement between the two implants is acceptable. The cement becomes more porous and fragile after many years and can be “impacted” by the clamping effect of the nail. Furthermore diaphyseal widening of the femur is a phenomenon observed in our geriatric patient group and reported in literature.\textsuperscript{23} Together with a small interface between the nail and the cortical bone”, these aspects of the geriatric prosthetic femur offer the possibility to perform the osteosynthesis with the Bridging nail. During operation the moment of engagement of the nail and hip stem is clinically noticeable. Rigidity or stability of the osteosynthesis can be judged by the surgeon directly. The clamping effect of the Bridging nail has a favourable effect on loosening of the stem. Extensive surgery to stabilize the hip stem is avoided by this method and the nail can serve as a definitive implant in these low-demand patients.

In PPF with well fixed stems removal of the cement was carried out by a recently developed hollow drill. With an image intensifier the cannulated hollow drill can provide a narrow space around the tip of the stem to secure the retrograde nail. However, in some cases a small direct vastus splitting approach of the fracture may be necessary to remove redundant cement. Although tapered straight stems are best served by retrograde nailing, adequate fixation has been obtained with a curved Muller stem and anatomically designed SP prostheses as well.

In conclusion, healthy patients with femoral fractures near implants benefit from classic treatment. However, in compromised or geriatric low-demand patients, retrograde intramedullary nailing of the hip stem offers a minimal invasive method for stabilisation of periprosthetic fractures. Retrograde nailing provides minimal morbidity for the old compromised patient. Partial weight bearing is possible shortly after the operation, creating favourable nursing conditions.
Reference list


Retrograde Bridging nailing of periprosthetic femoral fractures


CHAPTER 8

A less invasive salvage procedure for fractures below intramedullary nails of the proximal femur.

RG Zuurmond, P Pilot, AD Verburg, SK Bulstra

Submitted
Abstract

Fractures around the intramedullary component of a trochanteric nail are rare complications but a large threat to the geriatric patient. Standard therapy consists of removal and re-insertion of a longer nail or the use of extramedullar implants. A less invasive method is the use of a retrograde nail which clamps the distal intramedullary nail. This eliminates the removal of the lag screw and exposure of the trochanteric region. Four patients (mean age 86.8 years), all female, were treated with the Bridging nail. The mean operative time was 75 minutes. At follow-up (mean 23.5 months) all patients regained preoperative functional level. The fractures showed consolidation in all cases. In conclusion, in geriatric patients, the retrograde bridging nail is a therapeutic option in treatment of fractures around an intramedullary nail in the proximal femur.
Introduction

Subtrochanteric fractures of the femur, caused by low-energy trauma, are less common than other proximal femoral fractures, however they occur in a similar population of elderly individuals.\textsuperscript{1} For the surgical fixation of extracapsular hip fractures two types of implants are mainly used; intramedullary nails and Sliding hip screws (SHS).\textsuperscript{2} Operative stabilisation of these fractures in the elderly is often technically difficult because of fracture comminution and osteoporosis.\textsuperscript{2} The optimal treatment of extracapsular hip fractures is still under debate, particularly for unstable multifragmented fractures. Of the intramedullary nails, the Gamma nail(r) is the most frequently used device, other intramedullary implants are the intramedullary hip screw (IMHS), the proximal femoral nail (PFN) and the Küntscher-Y nail.

The primary reason that the SHS is favoured in the meta-analysis by Parker\textsuperscript{2} is the occurrence of late fractures below the nail. This complication, although rare, is devastating for the patient requiring either major revision surgery or a prolonged period of traction and bed rest.\textsuperscript{2} This complication occurred in 2.7% of Gamma nailing and only in 0.16% of the cases of SHS fixation.\textsuperscript{2} Pooled results show that using these nails results in one extra later femur fracture in every 50 trial participants (95% CI; 1 in 33 to 1 in 100) and one extra re-operation in every 50 trial participants (95% CI; 1 in 33 to 1 in 100).

Treatment options for these fractures are: Removal of the nail and insertion of a long gamma-nail, a long DCS, LISS(R)-plating, cerclages (e.g. Partridge) with or without cortical allograft struts\textsuperscript{®} and various systems of cable-plate fixation.\textsuperscript{3-5}

Closed retrograde nailing is a common solution for distal femoral fractures below an intramedullary nail and attractive for its minimal invasive aspects. However, retrograde nailing below an intramedullary leaves a possible stress-rising zone between the ends of the implants. Creating a rigid fixation between the intramedullary implant and the stem would solve this problem.

Good salvage experiences in treating periprosthetic fractures with retrograde femoral nails, that were guided over the tip of hip prostheses through a retrograde approach, initiated the use of the nail in fractures below the Gamma-nail(r).\textsuperscript{6} The first four patients treated with this Bridging nail are presented.

Materials & Methods

An adapted retrograde femoral nail is used to perform the osteosynthesis. The length is measured using an image intensifier and a sterile measuring staff during operation. The diameter of the tip of the gamma nail is 11 millimetre. A 13 millimetre diameter retrograde nail is used to perform the osteosynthesis. The patient is positioned supine on a radiolucent table with a bolster to flex the knee 60° and align the fracture. In the first phase a universal antegrade femoral nail was shortened with a sterilised industrial handsaw and polished with a file under aseptic conditions. In a later phase a complete set of nail sizes became available.
Through a short medial parapatellar incision the medullary canal of the distal femur is opened percutaneously under radiographic control. Limited reaming of the isthmus is usually necessary. Alignment of gamma-nail and bridging nail is more difficult in patients with contractures (Parkinson’s disease) and proximal long spiral fractures. A small direct lateral vastus splitting approach at the tip of the stem is needed to remove the locking bolt. Furthermore the nail can be guided at the tip of the implant through this incision in these cases.

When a rigid fixation is achieved by hammering the nail over the tip of the intramedullary nail, the nail is locked in the distal femur. For fractures reaching the supracondylar area, locking around the knee is best performed with thick bolts. For this purpose the Bridging nail has two holes, with a six millimetre diameter. At least three centimetres overlap of stem and nail was pursued. We found stability of the junction by mechanical testing done with an overlap of three centimetres average.

**Results**

Between 2000 and 2006, 4 patients, (all female) were treated with retrograde nailing of the intramedullary nail. Mean age at operation was 86.8 years (range 82-94). Patient characteristics are summarised in Table 1. Mean operation time was 75 minutes (range 60-120). In patient number 3 two cerclages wires were needed to reduce the osteoporotic fracture fragments around the lengthened implant which showed a stable connection. No adverse effects of the technique were seen during and after surgery concerning the hip screw or femoral head. All patients were instructed as good as possible to early mobilization and partial weight bearing. Patient 2 died after 23 months of cardiorespiratory failure. She lived in a nursing home and was able to mobilise with aid. Consolidation of the fracture was seen in all patients. The functional level was adequate considered the age group. Femoral shortening of 2 cm was noted in one patient, treated with a shoe raise. Pre and postoperative X-rays of patient number 3 are depicted in figure 1.

<table>
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<tr>
<th>Patient</th>
<th>Age</th>
<th>Co-morbidity</th>
<th>Time to fracture</th>
<th>Operation time</th>
<th>Blood loss (ml)</th>
<th>Follow up</th>
<th>Consolidation outcome</th>
<th>Functional</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>87</td>
<td>IDDM, breast ca.</td>
<td>2 weeks</td>
<td>60</td>
<td>500</td>
<td>60m</td>
<td>+</td>
<td>Bed-chair</td>
</tr>
<tr>
<td>2</td>
<td>94</td>
<td>Dementia</td>
<td>19 m</td>
<td>60</td>
<td>300</td>
<td>23m</td>
<td>+</td>
<td>FWB with aid</td>
</tr>
<tr>
<td>3</td>
<td>82</td>
<td></td>
<td>21 m</td>
<td>120</td>
<td>100</td>
<td>3m</td>
<td>Callus formation</td>
<td>FWB with aid</td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>IDDM COPD</td>
<td>20 m</td>
<td>60</td>
<td>200</td>
<td>8m</td>
<td>+</td>
<td>FWB</td>
</tr>
</tbody>
</table>

m= months, FWB=full weight bearing, IDDM= Insulin dependent Diabetes Mellitus, ca.=Carcinoma, COPD= chronic obstructive pulmonary disease.
Discussion

The compromised geriatric patient has often a poor physical condition not suitable for extensive surgery. We presented four compromised patients with fracture below a gamma nail treated with a retrograde Bridging nail. Satisfactory functional results were achieved and slow but reliable union of all femoral fractures has been observed with the intramedullary nail in situ.

Nowadays retrograde nailing is common practice in the treatment of femoral fractures and multiple studies demonstrate its safety. Positive experiences with periprosthetic fractures initiated the use of the retrograde bridging nail in frail patients with a fracture below an intramedullary implant. The compromised group benefits from reduced duration of surgery with minimal dissection that enables early postoperative mobilisation. The exposure of the trochanteric region with removal of the nail increases the intensity of the operative hazard. Complications associated with nail removal are weakening of the collum femoris, fracture of the proximal femur, infection and wound complications. The tip of the lag screw is self tapping with a tapered neck. Modern designs exclude a tapered contour. Counterwise rotation for extraction of the hip screw could create additional damage to the bony screw hole hereby weakening the collum femoris. In case of revision to long gamma nail, less grip of the new lag screw during reinsertion is expected. This can lead to inadequate implant fixation.

The necessity for removal of the intramedullary implant is eliminated by the Bridging nail, hereby avoiding the possible problems described above. Dissection of the trochanteric region is prevented and the medullary cavity is only distally opened which reduces postoperative bleeding and less surgical trauma.

The phenomenon of femoral widening of the diaphysis is seen in osteoporosis and geriatric patients. As a result the diameter of the medullary cavity is usually large enough for the nail to be inserted with only minimal reaming. Besides the minimal invasive aspects, elimination of a stress rising zone initiated the development of the Bridging nail. In the treatment of fractures near intramedullary implants elimination of stress risers, contributing to re-fracturing, is desirable. Overlapping implants tolerate the highest loads. When it is impossible to achieve overlapping a minimum distance between implants of twice the diameter of the shaft is advised in literature based on biomechanical testing\textsuperscript{7,8}

The gamma nail is slightly tapered and a rigid fixation is achieved after 3 centimetre bridging. When the retrograde nail engages the tip of the gamma nail, additional a minimum of 2 centimetres is necessary for adequate stability. Mechanical evaluation of the junction of the nail with hip stems shows adequate stability with 2.0 cm pure contact overlapping. This is described in chapter 6 of this thesis. In plate-osteosynthesis overlapping is not always possible. The idea of LISS plating for fracture treatment is combining the principles of rigid fixation with minimal invasive surgery. Furthermore, arthrotomy of the knee is avoided. However, callus formation is
commonly slow and complete bridging of the fracture usually takes several months. Moreover, weight bearing after LISS plating is delayed to avoid plate breakage while early loading is possible after intramedullary nailing. In our series early weight bearing was not encouraged but permitted in this age group. No adverse effects were seen of this policy. In geriatric patients this early load bearing makes rapid ambulation possible which is desirable to prevent complications due to inactivity. Especially in patients with poor compliance after surgery this might be an important reason the treat with the Bridging nail.

In conclusion, retrograde nailing seems a less invasive salvage procedure for the old compromised patient eliminating the necessity for removal of the hip screw. Weight bearing is possible shortly after the operation, creating favorable nursing conditions.
A less invasive salvage procedure for fractures below intramedullary nails

Reference list


CHAPTER 9

No significant corrosion after Bridging nail osteosynthesis of a periprosthetic fractured femur; a retrieval report

RG Zuurmond, P Pilot, AD Verburg, SK Bulstra, P Buma
Abstract

The application of the retrograde Bridging nail in periprosthetic fracture treatment offers a treatment modality for geriatric patients. The retrograde nail is in close contact with the hip implant. The use of different metals cause galvanic effects and corrosion may occur. Corrosion can lead to foreign body reactions. A retrieved femur with a three year old osteosynthesis (consisting of a standard adapted AO femoral nail and a Muller straight hip stem) of a 79 year old female was prepared for histological analysis. The goal of the study was to evaluate foreign body reactions at the metal-metal interface, osteolysis and periprosthetic fracture healing. At five levels specimens were taken for light microscopy. Few macrophages were present with engulfed wear particles. None of the sections showed intense periosteal reaction or an aggressive osteoclastic resorption. The fracture showed normal callus formation. Although systemic effects could not be evaluated in this study, we believe that the femoral osteosynthesis with a retrograde nail with a bridged junction of the hip stem can serve as a long-term implant without severe local adverse effects, when primarily a stable construction is achieved.
Introduction

Periprosthetic fractures of the hip are a complex problem for patient and surgeon. The general condition of geriatric patients often prohibits extensive surgery. Standard treatment consists of revision to a long stem prosthesis and various plating techniques. These techniques often need a long operation time and a large exposure. Moreover, high morbidity and mortality after surgery is seen. Mortality rates up to 20% are reported in this population mainly due to poor overall condition.1 Furthermore the plating techniques are associated with a considerable number of re-operations.2 Treatment of a Vancouver type C periprosthetic fracture is not uncommon.3,4 However, retrograde nailing below a hip stem leaves a possible stress-rising zone between the ends of the implants. Creating a rigid fixation between the intramedullary implant and the stem solves this problem. Antegrade solutions were reported first, using custom made lengthened implants.5,6 These reports lead to the use of a manually adapted standard AO femoral nail which was advanced over the tip of the prosthesis in a retrograde fashion.7 This technique has evolved to a treatment system named Bridging nailing. Advantages of the retrograde Bridging nail are the minimal invasive aspect and shorter operation time. Besides benefits of the Bridging nailing system some concerns arise, especially regarding long-term effects. It is not possible to obtain retrograde nails that have exactly the same alloy as the implanted hip stem. Mismatch between the metal composition of the nail and the implant could create a potentially dangerous corrosive process. Several types of corrosion can occur due to micromotion at the junction and due to different implanted metals. The corrosion of biomaterials depends on geometric, metallurgical and solution chemistry parameters.8 These types of corrosion are fretting, putting, crevice and galvanic. Whenever corrosion occurs, this process enhances the risk of crack propagation and fatigue fractures.8 Implant failures have been reported at modular interfaces.9-11 Furthermore the presence of metal ions may trigger a foreign body response.8,9,11,12 This foreign body response can lead to focal osteolysis and cortical thinning.

These concerns lead to the following research questions; is the healed bone vital at fracture level? Are there, due to corrosion, inflammatory tissue reactions or metallosis noticeable?

Case

A 76 years old lady was admitted at the emergency department with pain in her right leg, after a fall at home. Patient was diagnosed with a periprosthetic fracture (Vancouver type B1).9,13 Medical history showed a hypertension for about twenty years, Diabetes Mellitus (oral medication), a cemented total hip arthroplasty on the left side in 1989, on the right side in 1992 and a total knee arthroplasty on the left side in 1993.
Because of her well-fixed Muller straight stem (Protasul™ S30; FeCr12Ni10Mn4Mo2NNb, Sulzer-medica, Swiss) and considerable comorbidity the patient was treated with a retrograde nail osteosynthesis (shortened standard 13 mm AO-nail, Wrought Fe18Cr14Ni2.5Mo), bridging the tip of the prosthesis as described by Verburg. The surgery was performed with a parapatellar approach. The medullary canal of the distal femur was opened under radiographic control. Limited reaming of the isthmus was necessary. A small lateral incision through m.vastus lateralis was made and a small pointed fracture fragment was resected. With visual control, the tip of the nail was slided over the tip of the prosthesis. A rigid fixation was achieved by hammering the nail over the tip of the stem. At least three centimetres overlap of stem and nail was pursued. The nail was locked in the distal femur with two screws, providing a stable fixation.

After surgery the patient was allowed full weight bearing, with crutches. A shortening of the right leg of about 3 cm was observed which was treated with a shoe-raise. Patient was discharged after 11 days. At 6 weeks she was fully self supporting. At 14 weeks the x-ray, showed consolidation of the fracture. One year after the trauma, patient was pain free, used a walker and had a good hip and knee (F/E 120/0/0) function, although she had a Duchenne gait. At two-year follow-up the patients was still pain free. On X-ray examination no signs of focal osteolysis were seen during follow-up. After 34 months the patient, was admitted with congestive heart failure and died ten days later. The total femur was excised for analysis after consent was obtained (Figure 1). After storage at -80°C the bone was totally embedded in polymethylmethacrylate (PMMA) to preserve tissue integrity during sawing which was done using a water cooled diamond coated saw (WOCO). After polymerisation thin slices were made at various levels along the stem and nail (Figure 2 level A-E). Radiographs of the slices were obtained (Figure 3) and thereafter the metal implants were gently removed and thin sections were obtained with a microtome (Leica RM 2155) Sections were stained with Haematoxilin and Eosin (HE) for histological evaluation by light microscopy.

Figure 1. Retrieved femur with fracture site marked
Results

At manual inspection of the femur with implant, the stem was firmly fixed in the bone but upon manipulation micro-motion was visible. Sections were analysed at five levels along the reconstruction (see Figure 2 for locations). Section A was through the proximal femur, sections B and C through the fracture site, sections D through the transition of the fracture site with the more distal femur and section E through the metaphyse and the nail.

Irrespective to the location, the bone of the femur was a circumpherential structure without any visible interruption in HE sections. With polarised light the transition between the normal Haversian structure of cortical bone and the more woven callous bone that has been formed in the fracture gap was present in sections B-D. (Figure 4) The newly formed callous bone was partly replaced by lamellar bone.

A second difference between the two types of bone was that the original cortical bone was largely necrotic with only locally areas that were vital and revascularised. However, this newly formed callous bone was vital throughout. (Figure 4b)

The interface tissue with the implant was a mixture of necrotic fibrous tissue with scattered vital areas. In sections A-C more vital areas were found irrespective to the location. The interface contained some sheets of macrophages that had engulfed wear particles. In sections A-C the interface had a variable thickness of between ca 50 μm and 2 mm. More distally in
sections D and E the interface was thinner, and the orientation of the collagen was regularly oriented in a circumpherential direction. The distal interface was almost entirely composed of collagen without any viable cells (Figure 5c). Locally necrotic cells remnants, some with wear particles, were present. None of the sections showed an intense periosteal reaction or an aggressive osteoclastic resorption.

Discussion

We presented a case of a periprosthetic fracture treated with a retrograde Bridging nail over a straight Muller stem with a different alloy. With the post-mortem examination of the retrieved femur we were able to study the morphology of the bone and fracture site, 34 months after surgery. No clinical relevant signs of corrosion were seen at retrieval. The retrieval
showed a healed fracture macroscopically as well as microscopically and metallosis or foreign body reactions were not seen. Vital bone was present throughout the entire fracture site.

The Bridging nail is a new concept for the treatment of periprosthetic fractures. Good clinical results, regarding fracture healing and mobilisation, of the first series of compromised patients treated are available. However long term effects of the Bridging nail in situ are not known. This treatment modality was only used for compromised patients with a reduced life expectancy, by this avoiding extensive surgery possibly leading to reduced morbidity and mortality.

However, the concept of the Bridging nail implicates two different metals in close contact to one another possibly causing corrosion related problems. Most of the fabrication related factors contributing to corrosion have been eliminated in modern implants. The most relevant forms of corrosion in our case are galvanic, fretting and crevice corrosion or a combination of these three forms. Galvanic corrosion can occur when dissimilar metals are in electrical or physical contact (the former through an electrolyte).

In orthopaedic implants different alloys rely on the forming of a passive film to prevent oxidation. Micromotion between components can result in fretting corrosion through disruption of this film. This can lead to initiation of crevice corrosion. In our case the implants were susceptible to micromotion and stress, particularly just after the operation with the un-united fracture. This could lead to increased levels of corrosion and its adverse effects on the human tissue. No focal osteolysis was seen on x-ray examination of the femur and no extensive inflammatory reaction was observed histologically. Presumably the junction of the nail and the prosthesis does not prevent the formation of the passive protective film.

Corrosion can weaken implants resulting in failure as is described at femoral tapered necks in cobalt alloy stems with cobalt alloy heads. In the case of the Bridging nail a stable connection was observed without signs of failure through the entire patient series. Stress on the junction is could be reduced after fracture healing thereby diminishing the possibility of implant breakage. Furthermore we expect the amount of cyclic loads on the implant in this patient group to be lower compared to active healthy patients. Another effect of corrosion is the release of metal ions in surrounding tissue by particulate corrosion. The host immune system can be activated and a response may be initiated. Especially the formation of chromium-orthophosphate leads to macrophage monocyte activation in a dose dependent matter. In our retrieval study no extensive inflammation was seen at the level of the junction, this in contrast to extensive periprosthetic tissue necrosis that was reported in cobalt-chromium alloy modular prostheses.

The femur was frozen immediately after harvesting and defrosted in the research lab. The embedding in PMMA was necessary to preserve the periprosthetic tissue and its relation to the surrounding tissue during sawing. Artefacts as a result of these procedures are the only possible disturbing factors. However no hindering artefacts were seen with light microscopy.
The analysed implant consisted of a Muller straight stem and an AO universal femoral nail. We were able to evaluate the inflammatory reaction and bone healing around this specific combination of alloys. Although the metals used in the Muller straight stem are commonly used in orthopaedic surgery, no conclusions can be drawn concerning other compilations of metals.

In conclusion our patient with a periprosthetic fracture, treated with a Bridging nail, showed good fracture healing with vital bone surrounding the implant and no extensive tissue inflammation at retrieval, despite the suboptimal metallurgic environment for nearly three years. We believe that the retrograde nail osteosynthesis with a bridged junction of the hip stem can serve as a long term implant without severe local adverse effects, when primarily a stable construction is achieved.
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*No significant corrosion after Bridging nail osteosynthesis*
CHAPTER 10

General discussion
Chapter 10
General discussion

The earliest reports of periprosthetic femoral fractures (PPF) are published in the sixties.\(^1\) The last decade these fractures gained more attention as a result of an increase in incidence.\(^2-5\) Several classifications are mentioned in literature. The Vancouver classification is the most widely used, presumably by its simplicity and thereby high reproducibility.\(^3\) (Chapter 2) Suggestions for optimal treatment of PPF have repeatedly been adjusted after acquired experience from analysed series.\(^6,7\)

The number of PPF has increased the past decades. The rising numbers are explained by the increasing numbers of arthroplasties performed. Besides, people have a longer life-expectancy, and therefore have a longer timeframe being vulnerable to develop a PPF. And finally, arthroplasties are performed in patients who formerly were regarded as to old or to sick.

Most PPF originate from low energy or even minimal trauma. High energy trauma is rare. As in regular hip fracture a clear relation with osteoporosis is identified. Bone quality in general is a subject of research in many reports concerning PPF.\(^7-9\) Besides bone stock, osteolysis plays a major role in the development of PPF. The femoral implant alters the stress patterns in the proximal femur. After a number of years remodelling causes accelerated widening and thinning of the cortex, which is part of a physiologic process. Although these phenomena are well known, there are no reports describing the strength of the femur with a prosthesis in situ. Osteolysis, a process closely related to loosening and wear, results in proximal femoral bone mass. The likelihood for fracturing is implant dependent and an interesting research subject. Non-cemented and revision procedures clearly lead to an increased fracture risk.\(^8,10-12\) The incidence of these fractures has been subject of research the past years. Lately the Swedish Hip Register enabled Lindahl and colleagues to accurately establish the incidence in the Swedish population.\(^12-15\) In these national registers a minimum set of data is recorded and although this minimal set provides us with a significant amount of valuable outcomes only recently this set has been extended with patient-based outcome measures and radiographic results to improve sensitivity.\(^16\) The current endpoint of revision or re-revision is clearly defined but leaves many questions regarding the true long term outcome. The same is even more evident for PPF.

For other regions the estimation depends on local registries of individual hospitals. From hospital admission data provided by the Prismant Institution, Utrecht, The Netherlands, the incidence of a periprosthetic fracture for a patient operated for primary total hip arthroplasty (THA) between 1991 and 1993 in ten years time is between 6.4 and 8.5 per thousand. (Chapter 3) No increase in incidence was observed in two consecutive cohorts (1991 and 1992). The number of patients who underwent primary hip arthroplasty increased from 13,086 in 1991 to 14,865 in 1992 explaining the increase in absolute numbers in these years. The analysis was performed with several assumptions. A method of elimination of re-admission codes for non-acute,
other diagnoses resulted in obtaining the records with suspected periprosthetic femoral fractures. However, these assumptions would not be necessary if an adequate coding system for orthopaedic implants had existed in The Netherlands. The previously mentioned Swedish Hip Register is a great example. Recent efforts to organize a new implant registration system in the Netherlands (LROI) will facilitate implant related research. It is essential that a separate code for periprosthetic fractures is embedded in the new registration. Besides, a unique citizen service number will eliminate confounding factors. Furthermore it would be advisable to include a separate DRG-coding for these fractures. The financial aspect associated with this very type of fracture would be more accurately charted and registered. This facilitates research and cost-evaluation. This is important as these patients have a long hospital stay and are prone to develop complications.

The treatment of PPF has evolved slowly as a result of the limited experience per institution. Conservative treatment, advised in the early reports, brings along increased risk of complications as thrombosis, pneumonia, urinary tract infection and decubital ulcers. During the last decennia several methods of fracture fixation found their use in periprosthetic fracture treatment and treatment protocols have been developed. The implementation of these algorithms in clinical practice and current treatment performed by Dutch orthopedic surgeons was evaluated by a query (Chapter 4). The relatively small numbers of PPF treated in individual Dutch hospitals and the diversity in treatment strategies emphasise the need for a good registration. More accurate results will then be available for research to improve the patient's outcome.

The emphasis is on revision arthroplasty in fractures with a loose stem. For stable implants numerous forms of internal fixation are at the disposal of the treating surgeon. Cerclage-systems offer little stability and should be accompanied by other forms of fixation. Plate fixation is associated with complications as well, specifically in type B1 fractures. Bone biology is an important aspect for fracture healing. Recent developments in plate osteosynthesis, including indirect fracture reduction and less invasive procedures, tend to respect surrounding tissue. Although this is beneficial to fracture healing, early ambulation and load bearing are frequently not feasible with these techniques. The complication rate of osteosynthesis in most reports is 20%. A retrospective analysis of our own cohort showed a high mortality rate as well, 11% in the first year. (Chapter 5). The PPF patient group is often compared to proximal femoral fracture patients in which these high mortality rates are acknowledged. The high numbers of local complications, observed after osteosynthesis, could be explained by underrating of the fracture and implant stability as suggested by Lindahl et al.

Currently most treatment algorithms are based on the Vancouver classification. In 2002 Haddad et al. described results for the Vancouver B1 fractures. Cortical strut grafts offered both mechanical and biological advantages. In case of a loose prosthesis the algorithm invariably ends with long stem hip replacement surgery. The advice of many authors is to evaluate
the stability of the pre-existing stem before and during surgery.\textsuperscript{6,7,14} Several remarks about these protocols can be made. Firstly, these series focused on fracture healing exclusively and the outcome depended on fracture union and patient satisfaction. Patients dying early after the large operative procedure were frequently excluded, leading to an underestimation of operative risks. Revision arthroplasty involves extensive surgery with considerable blood loss and a long operation time. The possibility to perform extensive surgery in these patients has to be critically evaluated prior to surgery and selection of the type of operation should be tailored to the patient’s general condition and physical demands. Secondly clinical relevance of a-symptomatic loosening of the stem prior to fracture is subject of debate. It is not clear if a stem should be revised with a fracture below the stem in a patient with restricted demands and a limited lifespan. For this patient group a new form of salvage treatment was developed.\textsuperscript{32,33} A retrograde partially slotted nail which slides over the tip of the prosthesis and provides stability offers a solution for low demand patients (Chapter 7). Frail geriatric patients with co-morbidity benefit from this minimal invasive procedure. The intramedullary nailing offers immediate ambulation with early weight bearing. Besides, nailing promotes secondary fracture healing even in conditions with impaired femoral bone stock. The technique is applicable to both cemented and uncemented prostheses. Closed nailing is feasible when alignment is correct and there is no intervening bone cement. Intramedullary removal of the cement can be performed with hollow cannulated drills possibly with computer assisted surgery. The latter, being subject of current research.

Mechanical evaluation of the nail-stem junction showed sufficient stability during cyclic loading tests to allow early load bearing. (Chapter 6) Especially in low-demand geriatric patients this is beneficial as they often cannot comply with restricted weight bearing instructions. The decision to perform a salvage procedure in favour of a revision arthroplasty is based on patient’s characteristics. Preferably a quantification of the general health and mobility would facilitate the decision. Research on geriatric demands and general health should be performed regarding the type of fracture surgery, analogous to recent initiatives in the proximal femoral fracture. The characteristics of a patient with an intramedullary implant following treatment for a proximal femoral fracture is comparable to PPF around hip stems. Fractures around these implants are seen more frequently. The incidence is up to 2\% of all patients treated for proximal hip fracture with intramedullary implants as reported by Parker and colleagues.\textsuperscript{20} Preferably the femoral fracture in these patients with intramedullary implants is treated by less invasive means. The early results of a small group of patients treated by retrograde nailing are promising. The Bridging nail with its retrograde synthesis concept offers a less invasive and easy solution to perform stable osteosynthesis in these patients. (Chapter 8)

In principle all modular systems are prone to the effects of the coupling of different metals. In time electrochemical reactions may lead to corrosion and fretting as is seen in modular taper surfaces.\textsuperscript{34} The Bridging nail, when
combined with another implant containing different metals, is subjected to these potentially adverse events. However histological evaluation of a retrieved human femur after 34 months showed no soft tissue reaction and a tranquil histological situation was encountered. (Chapter 9) The nail showed no signs of failure or cracks. As a salvage procedure in situ for almost three years the Bridging nail can be regarded as a safe implant when combined with commonly used hip stems. No histology of the Bridging nail in combination with other types of hip stems is available at present. However, in the clinical series there is no case of granuloma formation around the stem-nail junction. The clinical series at present involves different cemented stem designs and numerous titanium revision stems. (unpublished data)

**General conclusions**

- The incidence of periprosthetic femoral fractures in The Netherlands was distilled from a nationwide admission database, and is between 0.65% and 0.85% in a ten years post-operative period. This is comparable to international literature reports.
- There is no uniformity in selection of treatment for periprosthetic femoral fractures.
- The treatment of periprosthetic femoral fractures has a high complication rate (21% re-operations within one year). The mortality in the first postoperative year is high. This emphasises the complexity of the periprosthetic fracture treatment.
- The Bridging nail system offers less invasive periprosthetic fracture treatment in the frail patient.
- The Bridging nail system is a stable construction. Weight bearing circumstances in the frail geriatric patient can be allowed.
- The Bridging nail system has advantages in the treatment of fractures below femoral intramedullary implants.
- The combination of the Bridging nail and a common used hip prosthesis does not provoke severe electrochemical reactions after several years. The surrounding bone shows no adverse effects and the fracture unites normally.

The problem of periprosthetic fractures is seen in 0.65-0.85% of total hip arthroplasties performed. Frequently these patients suffer from co-morbidity and complications. Re-operation rates are high as well as mortality rates. In the geriatric patient group with low demands the Bridging nail can serve as an alternative therapeutic option, providing less invasive surgery and solid fracture fixation. The construction is able to withstand weight bearing loads. This is beneficial to non-compliant patients with difficulties to obey to limited weight bearing protocols. In general the registries lack specific data concerning PPF, thereby providing limited information on the optimal treatment forms for the individual patient with a specific type of PPF.
Future research

- The need for well controlled larger series of patients with periprosthetic fractures is evident as the treatment of these fractures is highly individualised. Only a large concentration of patients and fractures with similar characteristics allow a critical evaluation of treatment regimens. Ideally not only a fracture specific classification should be recorded. Health measurement scores and functional scores should be included in the study as well. The Groningen Activity Restriction Scale (GARS)\textsuperscript{35} is an example of such a score which is easily recorded by observers and covers large parts of the general nursery intake.

- In order to observe the expected increase in incidence, the analysis of hospital admissions could be repeated with a longer cohort interval. When e.g. the cohort of total hip arthroplasties of 1995 could be evaluated, the difference in incidence could be established regarding the 1991 cohort.

- The mechanical aspects of the femur with a hip prosthesis in situ should be subject of research. Not much is known about the fracture risk and patterns of these femora. By learning more about these femoral characteristics, preventive measures could be taken in specific patient groups.
Reference List


Summary
Summary
Postoperative periprosthetic femoral fracture is a severe complication of total hip arthroplasty (THA). It is likely that periprosthetic femoral fractures (PPF) will become more common in the future. These PPF usually have a large impact on the general health of a patient. Frequently a large operation is needed to treat these fractures. Especially compromised geriatric patients suffer from the operation and its complications. This thesis will address the magnitude of the problem, the perception of the surgeon with this problem and presents the need for less invasive alternatives for the compromised geriatric patient. Little is known about the extension of the PPF problem in The Netherlands. To document the problem of PPF in The Netherlands and to evaluate the new form of less invasive periprosthetic fracture stabilisation in the elderly, several hypotheses were developed.

An overview of PPF in historic perspective and treatment options to date are described in Chapter 2. In literature, these PPF of the femur are reported since 1964. Several patient series have been evaluated to improve understanding and give treatment guidelines. The first reports were mainly descriptive, later studies benefited from nationwide databases and clinical records that lead to the design of clear treatment protocols and algorithms. An important subject in all these studies are the complications associated with the treatment. Frequently high complication rates are reported. The use of more standardised treatment algorithms should facilitate research and improve patient treatment.

In Chapter 3 the extension of the PPF problem is addressed. The incidence of periprosthetic femoral fractures is incidentally reported in literature and more often estimated from hospital figures. Monitoring the incidence is important regarding treatment strategies, research and health costs. The purpose of this study was to determine the incidence of PPF in The Netherlands. Hospital admission data from the Prismatic Institution register, Utrecht, The Netherlands, were used to determine total hip arthroplasty patients. All data from patients who underwent total hip arthroplasty (THA) in 1991 and 1992 were collected and two cohorts were defined. All re-admissions in the following ten registration years were obtained and analysed. Acute readmissions for a suspected periprosthetic fracture were counted and analysed. In 1991 a total of 13,086 THA procedures were performed and in the next 10 years 106 (0.81%) periprosthetic fractures were noted from this cohort. Mean age at time of fracture was 76.1 years. Mean length of hospital stay was 30.8 days. 14,652 THA's were recorded in 1992. 124 (0.86%) patients were treated in the next 10 years for PPF. Mean age at fracture was 74.9 years. Mean overall time from initial operation to fracture development was 52.5 months. The fractures were distributed among 51-53 hospitals in The Netherlands. The incidence of PPF of a cohort of THA patients lies between 0.81% and 0.85%. These figures are the first reported in The Netherlands derived from a nationwide register. The numbers are
consistent with the scarce international reports concerning the incidence of these fractures. The analysis of the extension of the PPF problem would be facilitated if a good implant registration system is operational.

To document the applied treatment modalities and the amount of cases per hospitals in The Netherlands a questionnaire was send to 88 Dutch orthopaedic departments concerning periprosthetic fractures in 2006. The results of this survey are presented in Chapter 4. The response rate was 76%. The majority of the questioned units treated 1-5 cases a year, most of them by performing an operative procedure. Direct ambulation was allowed by 94% of the respondents in patients treated with osteosynthesis. Opinions differ about the optimal choice of treatment. 58% of the respondents considered a PPF a major health risk. Therefore these fractures deserve a thorough evaluation considering the high numbers of complications and mortality. Again, the importance of a nationwide implant register for research, quality control and improvement of treatment is emphasised.

To determine the clinical outcomes of PPF treatment in to large hospitals in the north of The Netherlands an observational study is presented in Chapter 5. The medical records of patients treated for a periprosthetic fracture between 1993 and 2006 were obtained. Radiographic evaluation was performed according to the Vancouver classification. Patients were contacted to obtain an Oxford Hip Score to assess their functional performance. For 71 patients with 71 fractures, medical records and radiographs were available. Mean age at time of fracture was 73.4 years (38-95). The mean time between primary operation and fracture was 6.3 years. Of these 71 fractures 44 occurred in patients with primary hip arthroplasty (62%) and 27 fractures developed in patients with revision implants (38%). Of this total number of patients, 34 patients (48%) suffered from a complication, leading to a re-operation in 22 cases (33%). The most frequent indication for re-operation was re-fracture or implant failure. Noteworthy Vancouver type C fractures lead to re-operations in 52% of the cases (11 of 20). At final follow-up 36 patients (51%) were able to complete an Oxford Hip Score after a mean period of 64.9 months (16-157). The other patients were tracked and confirmed lost to follow up (death 45%, mentally impaired 4%). Mean Oxford score was 27.8 (12-57) and significantly higher in patients suffering from a complication (p=0.02) and in patients with a fracture after revision surgery (p=0.02). As is commonly reported in literature, the treatment of periprosthetic femoral fractures has a high complication rate and number of re-operations. The unusually high complication rate in Vancouver type C fractures makes it important to critically analyse the osteosynthesis and consolidation in future research. Overall long term clinical results are compromised by the event of complications, a finding that is supported by the low functional performance scores that were found.
The study in *Chapter 6* consists of a biomechanical analysis of the stability of the Bridging nail concept. The retrograde intramedullary femoral nail designed to stabilise periprosthetic femoral fractures. It offers a minimal invasive surgical approach in combination with early mobilisation. The goal of this study was to evaluate the osteosynthesis under full weight bearing conditions. Three groups of five composite fibreglass femora, were prepared with a cemented hip stem. Group 1 underwent cyclic axial loading with 1500 N during 150,000 cycles. After completion, linear loading to failure was conducted. Group 2 and 3 were submitted to linear increased torsional loading with and without an axial load, respectively. Failure was defined as rotational movement of the connection (slippage). In the axial cyclic loading configuration one specimen failed after 122,000. Four specimens passed 150,000 cycles and failed after linear increasing axial loading of 1,940-2,600 N (mean 2,408 N ± 313 SD). Slippage was first detected at a torque varying between 2.5 and 8.2 Nm (mean 5.1 Nm ± 2.1 SD) in Group 2 and between 10.0 and 15.4 Nm (mean 13.0 Nm ± 2.3 SD) in Group 3. The Bridging nail offers a stable connection with the stem of a hip arthroplasty which can resist high repetitive loads, representative for direct full axial weight bearing. The biomechanical results support the clinical experience of a stable osteosynthesis enabling early postoperative mobilisation.

The clinical results of the first series of patient treated with the Bridging nail concept are presented in *Chapter 7*. Eighteen patients (4♂, 14♀) were treated with this retrograde nail between 1995 and 2003. The mean age was 81.4 years (range 61-96) with a mean follow-up of 21 months (range 4-61 months). Eight patients suffered from severe co-morbidity. Mean surgical time was 91 min. Fourteen patients regained their preoperative functional level. Six patients died within the first post-operative year of natural causes. Their knee- and hip-function were reasonable considering the age group and co-morbidity. One revision was required and one patient had a protruding nail. In all patients radiological union of the fracture was seen between 4 and 12 months after surgery. Retrograde Bridging nailing of the periprosthetic fractured femur is a therapeutic option in compromised geriatric or low demanding patients and can serve as a definitive implant.

Due to the success of the Bridging nail in PPF the problem of fractures around the intramedullary component of a trochanteric nail was addressed in *Chapter 8*. These are rare complications but a large threat to the geriatric patient. Standard therapy consists of removal and re-insertion of a longer nail or the use of extramedullar implants. A less invasive method is the use of a retrograde nail that clamps the distal end of the pre-existent intramedullary nail. This eliminates the removal of the hip screw and exposure of the trochanteric region. Four patients (mean age 86.8 years), all female, were treated with the Bridging nail. The mean operative time was 75 minutes. At follow-up (mean 23.5 months) all patients regained preoperative functional level. The fractures showed consolidation in all cases. In geriatric patients,
Summary

The retrograde Bridging nail is a therapeutic option in treatment of fractures around an intramedullary nail in the proximal femur.

The retrograde nail is in close contact with the hip implant. The use of different metals can cause galvanic effects and by this corrosion may occur. Corrosion can lead to foreign body reactions. Therefore, Chapter 9 handles on the possible side effect of corrosion when the Bridging nail is used in a femur with a pre-existent implant. A retrieved femur with a three year old osteosynthesis (consisting of a standard adapted AO femoral nail and a Muller straight hip stem) of a 76 year old female was prepared for histological analysis. The goal of the study was to evaluate foreign body reactions at the metal-metal interface, osteolysis and periprosthetic fracture healing. At five levels specimens were taken for light microscopy. Few macrophages were present with engulfed wear particles. None of the sections showed intense periosteal reaction or aggressive osteoclastic resorption. The fracture showed normal callus formation. Although systemic effects could not be evaluated in this study, the femoral osteosynthesis with a retrograde nail with a bridged junction of the hip stem can serve as a long-term implant without severe local adverse effects, when primarily a stable construction is achieved.

Finally in Chapter 10 a critical evaluation of the research conclusions and recommendations for future research are given.
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Postoperatieve periprothetische fractures van het femur vormen een groot probleem na totale heup prothesechirurgie (THP). Daarnaast is de verwachting dat het aantal van dit type fractures zal toenemen. Deze periprothetische fractures (PPF) hebben in het algemeen grote impact op de gezondheid van een individu. Regelmatig is een grote operatieve procedure aangewezen. Met name hoogbejaarde, gecompromitteerde patiënten hebben veel te lijden onder deze operatie met zijn kans op complicaties. Dit proefschrift beschrijft de actuele omvang van het probleem, de perceptie van de behandelaar ten opzichte van het probleem en bevat een wetenschappelijke onderbouwing van een nieuwe minder invasieve methode om deze fractures te behandelen bij de geriatrische patiënt. Slechts weinig gegevens zijn beschikbaar ten aanzien van het vóórkomen van PPF in Nederland. Een aantal hypothesen werd opgesteld om het probleem in kaart te brengen en om de nieuwe operatieve behandelmethode te evalueren.

Een overzicht van PPF in historisch perspectief, alsmede een overzicht van actuele behandelmethoeden wordt gegeven in hoofdstuk 2. In de literatuur wordt sinds 1964 melding gemaakt van PPF. Verschillende series van behandelde patiënten zijn geanalyseerd en beschreven. Hierdoor zijn inzichten verkregen voor de behandeling. De eerste publicaties zijn met name beschrijvend, latere studies zijn gebaseerd op landelijke databases, welke hebben geleid tot het opstellen van behandel algoritmen. Een belangrijk onderwerp in deze studies is het frequent optreden van complicaties bij de behandeling. Door gebruik te maken van geadviseerde gestandaardiseerde behandelstrategieën zou het onderzoek vergemakkelijkt kunnen worden en zou dit ten goede komen aan de behandeling van de patiënt.

In hoofdstuk 3 wordt de omvang van het probleem beschreven. De incidentie van PPF is incidenteel weergegeven in de literatuur en dan vaak geschat vanuit ziekenhuis registratie gegevens. Het vaststellen van het vóórkomen van PPF is van belang in verband met de kosten van behandeling en het uitvoeren van onderzoek naar dit probleem. Het doel van de studie in dit hoofdstuk was om een schatting te maken van de incidentie van PPF in Nederland. Ziekenhuis opnamegegevens verkregen via Prisman, Utrecht, Nederland, werden gebruikt om een het totale aantal THP ingrepen vast te stellen in 1991 en 1992. Deze twee cohorten werden de navolgende tien jaar geanalyseerd ten aanzien van heropnamen. Acute heropnamen voor een vermoedelijke periprothetische fractuur werden geteld en verder geanalyseerd. In 1991 werden 13.086 totale heup prothesen geplaatst. In de 10 volgende jaren werden 106 (0,81%) periprothetische fractures geconstateerd. Gemiddelde leeftijd ten tijde van de fractuur was 76,1 jaar. De gemiddelde opnameduur was 30,8 dagen. In 1992 werden 14.652 totale heup operaties verricht. 124 (0,86%) patiënten werden in de navolgende 10
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jaar heropgenomen in verband met een periprothetische fractuur. De gemiddelde leeftijd was ten tijde van de fractuur 74,9 jaar. Het interval tussen initiële operatie en fractuur was gemiddeld 52.5 maanden. De fracturen waren verdeeld over 51-53 ziekenhuizen in Nederland. In deze cohorten ontwikkelt 0,81-0,85% van de patiënten een periprothetische fractuur binnen 10 jaar na de THP. Deze gegevens zijn nog niet eerder in Nederland vastgesteld. De aantallen en gemiddelden zijn in overeenstemming met internationale publicaties. Een goede operationele implantaatregistratie zou de analyse PPF ten goede komen.

Voor het in kaart brengen van de behandelmethoden en de hoeveelheid fracturen per ziekenhuis werd een enquête verzonden naar 88 orthopedische vakgroepen in Nederland met betrekking tot PPF in 2006. Resultaten zijn beschreven in hoofdstuk 4. De respons bedroeg 76%. De meerderheid van de vakgroepen behandelden 1-5 PPF per jaar, meestal operatief. Directe postoperatieve mobilisatie van de patiënt was toegestaan door 94% van de respondenten bij patiënten behandeld met een osteosynthese. De meningen liepen uiteen met betrekking tot de optimale behandeling. 58% van de respondenten beschouwt de PPF als een groot gezondheidsprobleem in Nederland. Dit benadrukt de noodzaak voor een goede (wetenschappelijke) evaluatie van periprothetische fracturen, zeker gezien de hoge morbiditeit en mortaliteit. Het belang van een goed functionerende implantaatregistratie voor onderzoek en verbetering van behandelmethoden kan niet genoeg worden benadrukt.

De klinische uitkomsten van behandelde PPF in twee grote centra in Noord Nederland worden beschreven in hoofdstuk 5. Medische gegevens van patiënten met PPF tussen 1993 en 2006 werden verzameld. Röntgenfoto’s werden beoordeeld volgens de Vancouver classificatie. De patiënten zijn benaderd om een Oxford Heup Score te bepalen. Voor 71 patiënten met 71 periprothetische fracturen was medische documentatie voorhanden. De gemiddelde leeftijd bij fractuur was 73,4 jaar. De leeftijd van het implantaat bij fractuur bedroeg gemiddeld 6,3 jaar. 44 fracturen traden op na primaire THP (62%) en 27 fracturen na revisie procedures (38%). 34 patiënten (48%) kregen een complicatie, van wie 22 een re-operatie hebben ondergaan (33%). De meest voorkomende oorzaak van re-operatie was een re-fractuur of implantaat falen. Vancouver C fracturen waren aanleiding tot re-operatie in 52% van de gevallen (11 van 20). 36 patiënten (51%) waren in staat een Oxford Heup Score af te geven gemiddeld 64,9 maanden (16-157) na operatie. De overigen waren overleden (45%) of mentaal gecompromiteerd (4%). De gemiddelde Oxford score was 27,8 (12-57) en significant hoger bij patiënten met die een complicatie kregen (p=0,02) en bij patiënten met een periprothetische fractuur na revisie procedure (p=0,02). Conform publicaties in de internationale literatuur gaat de behandeling van PPF gepaard met een hoog complicatie percentage en aantal re-operaties. Het hoge aantal complicaties bij patiënten met een Vancouver C fractuur maakt het belangrijk
de osteosynthese en fractuurgenezing bij dit type fracturen kritisch te analyseren. Het optreden van een complicatie gaat gepaard met een slechter functioneren op de lange termijn.

Het onderzoek in hoofdstuk 6 bestaat uit een biomechanische analyse van de stabiliteit van het Bridging nail concept. Een vanuit de knie ingebrachte mergpen werd ontwikkeld om periprothetische fracturen te behandelen. De overlapping van de heupsteel door een holle pen biedt, door klemming, een rigide fixatie. Naast een minder invasieve operatie biedt het concept een vroege postoperatieve mobilisatie van de patiënt. Het doel van deze studie is het bepalen van stabiliteit van de retrograde pen-osteosynthese bij belasten. Drie groepen van vijf composiet modelfemora werden voorzien van een gecementeerde heupsteel. Een schuine osteotomie distaal van de steel simuleert een periprothetische fractuur. Groep 1 onderging een axiale belasting van 1500 Newton (N) gedurende 150.000 cycli. Na voltooiing werden de specimens onderworpen aan een faaltest. Groep 2 en 3 werden onderworpen aan een oplopende torsiebelasting respectievelijk zonder en met gelijktijdige axiale belasting. Falen werd gedefinieerd als een rotatoire beweging in de connectie. In groep 1 faalde een specimen na 122.000 cycli. Vier femora 150.000 cycli van 1500 N en faalden na lineaire belasting van 1940 N tot 2600 N (gemiddeld 2408 N). Torsiebelasting liet in groep 2 tussen 2,5 en 8,2 Nm (gemiddeld 5,1 Nm) een verlies aan rotatoire weerstand zien. In groep 3 werd dit falen gezien tussen 10,0 en 15,4 Nm (gemiddeld 13,0 Nm) Het Bridging nail concept leverde een stabiele connectie tussen heupsteel en mergpen, welke hoge belasting kan ondergaan, representatief voor volledige belasting. De biomechanische experimenten ondersteunen de klinische ervaring van een stabiele osteosynthese met de mogelijkheid van vroeg postoperatief mobiliseren.

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In hoofdstuk 8 wordt beschreven hoe de positieve ervaring met het Bridging nail concept bij heupprothesen leidde tot de toepassing van het concept bij fracturen rond implantaten van het proximale femur. Deze fracturen komen niet zeer frequent voor, maar zijn een grote bedreiging voor de algemene gezondheid van een patiënt. De standaard therapie bestaat uit het verwijderen van het materiaal en het plaatsen van een langere pen of een extramedullair implantaat. Een minder invasieve methode is het vanuit de knie inbrengen van een een mergpen die vervolgens vastklemt aan het bovenliggende implantaat. Dit maakt het een benadering van de heupregio en het verwijderen van de schroef in de femurhals overbodig. Vier patiënten (gemiddelde leeftijd 86,8 jaar), allen vrouw, werden behandeld volgens het Bridging nail concept. Gemiddelde operatietijd bedroeg 75 minuten. Ten tijde van follow-up (gemiddeld 23,5 maanden) waren alle patiënten op hun oorspronkelijke functioneringsniveau. Alle fracturen waren geconsolideerd. In geriatrische patiënten is het retrograde Bridging nail concept een therapeutische optie bij de behandeling van fracturen onder een intramedullair implantaat in het proximale femur.

De retrograde pen is in nauw contact met het heupimplantaat. Het gebruik van verschillende metalen kan galvanische effecten geven en corrosie veroorzaken. Corrosie kan vreemd lichaam reacties opwekken. In hoofdstuk 9 wordt ingegaan op het mogelijke effect van corrosie indien de mergpen in een preëxistente heupsteel. Een verkregen kadaverfemur met een drie jaar bestaande osteosynthese (een aangepaste AO mergpen en een Muller straight stem heupsteel) van een 76 jarige vrouw werd geprepareerd voor histologische analyse. Het doel van dit onderzoek was de evaluatie van osteolyse, fractuurgenezing en vreemd lichaam reacties ter plaatse van de metal-metal verbinding. Van vijf verschillende niveaus werden preparaten vervaardigd voor licht microscopie. Enkele macrofagen waren aanwezig met metaalpartikels. Geen enkel preparaat liet een intense periostale reactie zien of agressieve osteoclastische resorptie. De fractuur vertoonde normaal callus weefsel. Systemische effecten in deze studie niet konden worden geëvalueerd. De retrograde pen volgens het Bridging nail concept, met een verkregen stabiele verbinding, zou kunnen dienen als implantaat voor de lange termijn zonder ernstige locale effecten.

Ten slotte wordt in hoofdstuk 10 een kritische evaluatie van de onderzoeksbevindingen gegeven en daarnaast aanbevelingen voor verder onderzoek.
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Dankwoord
Dankwoord

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Curriculum vitae

Rutger Zuurmond was born on May 11, 1976 in Zaandam. He attended the VWO at the Blaise Pascal College in Zaandam until graduation in 1994. Medicine was studied at the Vrije Universiteit in Amsterdam. After graduation in 2000 he started his medical career as a registrar orthopaedic surgery in the Maasland Ziekenhuis Sittard (Dr. A.D. Verburg). Basic training in surgery was performed at the Twenteborg Ziekenhuis Almelo (Dr. J.G. van Baal). Training in orthopaedic surgery at the Martini Ziekenhuis Groningen (Dr. J.J.A.M. van Raay) and the University Medical Centre Groningen (Prof. Dr. S.K. Bulstra) was completed at the Martini Hospital in 2008. He started as an orthopaedic surgeon in the Isala Klinieken Zwolle. In 2008 he moves to Edinburgh, Scotland for a clinical trauma fellowship at The Royal Infirmary. He will return to Zwolle to practice orthopaedic surgery and trauma. Rutger is married to Karen Tromp and has two daughters, Laura and Eveline.
Publications


Presentations

2007 The Bridging nail. Annual meeting Dutch Trauma Society, Kaatsheuvel
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