Entry Point Related Outcome in Antegrade Femoral Nailing

experimental and clinical studies

C.M.S. Ansari Moein

Entry Point Related Outcome in Antegrade Femoral Nailing experimental and clinical studies

C.M.S. Ansari Moein

ENTRY POINT RELATED OUTCOME IN ANTEGRADE FEMORAL NAILING
Experimental and clinical studies
C.M.S. Ansari Moein

The Robert Mathys Foundation, Bettlach, Switzerland and the AO Foundation, Davos, Switzerland financially supported the studies presented in this thesis.

Kind contribution for the publication of this thesis by:

Erasmus Medical Centre Dept. of Surgery
Trauma Research Unit Erasmus MC (TRUE)
Parnassia Academy
ABN AMRO Bank
PsyQ
Maatschap Plastische Chirurgie Midden Brabant
THP Financial Guidance
Post Notariaat

Cover illustration by Rob Veen
Printing and lay-out by Optima Grafische Communicatie, Rotterdam, The Netherlands

ISBN 978-94-6169-867-4

Entry Point Related Outcome in Antegrade Femoral Nailing experimental and clinical studies

Entreeplaats gerelateerde uitkomst van antegrade mergpen ostheosynthese bij femurfracturen experimentele en klinische studies

Proefschrift

ter verkrijging van de graad van doctor
aan de Erasmus Universiteit Rotterdam
op gezag van de rector magnificus
Prof. Dr. H.A.P. Pols
en volgens besluit van het College voor Promoties

De openbare verdediging zal plaatsvinden op
vrijdag 20 mei 2016 om 13.30 uur

door

Chloé Mahsima Ansari Moein
geboren te Tehran, Iran

Erasmus University Rotterdam

PROMOTIECOMMISSIE

promotoren:
Prof. dr. M.H.J. Verhofstad
Prof. dr. H.J. Ten Duis
overige leden:
Prof. dr. H.J. Stam
Prof. dr. J.A.N. Verhaar
Prof. dr. L.P.H. Leenen

All human beings are members of one frame,
Since all, at first, from the same essence came.
When time afflicts a limb with pain
The other limbs at rest cannot remain.

Sa'adi Shirazi. *Bani Adam, Gulistan* (The Rose Garden) 1258 A.D. Persia

To Matzi and Joun

CONTENTS

INTRODUCTION

Chapter 1

Historical perspective and study objectives

Chapter 2

Trochanteric fossa or piriform fossa of the femur: time for standardised terminology?

1 Historical perspective and study objectives

HISTORICAL PERSPECTIVE

Intramedullary nailing is currently a well established surgical technique to treat femoral fractures. However, its development from anecdotal reports to routine implantation is believed to span at least four centuries.

From the earliest recorded examples in 16th century Mexico to the current procedures of today, there has been an evolution of design, materials, and basic science principles. This has resulted in a well accepted and successful technique for the past several decades. Bernardino de Sahagun, a 16th century anthropologist who traveled to Mexico, recorded the first account of the use of an intramedullary device[1]. De Sahagun witnessed Aztec physicians placing wooden sticks into the medullary canals of patients with long bone nonunions. Further anecdotal reports colour the next centuries to come.

By the mid 1800s through the first decade of the 1900s the first experimental intramedullary fixations of nonunions were performed in Europe. Most of this work appears to revolve around the use of ivory pegs. It had been observed that ivory pegs would reabsorb in the human body compared to metallic implants, which became encapsulated with fibrous material. Among the pioneers were Dieffenbach (Berlin, 1846), von Langenbeck (Berlin, 1850) and Bircher (Bern, 1887) who was the first to recommend the use of ivory pins for stabilisation of fresh fractures (Figure 1)[2-4].

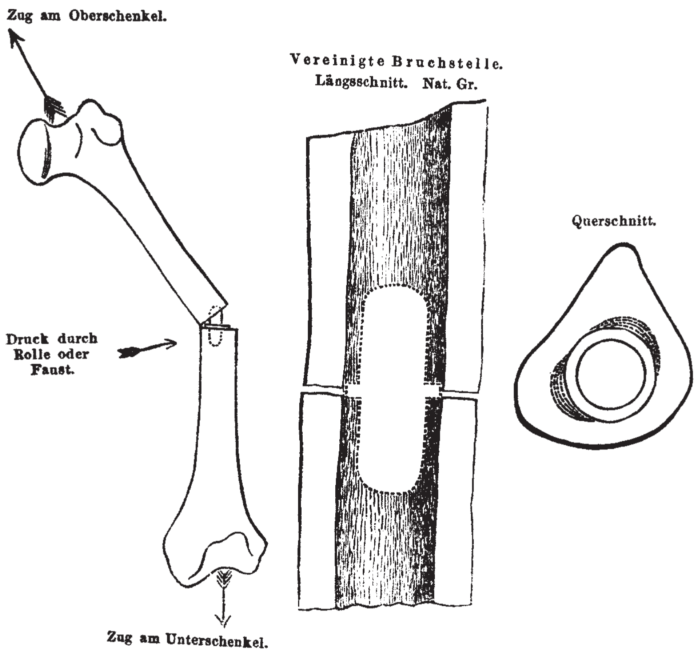

Figure 1. Bircher's method of intramedullary ivory pegs for diaphyseal fractures. From H. Bircher, "Eine neue Methode unmittelbare Retention bei Fracturen der Rohrenkrochen." *Arch Klin Chir* 34(1893):410-22.

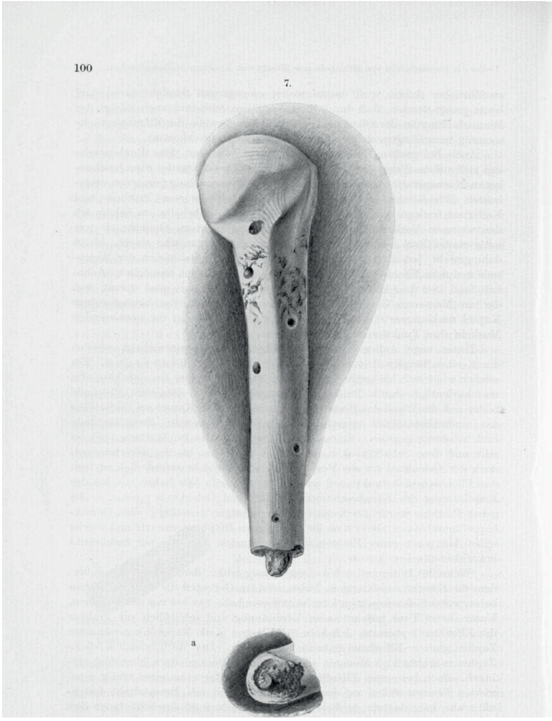

Figure 2. König's ivory peg illustrated in a humerus. From F. König "Über die Implantation von Elfenbein zum Ersatz von Knochen und Gelenken. Nach exerimentellen und klinischen Beobachtungen". *Beitr Klin Chir* 1913;85:91-114.

König employed the ivory pin technique for fresh fractures and presented during the first and second decades of 1900 multiple experiments and cases (Figure 2)[5,6]. While ivory seemed to be the material of choice reported in the German literature, Hoglund from the United States reported the use of autogeneous bone as an intramedullary implant in 1917[7]. He described a technique in which a span of the cortex was cut out and then passed up the medullary cavity across the fracture site.

The routinazation of these innovative techniques was thwarted by lack of aseptic conditions and unsuitable materials[3]. Ground-breaking biological developments would have to occur before surgeons could concentrate on the biomechanics of a stable fixation. The recognition of antiseptics and anesthesia began in the mid 1800s and the so-called "anti-septic age" began when Lister, professor of surgery at the University of Glasgow, found an effective agent against microbes (phenol) and published his findings in the *Lancet* in 1873[7,8]. The advent of aseptic conditions and anesthesia (ether and chloroform) not only greatly enhanced the chances for succesful surgery, but also provided impetus for the development of new materials and techniques. Nicolaysen of Norway who is often referred to as the 'father of intramedullary nailing' was the first to

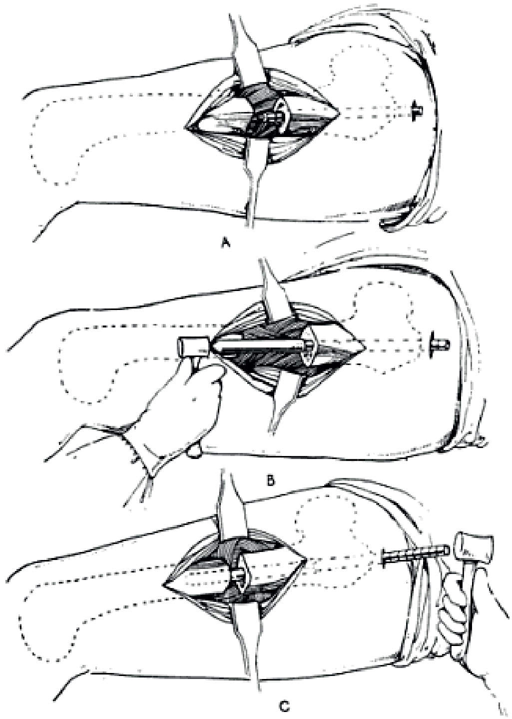

Figure 3. Hey-Grove's method of open retrograde intramedullary nailing of fractures of the shaft of the femur. From: Watson-Jones. "Medullary Nailing of fractures after 50 years." *J Bone Joint Surg* 32B 1950

elaborately outline the biomechanical principles, emphasizing that the length of the intramedullary implant be maximised to provide the best results[9].

During World War I, Hey Groves from England reported the use of metallic rods for the treatment of gunshot wounds[2,10,11]. These rods were passed retrograde into the medullar cavity through an incision made over the fracture site (inside-out technique; Figure 3).

This technique appeared to have a high infection rate and was not universally accepted. It was not until Smith-Petersen's 1931 report of the successful use of stainless steel nails for the treatment of femoral neck fractures, that the application of metallic intramedullary implants began to expand rapidly (Figure 4)[12].

In the United States, Rush and Rush described in 1939 the use of metallic Steinman pins placed in the medullary canal to treat fractures of the proximal ulna and proximal femur (Figure 5)[13].

Origin and evolution of Küntscher nailing

Gerhard Küntscher was born in Germany in 1900. His early interest in intramedullary devices resulted from his work with the Smith-Petersen nail in the treatment of femoral

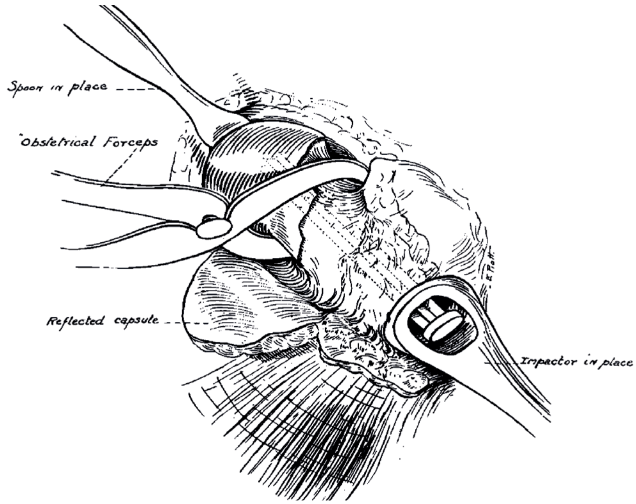

Figure 4. Smith-Peterson's 3 flanged stainless steel nail. Diagram shows the " method of impacting the fracture". From: Smith-Peterson "Intracapsular fractures of the neck of the femur. Treatment by internal fixation." *Arch Surg* 1931;23:713-59.

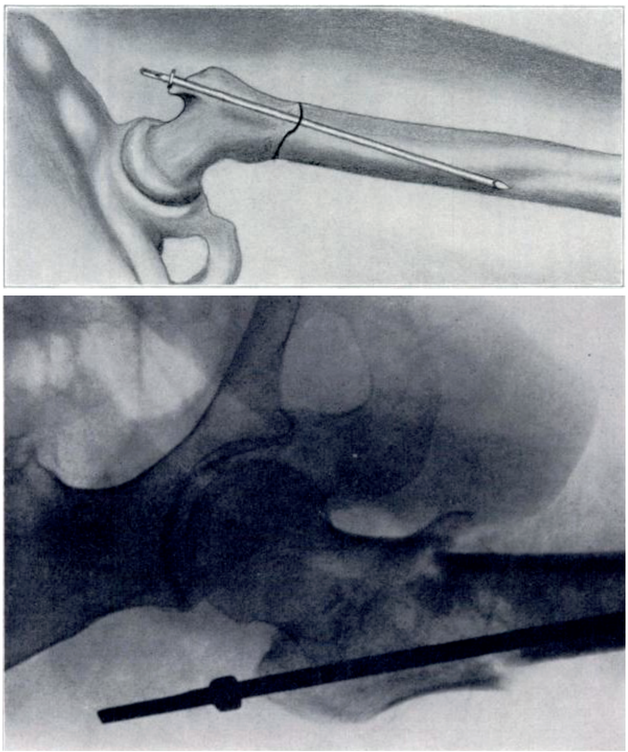

Figure 5. Rush and Rush's intramedullary fixation: open reduced subtrochanteric fracture and fixed by author's pin. Diagram and case report. From LV Rush and HL Rush "A technique for longitudinal pin fixation of certain fractures of the ulna and of the femur." *J Bone Joint Surg* 1939;21:619-26.

Figure 6a. Gerhard Küntscher, 1900-1972.

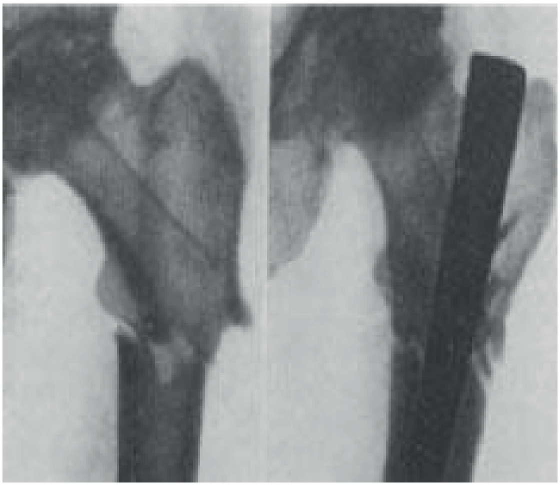

Figure 6b. Küntscher nail the greater trochanter tip

neck fractures. Up untill then the nailing technique had been virtually unchanged, regardless of the materials used, i.e., insertion of the implant directly into the medullary cavity after exposing the fracture; today this would be referred to as the open technique. Küntscher believed the same basic science principles of the Smith-Petersen nail would be applicable in the treatment of diaphyseal fractures; inserting the nail distant from the fracture site and thus avoiding disturbance of the zone of the injury[14]. During development of his "marrow nail," he conducted cadaveric and animal studies. His original intramedullary nail was a V-shaped stainless steel nail that was inserted in an antegrade way (Figure 6). Intraoperative reductions were achieved with the use of multiple slings; while head worn fluoroscopy was used for bony visualization. Küntscher believed that proper insertion of his nail would allow for immediate functional mobilization of the patient.

Küntscher's early work was not well received in Germany, and early in World War II he was sent to the northern Finnish front, where he collaborated with Finnish surgeons to refine the technique[15]. American soldiers who had returned from Europe surprised the docters in the United States finding the soldiers were carrying a nail lenghtwise in their femoral canal[15,16]. By the late 1940s, Küntscher had begun to abandon use of the V-shaped nail design in favor of another Küntscher design, the cloverleaf nail. However, nail designs based on Küntscher's ideas were slotted and semi-rigid at the time and had suboptimal weight bearing and fracture-healing results on their behalf.

Furthermore, many surgeons abandoned during the 1940s and 1950s early radiology techniques such as head fluoroscopy (Figure 7), because of the side effects for both surgeon and patient. This development forced the surgeons to adopt an open technique again.

After 1950 Müller from Switzerland popularized the use of compression plates to achieve internal fixation. Plate fixation was already a known technique due to extensive work by masters as Lambotte (1913, Belgium) and his student Danis (1949, Belgium)[17,18]. Having been a student of Danis, Müller founded with his Swiss colleagues the Arbeitsgemeinschaft für Osteosynthesefragen or the Association for the Study of Internal Fixation (AO/ASIF, Switserland). They presented their basic principles on anatomical reduction and rigid internal fixation in their first book in 1963[19]. Enthusiasm for compression plating of long bone fractures exploded during that period.

However, the exuberance that accompanied the introduction of compression plating quickly diminished in the 1970s for multiple reasons e.g. high infection rates, devitalized bone and extensive soft tissue damage. Simultaneously, the improvement of intra-operative radiological image intensification in the 1960s and 1970s allowed the surgeons to readopt closed nailing techniques with much lower risk. Thus, a renewed interest in refining closed nailing techniques appeared. New nails were designed which were to be rigid and interlocking, improving fracture and nail stability and early weight bearing. Kempf and Grosse (1976) enhanced the interlocking nail further[20]. As there was certain progress as far as nail design and materials are concerned during the 1980s and

Figure 7. Surgeons used head fluoroscopy for image intensifier with health hazards for both surgeon and patient. From: "Beth A. Schueler PhD. 2000. From the Department of Diagnostic Radiology, Mayo Clinic. Journal of continuing medical education in radiology."

1990s, the major advancement came with the expanding indications for reamed and unreamed intramedullary nailing[21-23].

Concerning the entry point of closed intramedullary nailing of the femur (proximal and midshaft fractures), Küntscher recommended a nail entry point at the laterally located greater trochanter tip in order to protect the neurovascular structures of the hip region to be safe (Figure 6b).

Until the 1990s, little attention was paid to the entry point related results of intramedullary nailing in development of the technique. For the new rigid nails that were developed at the time, focus was on maximum load bearing and fracture stability properties. Therefore the designed nails were straight in line with the medullary canal and consequently also had to have their entry point in line with the femoral canal, at the trochanteric fossa, also known as the piriform fossa, e.g. the Russell-Taylor Reconstruction Nail (Smith-Nephew, Memphis, TN, USA) and the AO Unreamed Femoral Nail (Synthes, Bettlach, Switzerland) (Figure 8)[24,25].

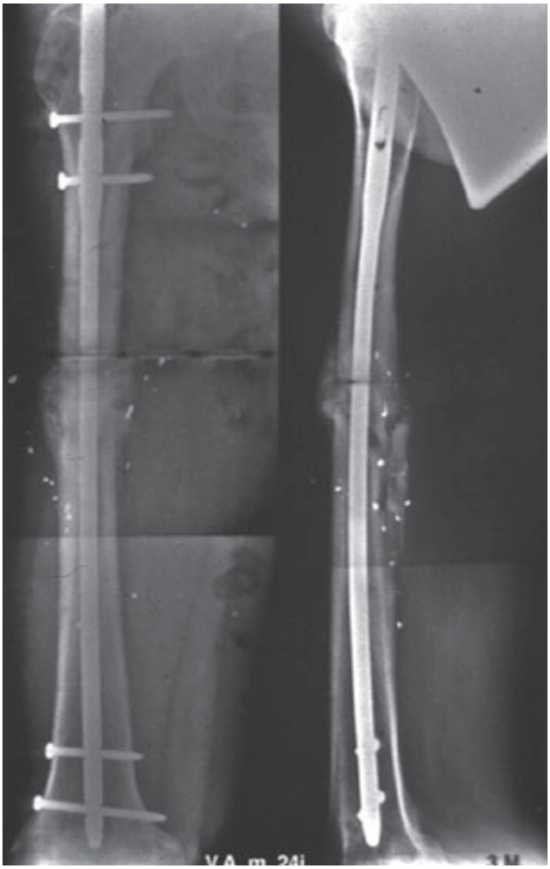

Figure 8. Standard Unreamed Femoral Nail (UFN) procedure through the trochanteric fossa (piriform fossa).

Intramedullary nailing through the trochanteric fossa has been the state of the art procedure in management of proximal and midshaft femoral fractures since the 1980s[26,27]. However, functional results with the procedure, have shown to be suboptimal in several clinical studies. For the patient this might result in residual pain and muscle weakness in the operated leg, sometimes severe enough to interfere with daily living or even result in limping with a discrete Duchenne limp. For the surgeon, nailing was quite a difficult procedure, with difficulties finding the trochanteric fossa and staying in line with the femoral canal, especially in obese patients[28-31]. Iatrogenic complications, though rare, have also been described: avascular necrosis of the femoral head (in adolescents), septic arthritis of the hip joint and intra-operative femoral neck fractures[32,33].

Currently, after several decades of experience with different rigid nail designs and their entry points, interest in refining closed nailing techniques is continuing. New rigid nail designs have been developed and produced, to meet both the requirement of full weight-bearing and fracture stability, as well as the needs for better functional postoperative results. These nails are on the market since the end of the 1990s and differ from the standard rigid nails in their lateral proximal bend in the frontal plane, which enables them to be entered in the femoral canal from laterally, at the greater trochanter tip. Current examples of such nail systems are the Proximal Femoral Nail Antirotation (PFNa, Synthes) and the Gamma Nail (Stryker, Kiel, Germany).

Most of the experience with new rigid bent nails is based on management of very proximal, peritrochanteric fractures, with promising results[34]. There is less experience with the new nail designs for femoral shaft fractures. Therefore, the rigid nail design with a proximal lateral bend has been subject for further development in order to be used for treatment of femoral shaft (subtrochanteric and midshaft) fractures as well.

STUDY OBJECTIVES

The main goal of this thesis was to evaluate the anatomical, mechanical and clinical differences of current rigid nailing systems with different entry points (piriformis fossa, trochanteric tip and lateral-to-trochanteric tip) and to find proof for the hypothesised principal and clinical benefits of an entry at or even lateral to the greater trochanter tip, concerning anatomical localization of the entry point in relation to soft tissue damage and postoperative functional outcome. Anatomical, mechanical and clinical implications were tested in experimental and clinical settings.

Chapter 2 aims to clarify the surgical and anatomical nomenclature of the different existing entry points around the hip region for antegrade intramedullary nailing.

Anatomical models

Chapter 3 deals with the soft tissue anatomy of the hip region with emphasis on surgical implications regarding choice of entry point. Anatomical dissections in fresh human femurs attempted to display the topographical relations between the hip soft tissues and two entry points, trochanteric fossa (piriform fossa) and tip of the greater trochanter. In **Chapter 4** iatrogenic damage to the soft tissues around the proximal femur during blind nailing through two different entry points is described in a cadaver study. Nailing procedures through the trochanteric fossa with an Unreamed Femoral Nail and through the greater trochanteric tip with an Antegrade Femoral Nail were performed in fresh human cadavers. Soft tissue injury was documented after the nailing procedures.

Mechanical model

The mechanical implications of eccentric entry points with congruent nail designs are dealt with in **Chapter 5**. The question in this chapter is whether using an eccentric entry point will increase surface cortical strains and the risk of iatrogenic fracture during the nailing procedure. As an attempt to answer this question, nailing was performed in fresh human cadaver femurs through three different entry points; the Cannulated Femoral Nail through the trochanteric fossa, the Antegrade Femoral Nail through the greater trochanter tip and a helical shaped nail (prototype Lateral Femoral Nail) through an entry point lateral to the greater trochanter tip. Intra-operative surface cortical strains and iatrogenic fractures were documented.

Clinical models

The clinical outcome in patients treated with an antegrade femoral nail is documented in Chapters 6 and 7. **Chapter 6** describes a retrospective study with in-depth measurements of functional outcome in patients with a subtrochanteric fracture who underwent nailing through the trochanteric fossa or the greater trochanter tip with the UFN and long PFN, respectively. **Chapter 7** describes the outcome of midshaft fracture management with comparison between nailing through the trochanteric fossa and the greater trochanter tip in a randomised controlled setting using the UFN and AFN, respectively.

Chapter 8 offers a general discussion and the conclusions of the above outlined studies.

The final chapter, **Chapter 9**, is a summary of the results and conclusions.

REFERENCES

1. Farill J. Orthopedics in Mexic. *J Bone Joint Surg. Am.* 1952;24-A-3:506-512.
2. Peltier LF. *Fractures: A History and Iconography of Their Treatment.* Norman Pub.; 1990.
3. Contzen H. Die Entwicklung der Marknagelung und des Verriegelungsnagels. *Aktuel Traumatol.* 1987;17:250-252.
4. Bircher H. Eine neue Methode unmittelbarer Retention bei Fracturen der Röhrenknochen: dem XV. *Congresse der Deutschen Gesellschaft für Chirurgie zu Berlin vorgelegt und auszugsweise am 4. Sitzungstage, 10. April 1886, mitgetheilt.* 1886.
5. König F. Über die Berechtigung frühzeitiger blutiger Eingiffe bei subcutanen Knochenbrüchen. *Langenbecks Arch Klin Chir.* 1905;76:725-777.
6. Payr E. Weitere Erfahrungen über die operative Mobilisierung anakylosierter Gelenke, mit Berücksichtigung des späteren Schicksals der Arthroplastik. *Deutsche Zeitschrift f. Chirurgie.* 1914;129(1): 341-463.
7. Hoglund E. New method of applying autogenous intramedullary bone transplants and making autogenous bone-screws. *Surg Gynecol Obstet.* 1917;24:243-246.
8. Hurwitz B, Dupree M. Why celebrate Joseph Lister? *The Lancet.* 2012;379(9820):e39-e40.
9. Nicolaysen J. Lidt on Diagnosen og Behandlungen av. Fr. colli femoris. *Nord Med Ark.* 1897;8:1.
10. Groves EWH. On the application of the principle of extension to comminuted fractures of the Long bone, with special reference to gunshot injuries. *Br J Surg.* 1914;2(7):429-443.
11. Groves EWH. *On Modern Methods of Treating Fractures.* Mac Donnell Press; 2010.
12. Smith-Petersen MN, Cave EF, Vangorder GW. Intracapsular fractures of the neck of the femur: Treatment by internal fixation. *Arch Surg.* 1931;23(5):715-759.
13. Rush LV, Rush HL. A technique for longitudinal pin fixation of certain fractures of the ulna and of the femur. *J Bone Joint Surg.* 1939;21(3):619-626.
14. Küntscher G. Marknagelung von Knochenbrucken. *Archiv Klin Chir.* 1940;200:443-455.
15. Rehnberg S. Treatment of fractures and pseudarthroses with marrow nailing. *Ann Chir Gynaec Fenn.* 1947;36:2.
16. Rush LV, Rush HL. Evolution of medullary fixation of fractures by the longitudinal pin. *Am J Surg.* 1949;78(3):324-333.
17. Lambotte A. *Chirurgie operatoire des fractures.* Masson; 1913.
18. Danis R. Théorie et Pratique de l'ostéosynthèse. Robert Danis. Paris, Masson et Cie, 1949. 1100 francs. *J Bone Joint Surg.* 1950;32(3):714-714.
19. Müller M, Allgöwer M, Willenegger H. *Technik der operativen Frakturbehandlung.* Berlin: Springer-Verlag; 1963.
20. Kempf I, A G. L'apport due verrouillage dans l'enclouage centro-medullaire des os longs. *Rev Chir Orthop Repar Appar Mot.* 1978;64:635-651.
21. Brumback RJ, Reilly JP, Poka A, Lakatos RP, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part I: Decision-making errors with interlocking fixation. *J Bone Joint Surg Am.* 1988;70(10):1441-1452.
22. Brumback RJ, Uwagie-Ero S, Lakatos RP, Poka A, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part II: Fracture-healing with static interlocking fixation. *J Bone Joint Surg Am.* 1988;70(10):1453-1462.
23. Brumback RJ, Ellison TS, Poka A, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part III: Long-term effects of static interlocking fixation. *J Bone Joint Surg Am.* 1992;74(1): 106-112.

24. Gibbons CL, Gregg-Smith SJ, Carrell TW, Murray DW, Simpson AH. Use of the Russell-Taylor reconstruction nail in femoral shaft fractures. *Injury.* 1995;26(6):389-392.
25. Stockenhuber N, Schweighofer F, Bratschitsch G, R. S. UFN-system. Eine methode der minimal-invasiven chirurgischen Versorgung von Oberschenkelschaftfrakturen. *Langenbecks Archiv fur Chirurgie.* 1996;381:267-274.
26. Winquist RA, Hansen ST, Jr., Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. 1984. *J Bone Joint Surg Am.* 2001;83-A(12):1912.
27. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg Br* 1988;70(2):206-210.
28. Bednar DA, Ali P. Intramedullary nailing of femoral shaft fractures: reoperation and return to work. *Can J Surg. J Can Chir.* 1993;36(5):464-466.
29. Benirschke SK, Melder I, Henley MB, *et al.* Closed interlocking nailing of femoral shaft fractures: assessment of technical complications and functional outcomes by comparison of a prospective database with retrospective review. *J Orthop Trauma.* 1993;7(2):118-122.
30. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br.* 1997;79(5):738-741.
31. Tucker MC, Schwappach JR, Leighton RK, Coupe K, Ricci WM. Results of femoral intramedullary nailing in patients who are obese versus those who are not obese: a prospective multicenter comparison study. *J Orthop Trauma.* 2007;21(8):523-529.
32. Astion DJ, Wilber JH, Scoles PV. Avascular necrosis of the capital femoral epiphysis after intramedullary nailing for a fracture of the femoral shaft. A case report. *J Bone Joint Surg Am.* 1995;77(7):1092-1094.
33. Simonian PT, Chapman JR, Selznick HS, Benirschke SK, Claudi BF, Swiontkowski MF. Iatrogenic fractures of the femoral neck during closed nailing of the femoral shaft. *J Bone Joint Surg Br.* 1994;76(2):293-296.
34. Simmermacher RK, Bosch AM, Van der Werken C. The AO/ASIF-proximal femoral nail (PFN): a new device for the treatment of unstable proximal femoral fractures. *Injury.* 1999;30(5):327-332.

2

Trochanteric fossa or piriform fossa of the femur: time for standardised terminology?

C.M.S. Ansari Moein, P.D. Gerrits and H.J. ten Duis

Injury. 2013;44(6):722-5

ABSTRACT

Piriform fossa, trochanteric fossa and greater trochanteric tip have each been described as entry points for antegrade femoral nailing. However, the terminology used for these entry points is confusing. The accuracy of the entry point nomenclature in published text and illustrations was recorded in this review study. The trochanteric fossa, a deep depression at the base of the femoral neck is indicated as 'piriform fossa' in the vast majority of the publications. Other publications indicate the insertion site of the tendon of the piriformis muscle on the greater trochanteric tip as 'piriform fossa'. As a result of recurrent terminology error and consistent reproductions of it, the recommended entry point in literature is confusing and seems to need standardisation. The piriform fossa does not appear to exist in the femoral region. The trochanteric fossa is the standard entry point which most surgeons recommend for facilitating a standard straight intramedullary nail, as is in line with the medullary canal. The greater trochanteric tip is the lateral entry point for intramedullary nails with a proximal lateral bend.

INTRODUCTION

Antegrade femoral nailing is currently the state of the art procedure for proximal and midshaft femoral fractures. An important step during nailing is localisation of the entry point.[1-6] Although the importance of the correct entry point is clear to any surgeon performing antegrade femoral nailing, the published data are confusing and the terminology of the different entry points is unclear. To date, five main anatomical landmarks have been mentioned as proximal entry points in literature: the tip of the greater trochanter, the piriform fossa, the trochanteric fossa, the digital fossa and the junction of the femoral neck and trochanter. The piriform fossa has been the most frequently recommended entry point for nailing of femoral shaft fractures.[1,7-11] This entry point has advantages because it is in line with the medullary canal and facilitates a straight nail. However, the term 'piriform fossa' seems to be a misnomer. Most authors indicate the 'piriform fossa' as the depression on the inner surface of the greater trochanter in line with the medullary canal, which is anatomically known as the 'trochanteric fossa'.[7-12] Other authors suggest that the 'piriform fossa' is located at the tip of the greater trochanter.[5,13] In this review the inconsistency in entry point nomenclature in antegrade nailing of femoral shaft fractures is studied with focus on the terms 'piriform fossa' and 'trochanteric fossa'.

MATERIALS AND METHODS

Articles in renowned journals and chapters in major medical books were selected on their suggested entry point in antegrade femoral nailing by reviewing their titles and abstracts. Additional references from the reference list of the selected articles were also reviewed. The review was limited to the English and German literature.

Inclusion criteria were published data including illustrations or drawings that referred to the entry point or data including clear anatomical description of the suggested entry point in their text. Data with no clear description of the anatomical landmarks or merely accompanied by pre-, intra-, or postoperative radiographs were excluded, as these were not accurate for defining the exact anatomical landmarks and entry points in the operation region. The type of fracture, the operation procedure and different nail designs were not taken into consideration, since these did not influence the terminology of the anatomical locations of the entry point.

The degree of accuracy and consistency in the published data were recorded.

RESULTS

We searched for the terms piriform fossa and trochanteric fossa in anatomical atlases and textbooks. 'Piriform fossa' is the English derivative of the Latin words Fossa Piriformis meaning 'pear shaped ditch' (fossa = ditch, canal, pit; Pyrum = pear, pear tree). The Nomina Anatomica, Gray's Anatomy and other anatomical atlases described the piriform fossa as a small peer shaped pit situated at both sides of the pharynx.[14-16] They did not describe a piriform fossa at the femur site.

As for the 'trochanteric fossa', the anatomical textbooks described this as a rough and deep depression at the junction of the medioposterior aspect of the greater trochanter and the neck, the exact location of the proximal end of the intramedullary curvature. The trochanteric fossa receives the tendon of the obturator externus.[14-16]

The greater trochanter surface provides attachment to most gluteal muscles: gluteus minimus to its rough anterior impression and gluteus medius to its lateral oblique strip. To the greater trochanter's upper border is attached the tendon of the piriformis muscle. To its medial surface, cranial to the trochanteric fossa, the common tendon of obturator internus and the gemelli are attached; at their attachments these tendons are often variably fused (Fig. 1).[14]

Twenty articles and surgical book chapters were found for further review meeting the inclusion criteria. Of these, 16 appointed the suggested entry point as 'piriform fossa', while their descriptions in text or illustration were consistent with the anatomical location of the 'trochanteric fossa' as described in the above mentioned anatomical textbooks.[1-4,6,8-12,17-21]

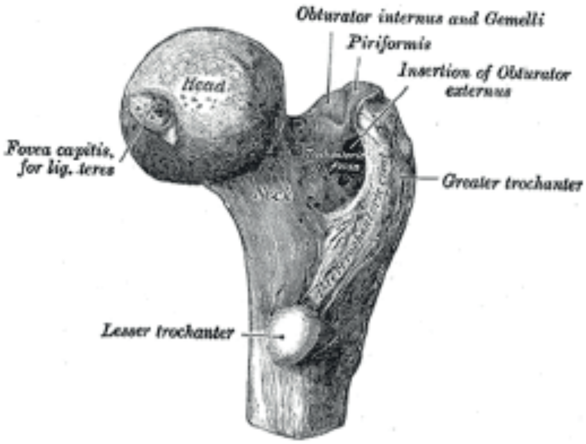

Figure 1. Upper extremity of right femur, seen from behind and above. (Gray's Anatomy, 1989). Insertion sites of the piriformis tendon and the obturator internus & gemelli tendons are shown at the medial border of the greater trochanter tip. Insertion site of the obturator externus tendon is shown at the trochanteric fossa.

One book chapter and two articles used the term 'trochanteric fossa' to describe the entry point in line with the femoral canal according to the anatomical landmark described in the anatomical atlases.[5,13,22,23] However, the two articles described also a 'piriform fossa' as a shallow depression on the tip of the greater trochanter, at the insertion site of the tendon of the piriformis muscle. Whittle[22] pointed out the 'trochanteric fossa' correctly in their illustration and text, but continued in the same chapter mentioning 'piriform fossa' as the entry point.

DISCUSSION

The femur is the longest and strongest bone in the human body. Its length is associated with striding gait, its strength with weight and muscular forces. Its surrounding muscles are thick and well vascularised and its blood supply is well protected; thus, an ideal bone for intramedullary nailing. The femoral shaft is straight in the frontal plane. In the saggital plane the bow of the femur is anterior and the proximal end of the curvature is situated more posterior. Numerous muscle attachments are located on or near the greater and lesser trochanters of the femur.[14-16]

Küntscher introduced intramedullary nailing through the trochanteric tip in the1940s to avoid risk of compromising the vascularisation of the femoral head and subsequent avascular necrosis and septic arthritis following intracapsular infection.[24-26] Intramedullary nailing was described earlier by Hey Groves in 1918, but with limited success due to inferior metal quality.[27] In order to enhance the nail through the trochanteric tip without friction, Küntscher's nail was slotted and semi-rigid. To improve the load-bearing qualities, the nailing technique evoluted into more rigid intramedullary nails. To avoid friction and comminution of the medial cortex, the starting point of the new rigid nail was shifted to medial, at the trochanteric fossa, which is located at the junction of the base of the femoral neck and the greater trochanter just in line with the medullary canal in all planes. Winquist and Hansen described the shift of the entry point towards medial in 1979.[7] In the same year McMaster published the new intramedullary nailing technique calling the entry point the 'piriform fossa', while describing the trochanteric fossa in their illustration.[1]

Since the 1980s the majority of surgical papers regarding antegrade femoral nailing use 'piriform fossa' or 'piriformis fossa' as indication for the trochanteric fossa.[1,7-12,17-21,28-31] Modern surgical technique brochures for rigid antegrade femoral nails consistently indicate the trochanteric fossa as 'piriform fossa' in their illustrations. It seems plausible that this is a result of rather careless reproduction of earlier illustrations and text or a terminology error.

Georgiadis *et al.* were the first authors who accurately described the 'trochanteric fossa' in a surgical context.[5] However, they introduced a 'piriform fossa', as a small shallow depression on the superior margin of the greater trochanter where the piriformis tendon is attached. These nomenclature suggestions were reproduced by Papadakis *et al.* accordingly.[13]

Whittle (Campbell, 2007) mentioned the 'trochanteric fossa' in their illustrations and some parts of text correctly, but inconsistency continued using the term 'piriform fossa' in the same chapter, probably addressing the same anatomical location.[22] Nork (Rockwood and Green, 2010) did acknowledge the terminology mismatch in their latest edition.[21] They mentioned the term 'trochanteric fossa' as the actual term for indicating the entry point in line with the medullary canal, but chose to continue to use the term 'piriformis fossa' for this entry point in their chapter, given the general acceptance of the 'piriform fossa' according to the authors. In earlier work of the authors of the current review, we as well chose to stay with the term 'piriform fossa' referring to the entry point in line with the femoral canal, instead of the actual term 'trochanteric fossa', in order to avoid misunderstandings.[28-31] However, to date this entry point is widely used, while the inconsistent terminology is still confusing.

Especially, since more recent articles suggest a new location for the 'piriform fossa' at the insertion site of the piriformis tendon at the tip of the greater trochanter as lateral

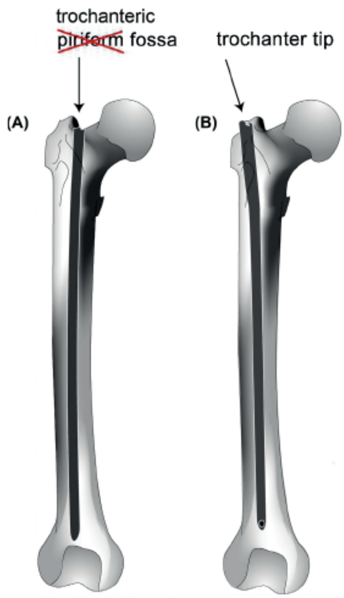

Figure 2. (A) Trochanteric fossa, in line with medullary canal, facilitates a straight intramedullary nail (Ansari Moein *et al.*). (B) Greater trochanter tip entry needs an implant with a proximal lateral bend (Ansari Moein *et al.*).

entry point. There seems to be no anatomical evidence for calling the insertion of the piriformis tendon at the greater trochanter the 'piriform fossa'. Moreover, the insertion site of the tendon of the piriformis muscle is not a standard entry point for lateral nail insertion at the greater trochanter and raises confusion by suggesting so.

With this review it was our attempt to readdress the mismatch in appellation of the entry point in antegrade femoral nailing. The terms 'piriform fossa' and 'trochanteric fossa' are used inconsistently in literature, while all authors emphasise the importance of the correct positioning of the entry point in the starting trajectory of antegrade nailing.

As accurate localisation of the entry point is critical to ensuring proper nail placement and fracture reduction, it should be clearly highlighted in text and illustrations, avoiding the consistent terminology mismatch.

Using the term 'piriform fossa' as entry point in the proximal femur is likely to raise confusion. Therefore, it seems reasonable to desert the term 'piriform fossa' in the femoral nailing literature and to re-introduce the original term 'trochanteric fossa' in further surgical communications (Fig. 2).

REFERENCES

1. McMaster WC. Closed insertion technique for the prebent Sampson femoral rod. *Clin Orthop Relat Res.* 1979(138):238-242.
2. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip. *Injury*. 2005; 36(11):1337-1342.
3. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg Br.* 1988;70(2):206-210.
4. Dora C, Leunig M, Beck M, Rothenfluh D, Ganz R. Entry point soft tissue damage in antegrade femoral nailing: a cadaver study. *J Orthop Trauma.* 2001;15(7):488-493.
5. Georgiadis GM, Olexa TA, Ebraheim NA. Entry sites for antegrade femoral nailing. *Clin Orthop Relat Res.* 1996(330):281-287.
6. Kale SP, Patil N, Pilankar S, Karkhanis AR, Bagaria V. Correct anatomical location of entry point for antegrade femoral nailing. *Injury.* 2006;37(10):990-993.
7. Hansen ST, Winquist RA. Closed intramedullary nailing of the femur. Kuntscher technique with reaming. *Clin Orthop Relat Res.* 1979(138):56-61.
8. Ricci WM, Schwappach J, Tucker M, *et al.* Trochanteric versus piriformis entry portal for the treatment of femoral shaft fractures. *J Orthop Trauma.* 2006;20(10):663-667.
9. Starr AJ, Hay MT, Reinert CM, Borer DS, Christensen KC. Cephalomedullary nails in the treatment of high-energy proximal femur fractures in young patients: a prospective, randomized comparison of trochanteric versus piriformis fossa entry portal. *J Orthop Trauma.* 2006;20(4):240-246.
10. Stockenhuber N, Schweighofer F, Bratschitsch G, R. S. UFN-system. Eine methode der minimal-invasiven chirurgischen Versorgung von Oberschenkelschaftfrakturen. *Langenbecks Archiv Chir.* 1996;381:267-274.
11. Winquist RA, Hansen ST, Jr., Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. 1984. *J Bone Joint Surg Am.* 2001;83-A(12):1912.
12. Miller SD, Burkart B, Damson E, Shrive N, Bray RC. The effect of the entry hole for an intramedullary nail on the strength of the proximal femur. *J Bone Joint Surg Br.* 1993;75(2):202-206.
13. Papadakis SA, Shepherd L, Babourda EC, Papadakis S. Piriform and trochanteric fossae. A drawing mismatch or a terminology error? A review. *Surg Radiol Anat.* 2005;27(3):223-226.
14. Standring S. *Gray's Anatomy.* 40th ed. ed. London: Churchill Livingstone; 2008.
15. Moore KL, AMR A. *Essential clinical anatomy.* 3rd ed. ed. Baltimore: Lippincott Williams & Wilkins; 2007.
16. Lang J, Wachsmuth W. *Regio Femoris der Oberschenkel.* 2e auflage ed. Berlin: Springer-Verlag; 1972.
17. Muller ME, Allgower M, Schneider R, HW W. *Manual of internal fixation.* Heidelberg: Springer; 1991.
18. Bucholz RW, RJ. B. *Fractures of the shaft of the femur.* 3rd ed. ed. Philadelphia: Lippincott; 1996.
19. Kottmeier S. *Femoral shaft fractures*. 2nd ed. ed. New York: The McGraw-Hill Companies; 1997: 480-496.
20. Browner BD, AE C. *Femur fractures: antegrade intramedullary nailing.* 2nd ed. ed. Philadelphia: Lippincott William & Wilkins; 2006:323-347.
21. Nork S. *Femoral shaft fractures.* 7th ed. ed. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins; 2010:1655-1777.
22. Whittle A. *Fractures and dislocations.* 11th ed. ed. St. Louis: Mosby; 2007:3190-3214.

23. Russel T. *Cephalomedullary nailing of the femur.* 2nd ed. ed. Philadelphia: William & Wilkins Media; 1996.
24. Küntscher G. Marktnagelung von Knochenbrucken. *Archiv Klinische Chirurgie* 1940;200:443-455.
25. Küntscher G. The technique of medullary nailing of fractures closed nailing of a fresh femoral fractur. *Clin Orthop Relat Res.* 1949.
26. Thometz JG, Lamdan R. Osteonecrosis of the femoral head after intramedullary nailing of a fracture of the femoral shaft in an adolescent. A case report. *J Bone Joint Surg Am.* 1995;77(9): 1423-1426.
27. Groves EWH. Ununited fractures with special reference to gunshot injuries and the use of bone grafting. *Br J Surg.* 1918;6:203-247.
28. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue anatomy around the hip and its implications for choice of entry point in antegrade femoral nailing. *Clin Anat.* 2008;21(6): 568-574.
29. Linke B, Ansari Moein C, Bosl O, *et al.* Lateral insertion points in antegrade femoral nailing and their influence on femoral bone strains. *J Orthop Trauma.* 2008;22(10):716-722.
30. Ansari Moein C, ten Duis HJ, Oey L, *et al.* Functional outcome after antegrade femoral nailing: a comparison of trochanteric fossa versus tip of greater trochanter entry point. *J Orthop Trauma.* 2011;25(4):196-201.
31. Ansari Moein CM, ten Duis HJ, Oey PL, de Kort GA, vd Meulen W, *et al.* Intramedullary nailing through the trochanteric fossa versus greater trochanter tip: prospective randomized study with in-depth functional outcome results. *Eur J Trauma.* 2011;37(6):615-622.

ANATOMICAL MODELS

Chapter 3

Soft tissue anatomy around the hip and its implications for choice of entry point in antegrade femoral nailing

Chapter 4

Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip

3

Soft tissue anatomy around the hip and its implications for choice of entry point in antegrade femoral nailing

C.M. Ansari Moein, M.H.J. Verhofstad, R.L.A.W. Bleys and Chr. van der Werken

Clin Anatomy. 2008;21(6):568-74

ABSTRACT

Antegrade intramedullary nailing is an accepted method of treatment for femoral shaft fractures. Some surgeons currently recommend entrance of the nail through the trochanteric fossa. This approach results in some cases, however, in loss of abduction strength and persistent pain. Nail insertion at he tip of the greater trochanter may be more favorable. In this study the anatomical relationships of the trochanteric fossa and of the tip of the greater trochanter were explored. Dissection was carried out in 10 fresh human cadaver femurs. The risks and safety of the two entry points with respect to the adjacent soft tissues were assessed. Abductor muscles and tendons, branches of the medial circumflex femoral artery and the hip joint capsule were at risk during nail insertion through the trochanteric fossa. These structures were not endangered during insertion through the trochanteric tip. The reported clinical morbidity after nailing through the trochanteric fossa may result from direct soft tissue injury and may be reduced by choosing the route through the greater trochanter.

INTRODUCTION

Intramedullary nailing is a well-accepted treatment for femoral shaft fractures.[1-3] Küntscher first recommended the tip of the greater trochanter as entry point for antegrade femoral nailing. The tip of the greater trochanter is located lateral to the alignment of the medullary canal and necessitates the use of a nail design with a proximal lateral bending in the frontal plane. Currently, the trochanteric fossa is a widely recommended entry point, which is perfectly in line with the medullary canal (Fig. 1A,B).[4-6]

Unfortunately, access to the trochanteric fossa is technically demanding and reported complications include iatrogenic fracture of the femoral neck[7], avascular necrosis of the femoral head, and septic arthritis from intra-articular penetration.[8] Persistent pain at the trochanteric region, the proximal thigh and in the scar area, interfering with lifestyle or mobility after nailing, has also been reported[4,9] as well as loss of abduction strength of the hip.[10,11] Percutaneous nail insertion involves blind dissection through the gluteal muscles on the approach to the entry point and thus multiple neurovascular and musculotendineous structures are at risk, especially when they are not directly exposed in the operation field.[12] Opening the medullary canal through the trochanteric fossa not only involves injury of the gluteal musculature but also jeopardizes tendons of the hip external rotators as well such as the obturator externus, gemelli, and obturator internus muscles. Direct damage to either the gluteal muscles or to the branches of the superior gluteal nerve may result in postoperative weakness of hip abductors.[10,11]

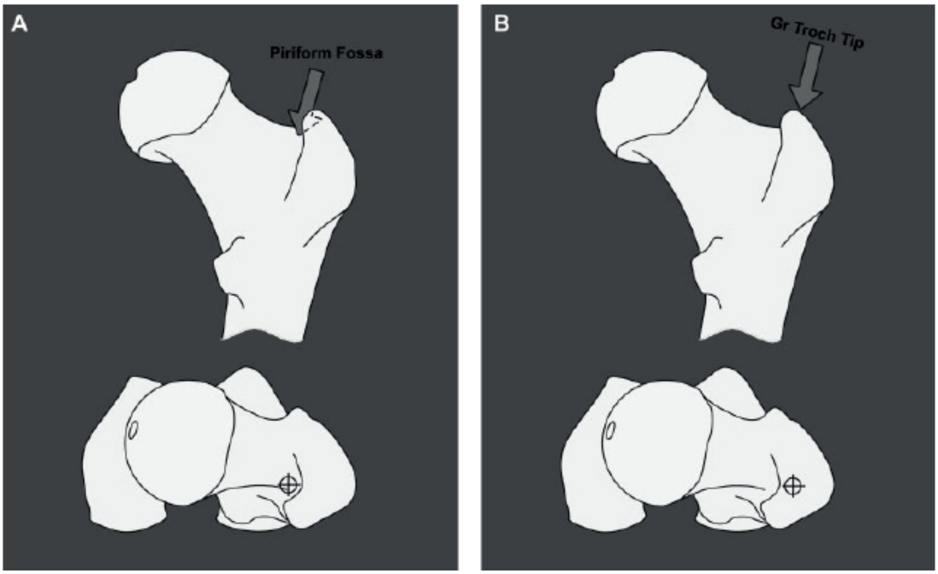

Figure 1. A: Arrow showing the trochanteric fossa, which is in line with the intramedullary canal. B: Arrow pointing at the tip of the greater trochanter, lateral from the intramedullary canal.

The trochanteric fossa is in close proximity to the deep branch of the medial circumflex femoral artery (MCFA) and the hip joint. Adverse penetration of the latter at operation may result in septic arthritis in cases of deep wound infection.[8,13] The MCFA provides the main blood supply to the femoral head.[14,15] Iatrogenic damage to its branches may jeopardize the vascularity of the femoral head and lead to avascular necrosis, especially in young adults.[14-16]

Although the course of the superior gluteal nerve and its surgical implications have been considered in numerous studies[10,16-18], the results of these studies show wide variations. Furthermore, in standard anatomy textbooks and atlases of surgical approaches there is insufficient detail and much variation in descriptions of the neurovascular structures in the hip region. In view of this and the importance to the surgeon of choosing the correct insertion point in intramedullary nailing of femoral shaft fractures, we dissected the gluteal region with emphasis on the abductor and external rotator muscles and tendons, the superior gluteal nerve and its branches, the exact course and position of the MCFA and the capsule of the hip joint. Our aim was to determine the topographic relationships of the aforementioned structures to the trochanteric fossa and the tip of the greater trochanter and to make an unbiased assessment of the risks and safety of the two entry points.

MATERIALS AND METHODS

We carried out 10 anatomical dissections of the hip region in five fresh human cadavers. Four males and one female were used with an age range of 69–80 years. None of the cadavers had sustained previous hip trauma or surgery of the hip. In all cadavers the superior and inferior gluteal arteries, the medial and lateral circumflex femoral arteries, and the obturator artery were identified and cannulated with catheters. The diameter of the catheters closely matched the internal diameter of each vessel. The popliteal artery was ligated to reduce the intravascular volume. The vessels were injected with 60 mL of Araldite© (Bodo Moller Chemie GmbH, Offenbach/Main, Germany) in different colors: green, blue, yellow, red, and black. To create a constant pressure at injection for all vessels, the catheters were mounted simultaneously on one air-driven pressure pump. Anatomical dissections of the gluteal region were carried out after polymerization of the Araldite©.

The topographic relationships between the soft tissues and the trochanteric fossa and the tip of the greater trochanter were assessed and recorded layer after layer, starting with the tensor fasciae latae muscle and the gluteus medius muscle. The intermuscular plane between the gluteal muscles was exposed by detaching the origin of the gluteus medius muscle from the iliac crest. The superior gluteal nerve and its branches were identified and followed to their termination in the gluteus medius, gluteus minimus, and tensor fasciae latae muscles. The gluteus minimus and the piriformis tendon were identified. The obturator internus and gemelli muscles were dissected, after which the MCFA was dissected. The deep branch of the MCFA was followed over the obturator externus tendon until it penetrated the hip joint capsule. Finally, the joint capsule was opened and the subsynovial branches of the MCFA were identified.

The trochanteric fossa and the tip of the greater trochanter were reference points in all dissections. During dissection of the anatomical layers, a 10-mm solid dummy nail was positioned at each reference point to assess the risk of soft tissue injury at the two entry points during surgical nailing. The dummy nail was a solid rod with the same geometric properties of a solid intramedullary femoral nail with a 10 mm diameter, which is most commonly used in clinical practice. Distances between possible structures at risk and the dummy nail positioned at each entry point were measured. Structures were considered to be at risk when they were either penetrated by or at a distance of less than 10 mm from the dummy nail.

All dissections were photographed.

RESULTS

Muscles and tendons

The course of a percutaneously inserted intramedullary nail to one of the two entry points was mimicked by the 10-mm dummy nail. Inevitably, the fascia lata and the underlying gluteus medius muscle were penetrated in all 10 specimens when the nail pursued its course to both the trochanteric fossa and the tip of the greater trochanter. The piriformis tendon and the gluteus minimus tendon, which were attached to the greater trochanteric tip, were jeopardized by the dummy nail at both entry points in eight specimens.

The obturator internus and gemelli tendons with their insertion at the medial surface of the greater trochanter just superior to the trochanteric fossa were at a distance of less than 5 mm from the dummy nail positioned at the trochanteric fossa. The obturator externus tendon inserted at the trochanteric fossa itself and was therefore at high risk if using a trochanteric fossa nail entry point. The tip of the greater trochanter as entry point did not endanger any of the above tendons. Table 1 summarizes the soft tissue structures at risk of damage during nailing.

The superior gluteal nerve

The main trunk of the superior gluteal nerve arose from the posterior aspect of the lumbosacral plexus and passed through the greater sciatic notch, superior to the piriformis

Table 1. Distances *(mm)* from the soft tissues at risk to the 10*mm* diameter dummy nail at the trochanteric fossa

	Distances *(mm)*			
	0	0 – 5	5 – 10	> 10
Obturator internus tendon	2	8	-	-
Gemelli tendons	1	9	-	-
Obturator externus tendon	3	7	-	-
Deep branch of MCFA	2	7	1	-
Hip joint capsule	-	6	4	-

muscle. In seven of the 10 dissections, the superior gluteal nerve divided within one or two centimeters of the superior border of the piriformis muscle into branches that fanned out along the intermuscular plane between the gluteus medius muscle and gluteus minimus muscle. The most inferior branch of the nerve innervated the gluteus minimus muscle and continued anteriorly, piercing the fused anterior edges of the gluteal muscles to supply the tensor fasciae latae muscle. Jacobs *et al.* described this nerve distribution pattern as the "spray pattern" (Fig. 2A). [10]

In the remaining three dissections the nerve distribution showed the so-called "transverse neural trunk pattern" described by Jacobs *et al.* (1989).[10] There was a long branch terminating in the tensor fasciae latae muscle, which gave off short branches to the gluteus medius and minimus muscles along its course (Fig. 2B). The mean minimum distance between the inferior branch of the superior gluteal nerve and the tip of the greater trochanter was 2.8 cm (range 2.3-6.5 cm). In seven dissections the inferior branch was within 5 cm from the tip of the greater trochanter.

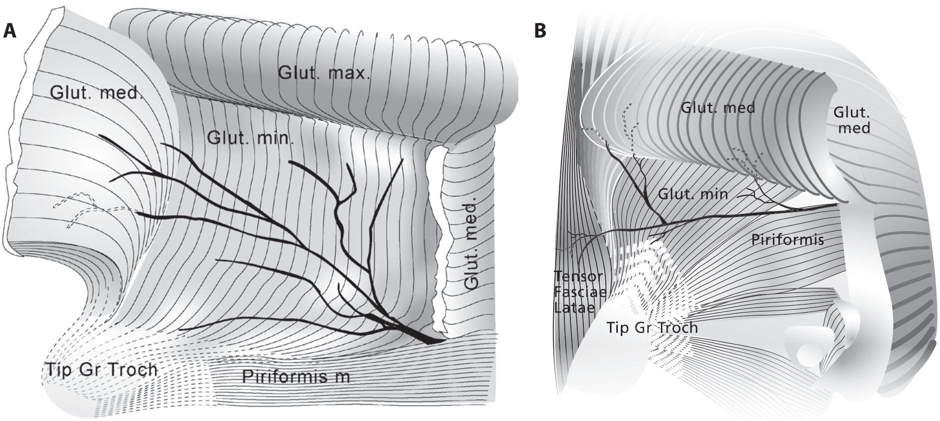

Figure 2. Schematic drawing showing the intermuscular plane of a left gluteal region with the spray pattern of the superior gluteal nerve (A) and the transverse neural-trunk pattern (B).

The branches of the superior gluteal nerve were not encountered by the dummy nail in any of the specimens, neither on its course to the tip of the greater trochanter nor to the trochanteric fossa.

The MCFA

In six specimens the MCFA originated from the profunda femoris artery and in the remaining four directly from the femoral artery just before the profunda femoris artery arose. The deep branch of the MCFA followed a semilunar course between the pectineus and iliopsoas muscles to the posterior side of the thigh between the quadratus femoris

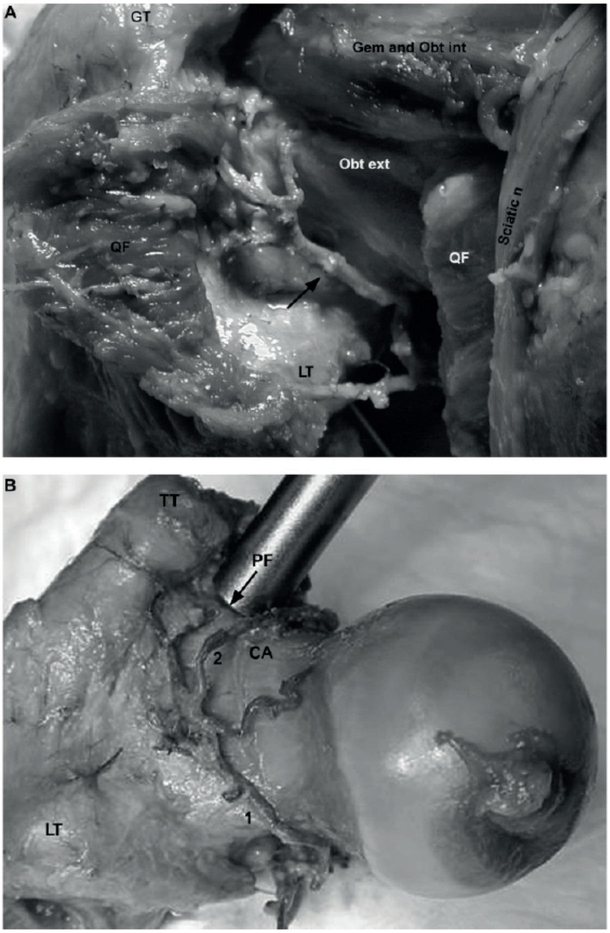

Figure 3. A: Photograph showing the course of the deep branch of the MCFA in a left gluteal region (arrow). GT, greater trochanter; QF, quadratus femoris muscle; LT, lesser trochanter. B: Left femur. The relationship between the dummy nail at the trochanteric fossa and the deep branch of the MCFA to the hip joint capsule. (1) deep branch of MCFA; (2) branch of MCFA perforating the fibrous joint capsule; PF, trochanteric fossa; CA, capsular attachment; TT, trochanteric tip.

and gemelli muscles along the caudal border of the obturator externus muscle. The deep branch then gave off a branch to the greater trochanter and continued its course to the intertrochanteric crest to perforate the hip capsule obliquely craniomedial to the obturator externus muscle. These terminal branches proceeded beneath the synovial sheath of the femoral neck and perforated the medial aspect of the neck posterocranially. Figure 3A shows the course of the deep branch of the MCFA to its terminal branches.

In all 10 dissections anastomoses were found between the deep branch of the MCFA and two other arteries, the obturator artery and the inferior gluteal artery. Furthermore, in all dissections the obturator and the inferior gluteal artery were interconnected with each other and with the lateral circumflex femoral artery as well. In one cadaver we found bilaterally an additional anastomosis between the deep branch of the MCFA and the ascending branch of the lateral circumflex femoral artery partly surrounding the femoral neck on its cranial aspect. In the remaining eight dissections no anastomoses were found between the two circumflex femoral arteries.

In nine dissections the deep branch of the MCFA was at risk with a distance less than 5 mm to the dummy nail at the trochanteric fossa. In the tenth dissection, the artery was at risk being less than 10 mm from the dummy nail at the trochanteric fossa. The relationship between the artery and the dummy nail is shown in Figure 3B. This deep branch of the MCFA was not encountered in the risk area near the tip of the greater trochanter.

The hip joint capsule

In six dissections the lateral border of the fibrous joint capsule was less than 5 mm from the dummy nail at the trochanteric fossa (Fig. 3B). In the remaining four dissections the distance to the trochanteric fossa was within 10 mm. These findings indicate that in all cases penetration of the hip joint was a substantial threat when using the trochanteric fossa as the nail entry point. The hip joint capsule was not jeopardized by the nail in any of the specimens when the tip of the greater trochanter was selected as the entry point.

DISCUSSION

Antegrade intramedullary femoral nailing through the trochanteric fossa is a well-accepted treatment of femoral shaft fractures. Little attention is paid to insertion site morbidity associated with this procedure, though reports of loss of abduction strength of the hip[11] and persistent pain in the trochanteric region, the proximal thigh and the scar area are not uncommon.[4,9] Partial avascular necrosis of the femoral head especially in adolescents[15] and septic arthritis in patients with wound infection after accidental penetration of the hip capsule[13] are reported. Our findings explain from an anatomical point of view why nail insertion through the trochanteric fossa may lead to such complications. Using a lateral entry point such as the tip of the greater trochanter with an appropriate nail design may avoid these complications. Our former study showed the actual injury of the neurovascular and musculotendineal apparatus sustained during the blind insertion procedure through both entry points.[12] In this study we explored the topographical relationships of various soft tissue structures to the trochanteric fossa and the tip of the greater trochanter and compared the safety of the two different entry points regarding the adjacent soft tissues, regardless of the capacities of the surgeon or random soft tissue injury due to the blindness of the procedure.

Our study showed that the surgical approaches of femoral nailing through the trochanteric fossa and through the tip of the greater trochanter will invariably produce musculotendineous injury to the fascia lata and the gluteus medius muscle. The gluteus minimus and piriformis tendons were endangered by both entry points. However, the exposure to danger in these structures was greater when selecting the trochanteric fossa. At the trochanteric fossa entry point, additional risk of injury was inevitable for the gemelli, the obturator internus, and the obturator externus tendons as their insertion sites are very near or at the trochanteric fossa itself.

The origin and course of the superior gluteal nerve is well documented. Numerous studies on the relationship of this nerve to the tip of the greater trochanter have been carried out, but their results differ markedly. Foster and Hunter[19] found a mean distance of 7.7 cm from the superior gluteal nerve to the tip of the greater trochanter. It was not clear from their study which branch of the nerve was used for measurement. Others described a "safe area" for surgery of 3–6.5 cm.[10,17,18] In our study the mean minimum distance from the inferior branch of the nerve to the tip of the greater trochanter measured 2.8 cm (range 2.3–6.5 cm) which means that the superior gluteal nerve is close to or in the operation area.

Although the incidence is low, avascular necrosis of the femoral head is a feared complication of nailing, especially in children and adolescents. Whether an open growth plate contributes to this increased risk is unclear. Orler *et al.*[15] mentioned the large size of the nail in relation to the small adolescent femoral neck as a possible explanation. We found significant and consistent anastomoses between the deep branch of the MCFA, a branch of the obturator artery and a branch of the inferior gluteal artery. Gautier *et al.*[20] presumed that the anastomosis between the inferior gluteal artery and the MCFA is the major compensating factor after iatrogenic injury of the latter. Furthermore they suggested that the lateral circumflex femoral artery contributes little to the vascularization of the femoral head. In our study the lateral circumflex femoral artery anastomosed in two specimens with the deep branch of the MCFA at the cranial aspect of the femoral neck. The deep branch of the MCFA, thus, may not only be compensated by the inferior gluteal artery, but also by the lateral circumflex femoral and obturator arteries as well when damaged. In all our 10 dissections the deep branch of the MCFA as well as the majority of its subsynovial branches were jeopardized when the trochanteric fossa was selected as entry point. In contrast, when choosing the greater trochanter tip, this artery was invariably in a safe zone. This finding indicates that use of the trochanteric tip for nail insertion prevents damage to the extramedullary vascular supply of the femoral head.

Septic arthritis of the hip joint after intramedullary nailing has been reported. If a deep wound infection occurs after opening the hip capsule accidentally, septic arthritis will develop. The lateral border of the hip joint capsule is close enough to be in jeopardy from the track of a nail directed towards the trochanteric fossa.

The muscles and tendons of the abductors, as well as the external rotators of the hip are significantly endangered by the course of a nail to the trochanteric fossa. Because of their proximity to the trochanteric fossa, the MCFA branches and the hip joint capsule are jeopardized as well. Choosing the trochanter tip as nail entry point, the risk of damage was limited to the hip abductor musculature. In light of these findings it is likely that the clinical morbidity after antegrade femoral nailing through the trochanteric fossa, may result from direct damage to adjacent soft tissues. To reduce these clinical problems, choosing an entry point through the greater trochanter, with the appropriate nail design, should be considered in the conventional nailing of femoral shaft fractures.

REFERENCES

1. Küntscher G. The technique of medullary nailing of fractures. *Clin Orthop.* 1968;60:105-112.
2. Burwell HN. Internal fixation in the treatment of fractures of the femoral shaft. *Injury.* 1971;2(3): 235-244.
3. Kempf I, Grosse A, Lafforgue D. [Combined Kuntscher nailing and screw fixation (author's transl)]. *Rev Chir Orthop Repar Appar Mot.* 1978;64(8):635-651.
4. Danckwardt-Lilliestrom G, Sjogren S. Postoperative restoration of muscle strength after intramedullary nailing of fractures of the femoral shaft. *Acta Orthop Scand.* 1976;47(1):101-107.
5. Harper MC, Carson WL. Curvature of the femur and the proximal entry point for an intramedullary rod. *Clin Orthop Relat Res.* 1987(220):155-161.
6. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg Br.* 1988;70(2):206-210.
7. Simonian PT, Chapman JR, Selznick HS, Benirschke SK, Claudi BF, Swiontkowski MF. Iatrogenic fractures of the femoral neck during closed nailing of the femoral shaft. *J Bone Joint Surg Br.* 1994; 76(2):293-296.
8. Bostman O, Varjonen L, Vainionpaa S, Majola A, Rokkanen P. Incidence of local complications after intramedullary nailing and after plate fixation of femoral shaft fractures. *J Trauma.* 1989;29(5): 639-645.
9. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br.* 1997;79(5):738-741.
10. Jacobs LG, Buxton RA. The course of the superior gluteal nerve in the lateral approach to the hip. *J Bone Joint Surg Am.* 1989;71(8):1239-1243.
11. Bain GI, Zacest AC, Paterson DC, Middleton J, Pohl AP. Abduction strength following intramedullary nailing of the femur. *J Orthop Trauma.* 1997;11(2):93-97.
12. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip. *Injury.* 2005; 36(11):1337-1342.
13. Bednar DA, Ali P. Intramedullary nailing of femoral shaft fractures: reoperation and return to work. *Can J Surg. J Can Chir.* 1993;36(5):464-466.
14. O'Malley DE, Mazur JM, Cummings RJ. Femoral head avascular necrosis associated with intramedullary nailing in an adolescent. *J Pediatr Orthop.* 1995;15(1):21-23.
15. Orler R, Hersche O, Helfet DL, Mayo KA, Ward T, R G. Die avaskulare Huftkopfnekrose als schwerwiegende Komplikation nach Femurmarknagelung bei Kindern und Jugendlichen. *Unfallchirurg.* 1998;101:495-499.
16. Baker AS, Bitounis VC. Abductor function after total hip replacement. An electromyographic and clinical review. *J Bone Joint Surg Br.* 1989;71(1):47-50.
17. Goodman SB. Does the direct lateral approach to the hip joint jeopardize the superior gluteal nerve? *Clin Anat.* 1991;4(2):123-128.
18. Bos JC, Stoeckart R, Klooswijk AI, van Linge B, Bahadoer R. The surgical anatomy of the superior gluteal nerve and anatomical radiologic bases of the direct lateral approach to the hip. *Surg Radiol Anat.* 1994;16(3):253-258.
19. Foster DE, Hunter JR. The direct lateral approach to the hip for arthroplasty. Advantages and complications. *Orthopedics.* 1987;10(2):274-280.
20. Gautier E, Ganz K, Krugel N, Gill T, Ganz R. Anatomy of the medial femoral circumflex artery and its surgical implications. *J Bone Joint Surg Br.* 2000;82(5):679-683.

4

Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip

C.M. Ansari Moein, M.H.J. Verhofstad, R.L.A.W. Bleys and
Chr. van der Werken

Injury. 2005;36:1337-42

ABSTRACT

Intramedullary nailing through the piriform fossa results in some cases in loss of abduction strength and persistent pain. Nail insertion at the tip of the greater trochanter may be favourable. The aim of this study was to assess (possible) iatrogenic injury to the abductor and external rotator musculature, branches of the superior gluteal nerve and branches of the MFCA in relation to the two different entry points.

In 10 fresh human cadaver femurs, five unreamed femoral nails (UFN) were inserted through the piriform fossa and five AO prototype nails (AFN) through the trochanteric tip. The iatrogenic injury at each nailing procedure was assessed.

Various muscles and tendons, branches of the MFCA along with the hip joint capsule were injured or largely at risk during nail insertion through the piriform fossa. Most of these structures were not exposed during insertion through the trochanteric tip. The reported clinical morbidity after nailing through the piriform fossa may find its origin in direct soft tissue injury and may be reduced by choosing a lateral nail entry point.

INTRODUCTION

Intramedullary nailing is a well-accepted treatment of femoral shaft fractures.[1-3] A widely recommended entry point for antegrade nailing is the piriform fossa, which is perfectly in line with the medullary canal so that a straight nail can be inserted (Fig. 1A).[4-6] Unfortunately, access to the piriform fossa is technically demanding and rarely reported complications include iatrogenic fracture of the femoral neck, avascular necrosis of the femoral head and septic arthritis from intra-articular penetration.[5,18] Persistent pain at the trochanteric region, the proximal thigh and in the scar area, interfering with lifestyle or mobility after nailing, has also been reported[8,9] as well as loss of some abduction strength of the hip.[1,14] Percutaneous nail insertion involves wiggling around between the gluteus muscles on the way to the entry point. Opening the medullary canal through the piriform fossa involves not only injury of the gluteal musculature but jeopardizes tendons of the hip external rotators as well: the obturator externus, gemelli and obturator internus muscles. In theory, the superior gluteal nerve is at risk in this approach. Direct damage to either the gluteus muscles or to the branches of the superior gluteal nerve may result in postoperative weakness of hip abductors.[7,8] The piriform fossa is in close proximity to the deep branch of the medial femoral circumflex artery (MFCA) and the hip joint. Adverse penetration of the latter at operation may result in septic arthritis in cases of deep wound infection.[9,10] The MFCA provides the main blood supply to the femoral head.[11] Iatrogenic damage to its branches may jeopardize the vascularity of the femoral head, which may lead to avascular necrosis, especially in young adults.[12-14] Küntscher first recommended the tip of the greater trochanter as femur nail entry portal. The tip of

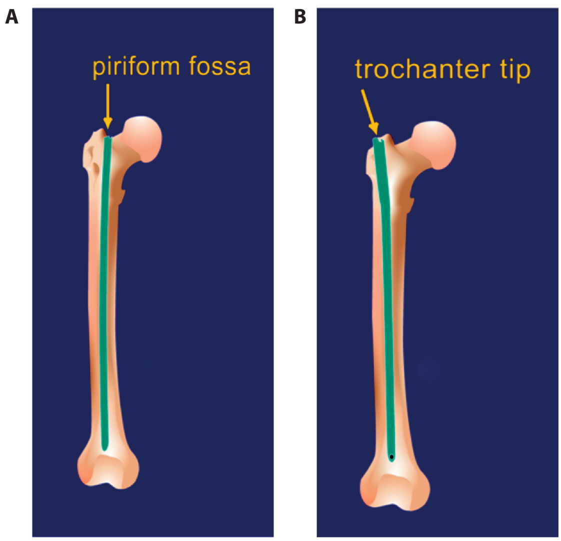

Figure 1. (A) The piriform fossa is in line with the intramedullary canal, which makes insertion of a straight intramedullary nail possible. (B) An antegrade femoral nail with a proximal bend in the frontal plane, inserted through the trochanteric tip.

the greater trochanter, however, is lateral to the central axis of the medullary canal and nail insertion here must be performed under an angle of approximately 6° to enter the canal (Fig. 1B). To overcome this practical problem, different nail systems with a proximal bend in the frontal plane are currently on the market, e.g. the long proximal femoral nail (AO/ASIF), the long gamma nail (Howmedica) and sirus nail (Sultzer/Centerpulse).

It remains unclear as to what extent direct injury to the musculotendineous structures in the gluteal region and their supplying nerves and vessels contributes to the reported clinical complications and to what extent these injuries are related to the entry point of the different nail systems. Therefore we performed a human cadaver study comparing two different entry points — the piriform fossa and the tip of the greater trochanter — in antegrade femoral nailing. Our aim was to assess (possible) iatrogenic injury to the abductor and external rotator musculature, branches of the superior gluteal nerve and branches of the MFCA in relation to one of the mentioned entry points.

MATERIALS AND METHODS

Cadavers

In 5 fresh frozen human cadavers with intact femurs (5 males, ages 59—75 years), 10 percutaneous antegrade femoral nailings were performed. Preoperative bi-planar radiographs excluded previous trauma or hip surgery. The AO/ASIF 9 mm x 38 cm unreamed femoral nail (UFN) and an AO/ASIF 10 mm x 38 cm cannulated nail prototype with a 6° proximal bend in the frontal plane (antegrade femoral nail, AFN) were inserted in random order (Fig. 1). The smallest available nail diameter was selected to demonstrate the critical spatial relationship to anatomic structures in the entry point area.

Nailing was performed with the cadaver in a supine position. The skin incision started at the tip of the greater trochanter and extended five centimeters cranially. The gluteus medius muscle was split bluntly and the entry point was localized. In five hips, the entry point was the piriform fossa for the UFN procedure and in the other five just lateral to the tip of the greater trochanter for the AFN prototype. This entry point and the insertion technique for the AFN prototype nail were derived from the guidelines for the long PFN insertion (Mathys Medical Ltd., Switzerland). The position of the K-wire (3.2 mm for the UFN and 2.8 mm for the AFN prototype) was checked under image intensifier control in the anterior-posterior and lateral views. The cortex was opened manually by a 13 mm and 14 mm (UFN and AFN prototype, respectively) cannulated reamer over the K-wire using a T-handle. A protecting drill sleeve was used to limit the soft tissue injury. The nails were introduced in the medullary canal with the insertion handle and advanced with a slotted hammer when indicated.

Dissection

After the percutaneous nail insertion, the gluteal region was dissected layer after layer and iatrogenic soft tissue injuries within each layer were assessed and recorded; starting with the tensor fasciae latae muscle and the gluteus medius muscle, thereafter with the superior gluteal nerve. The third plane encompassed the gluteus minimus, piriformis, obturator internus and gemelli muscles, after which the MFCA was dissected. Finally, the joint capsule was opened and accidental nail penetration was recorded. The subsynovial branches of the MFCA were studied for lesions as well, their dissection was facilitated by injecting Araldite© colour red into the deep branch of the MFCA proximally and identifying leakage of the Araldite© in the subsynovial area. All dissections were documented on photographs.

RESULTS

The nailing procedure was uneventful in all cases. All 10 nailings inevitably injured the fascia lata and the gluteus medius muscles. The injuries to the gluteus medius muscle were all muscular in the piriform fossa (UFN) group, while three of the five nailings with the tip of the greater trochanter as entry point resulted in pure tendinous lesions. In two cases, after one UFN and one prototype insertion, injury to the gluteus maximus muscle

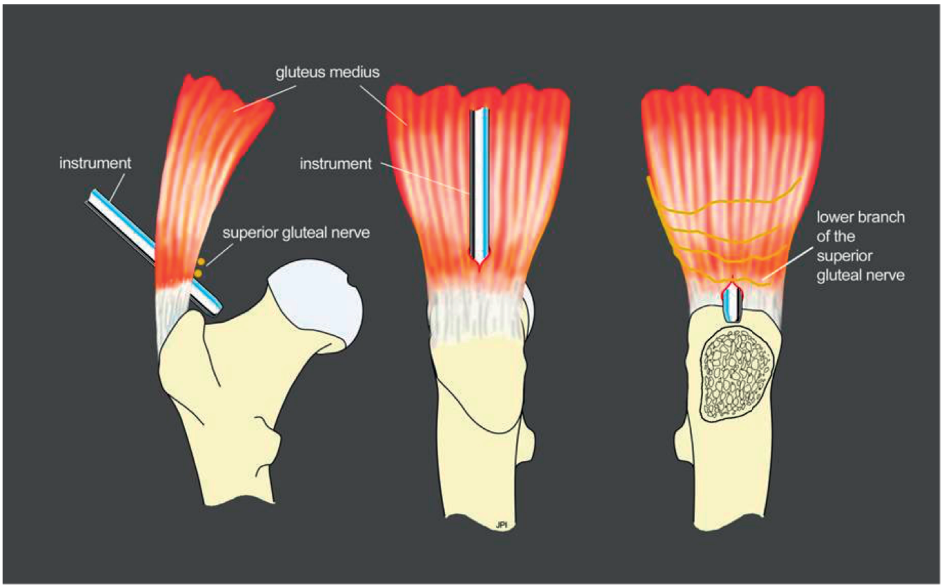

Figure 2. Diagram showing the spatial relation between nail insertion through the gluteus medius muscle and the most inferior branch of the superior gluteal nerve. Anterior-posterior, lateral-medial and medial-lateral views.

was found as well. Dissecting the second layer revealed that all branches of the superior gluteal nerve were intact in all specimens for both groups. However, in two cases, one UFN and one AFN prototype, the inferior branch of the superior gluteal nerve had been largely at risk, being at a distance less than 5 mm cranially to the surgical lesion in the gluteus medius muscle (Fig. 2).

For the third layer, limited injury to the piriformis tendon was encountered in three of the five AFN prototype nailings. No other injuries were encountered in this group. In

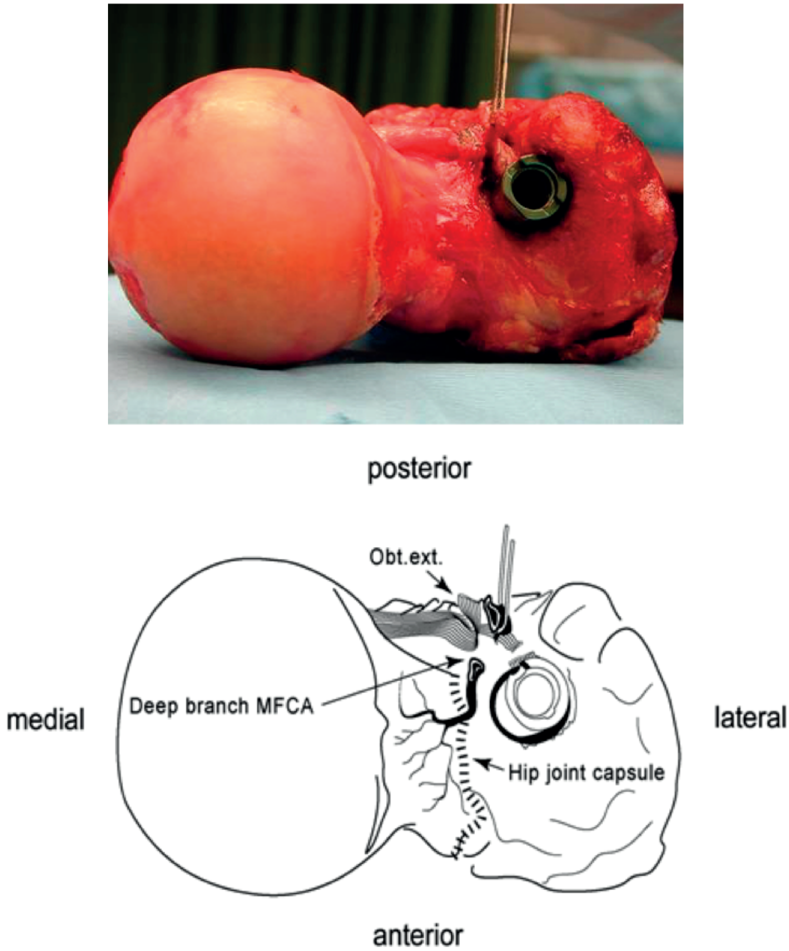

Figure 3. (A) Photograph showing the UFN being inserted in the piriform fossa, left hip, cranial view. The deep branch of the MFCA is injured as well as the external obturator muscle. (B) Diagram showing: the UFN in the piriform fossa cavity. The distal part of the injured deep MFCA branch is localized with a pincet. The damaged obturator externus muscle is adjacent to the injured artery. The proximity of the nail to the hip joint capsule is visible.

the UFN group, we saw a lesion of the piriformis tendon in one case while the gluteus minimus was damaged in three cases. The obturator internus and gemelli tendons along with the obturator externus tendon were all injured in three of the five UFN nailings. These tendons were not exposed by the AFN prototype nailings.

Damage to the deep branch of the MFCA was encountered in four specimens operated with a UFN and in the one remaining case the artery was at a distance of 2 mm from the entry hole. The deep branch of the MFCA was not encountered by any of the AFN prototype nails. One UFN nail had penetrated the hip joint capsule along with the

Table 1. Summary of soft tissue lesions for each entry point group

	Number of specimens with lesions in each entry point group	
Soft tissues	Piriform Fossa (*N*=5)	Tip of Greater Trochanter (*N*= 5)
Gluteus Medius muscle	5	1
Gluteus Medius tendon	0	4
Tendon lesions		
Gluteus Minimus	3	0
Piriformis	1	3
Obturator Internus and Gemelli	3	0
Obturator Externus	3	0
Vascular and joint capsule lesions		
Deep branch of MFCA	4	0
Subsynovial branches of MFCA	1	0
Joint capsule	1	0

subsynovial branches of the MFCA (Fig. 3). In three of the remaining four cadavers, the lateral border of the joint capsule was less than 5 mm to the entrance hole in the piriform fossa, which is close enough to be in real jeopardy.

The various soft tissue injuries in each nail group are summarized in Table 1.

DISCUSSION

Antegrade nailing with insertion through the piriform fossa is a well-accepted treatment of femoral shaft fractures. Little attention is paid to insertion site morbidity associated with this procedure. However, reports on iatrogenic fractures of the femoral neck are not uncommon[4,15] and persistent pain at the trochanteric region, the proximal thigh and in the scar area have been documented[5,15], as well as loss of abduction strength of the hip.[7,8] Factors that may lead to abductor weakness include injuries to the gluteal muscles or to the superior gluteal nerve.[5,15] The current study used the conventional AO/

ASIF technique for unreamed nailing and an AO/ASIF prototype of a proximally bent antegrade femoral nail to compare the iatrogenic injury of nail insertion through the piriform fossa to those of insertion through the tip of the greater trochanter.

Percutaneous nail insertion led to inevitable lesions to the fascia lata and the gluteus medius muscle for both entry points. However, nail insertion through the tip of the greater trochanter revealed smaller sized and in three cases tendinous lesions of the gluteus medius, as opposed to the piriform fossa group where the UFN had penetrated musculous fibres of the gluteus medius. Replacement of contractile muscle fibres by fibrous scar tissue may have more severe consequences for muscle function than replacement of tendon by scar tissue. Furthermore, nail entrance through the piriform fossa resulted also in damage to the tendons of the gluteus minimus, piriformis, obturator internus and the obturator externus muscles. The clinical significance of these lesions as to residual pain and impaired function is unclear, but presumable.

The superior gluteal nerve was never injured, but the surgeon should bear in mind the proximity of the branches of the nerve to the surgical incision.

Although the incidence is very low, partial avascular necrosis of the femoral head is a feared complication of nailing, especially in children and adolescents.[16] Whether and how an open growth plate contributes to this increased risk is unclear. In literature, the large size of implant in relation to the thin adolescent neck is mentioned as possible explanation.[17,18] In our study, inserting the nail through the piriform fossa resulted in substantial damage to the deep branch of the MFCA and its subsynovial branches, in contrast to the trochanter tip introduction. Septic arthritis of the hip joint after intramedullary nailing has been reported.[10] If a deep wound infection occurs after an operation in which the hip capsule is accidentally opened, a septic arthritis will develop. In one of the five piriform fossa cases the joint capsule was penetrated by the UFN, while in three cases the lateral border of the capsule was in close proximity to the entry hole and thus endangered.

As for the ease of the procedure, inserting the nail through the tip of the greater trochanter has many advantages, while access to the piriform fossa is demanding, especially in obese patients.

Significant injuries to the muscles and tendons of the hip abductors, as well as to the hip external rotators were demonstrated by nailing through the piriform fossa. Furthermore, inserting the nail through the piriform fossa resulted in injuries to the MFCA branches in all cases and in some cases to the hip joint capsule. After nailing through the trochanter tip the surgical injury was limited to — predominantly tendinous — lesions of the hip abductor musculature only. In light of these findings we postulate that the reported clinical morbidity after intramedullary nailing through the piriform fossa, may find its origin in direct soft tissue injury. These problems may be reduced by choosing a more lateral nail entry point.

REFERENCES

1. Burwell HN. Internal fixation in the treatment of fractures of the femoral shaft. *Injury.* 1971;2(3): 235-244.
2. Kempf I, Grosse A. L'apport due verrouillage dans l'enclouage centro-medullaire des os longs. *Rev Chir Orthop Reparatrice Appar Mot.* 1978;64:635-651.
3. Küntscher G. The technique of medullary nailing of fractures. *Clin Orthop.* 1968;60:105-112.
4. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg. Br.* 1988;70(2):206-210.
5. Danckwardt-Lilliestrom G, Sjogren S. Postoperative restoration of muscle strength after intramedullary nailing of fractures of the femoral shaft. *Acta Orthop Scand.* 1976;47(1):101-107.
6. Harper MC, Carson WL. Curvature of the femur and the proximal entry point for an intramedullary rod. *Clin Orthop Related Res.* 1987(220):155-161.
7. Bain GI, Zacest AC, Paterson DC, Middleton J, Pohl AP. Abduction strength following intramedullary nailing of the femur. *J Orthop Trauma.* 1997;11(2):93-97.
8. Jacobs LG, Buxton RA. The course of the superior gluteal nerve in the lateral approach to the hip. *J Bone Joint Surg Am.* 1989;71(8):1239-1243.
9. Bednar DA, Ali P. Intramedullary nailing of femoral shaft fractures: reoperation and return to work. *Can J Surg. J Can Chir.* 1993;36(5):464-466.
10. Bostman O, Varjonen L, Vainionpaa S, Majola A, Rokkanen P. Incidence of local complications after intramedullary nailing and after plate fixation of femoral shaft fractures. *J Trauma.* 1989;29(5): 639-645.
11. Gautier E, Ganz K, Krugel N, Gill T, Ganz R. Anatomy of the medial femoral circumflex artery and its surgical implications. *J Bone Joint Surg Br.* 2000;82(5):679-683.
12. Baker AS, Bitounis VC. Abductor function after total hip replacement. An electromyographic and clinical review. *J Bone Joint Surg Br.*1989;71(1):47-50.
13. Bos JC, Stoeckart R, Klooswijk AI, van Linge B, Bahadoer R. The surgical anatomy of the superior gluteal nerve and anatomical radiologic bases of the direct lateral approach to the hip. *Surg Radiol Anat.* 1994;16(3):253-258.
14. Goodman SB. Does the direct lateral approach to the hip joint jeopardize the superior gluteal nerve? *Clin Anat.* 1991;4(2):123-128.
15. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br.* 1997;79(5):738-741.
16. Mileski RA, Garvin KL, Crosby LA. Avascular necrosis of the femoral head in an adolescent following intramedullary nailing of the femur. A case report. *J Bone Joint Surg Am*1994;76(11):1706-1708.
17. Hernigou Ph, Karray M, L N. Osteonecrose de la tete femorale apre`s enclouage de la diaphyse femorale chez l'adulte. *Rev Chir Orthop.* 1995;81:622-625.
18. Miller SD, Burkart B, Damson E, Shrive N, Bray RC. The effect of the entry hole for an intramedullary nail on the strength of the proximal femur. *J Bone Joint Surg Br.*1993;75(2):202-206.

MECHANICAL MODEL

Chapter 5

Lateral insertion points in antegrade femoral nailing and their influence on femoral bone strains

5

Lateral insertion points in antegrade femoral nailing and their influence on femoral bone strains

B. Linke, C.M. Ansari Moein, Oliver Bösl, M.H.J. Verhofstad, Chr. van der Werken, K. Schwieger and K. Ito

J Orthop Trauma. 2008;22(10):716-22

ABSTRACT

Objectives: Insertion of rigid uniplane bent femoral nails through the piriform fossa has been reported to cause neurovascular complications. New nails were designed for more lateral entry points. However, these may be associated with a higher risk of iatrogenic fractures. This study investigated if two differently bent nails with more lateral entry points induce higher cortical bone strains than a uniplane bent nail introduced through the piriform fossa.

Methods: Three groups of 8 cadaveric femurs were instrumented using the following nail systems and entry points: Cannulated Femoral Nail, piriform fossa; Antegrade Femoral Nail, trochanteric tip; and helical nail, lateral of the trochanteric tip. During insertion, the maximum principal bone strains were recorded at 9 locations at the proximal femur and the diaphysis. The occurrence of iatrogenic fractures or fissures was documented.

Results: The highest strains recorded were between 2000 and 4500 μm/m and mainly located at the posterior aspect of the greater trochanter and at the medial side of the entry point. In most of these cases fissures or fractures occurred, the number of which was higher for the trochanteric tip group as compared with the other groups. This was thought to be due to the thin cortical walls as a result of the larger reamer diameter in this group. Low strains (below 2000 μm/m) occurred at the medial cortex where the laterally inserted nails were expected to impinge.

Conclusions: Bone strains at the medial impingement location were low for all nails. Entry portals with thin cortical walls due to, for example, larger reamer diameters and a small greater trochanter seem to be more susceptible to insertion accuracy, which may influence strain and fissure or fracture occurrence. Furthermore, we do not recommend determination of the entry point of laterally inserted nails based solely on anatomic landmarks of the greater trochanter because this may influence insertion accuracy. This implies that biplanar imaging is important for accurate and safe insertion of laterally started nails.

INTRODUCTION

Intramedullary nailing is a well-accepted treatment of femoral shaft fractures.[1-4] However, the entry point for nail insertion when the patient is supine remains controversial. For uniplanar nails the widely recommended entry point is the piriform fossa. Because it is in line with the medullary canal, a uniplane bent nail can be inserted.[4-7] However, access to the piriform fossa is technically demanding in the supine position, and proper alignment of the nail with the intramedullary canal is essential to avoid complications.[8] Misdirection may result in violation of the medial aspect of the proximal femur and iatrogenic fractures of the femoral neck.[9] Reported complications include avascular necrosis of the femoral head[10] and iatrogenic lesions of the superior gluteal nerve, leading to denervation of the m. gluteus medius and subsequent limping.[11] Persistent pain at the trochanteric region and the proximal thigh[12-14] and some loss of strength of the hip abductors[15] have also been reported. As Küntscher had advocated, a lateral entry position may avoid these complications because the soft tissues around the proximal femur are not touched. However, nails inserted lateral to the femoral canal tend to impinge against the medial cortex and may cause comminution of the proximal fracture fragment.[16-18] Johnson *et al.*[16] have shown that excessive medial or lateral placement of the entry hole from the neutral axis of the femur raises the hoop stresses in the diaphysis if a uniplane bent nail is used.

Recently, antegrade femoral interlocking nail systems have been introduced, which have a secondary proximal lateral bend to allow insertion of the nail at the tip of the greater trochanter (Trigen TAN Nail, Smith and Nephew Inc., Memphis, TN; T2 Recon/Antegrade Femoral Nail, Stryker, Kalamazoo, MI; Sirus Femoral Nail, Zimmer Inc, Warsaw, IN; Antegrade Femoral Nail, Synthes Inc., Bettlach, Switzerland).[11] Because these intramedullary devices may still create problems about the proximal femur, an experimental nail with a helical shape over its entire length was designed for this study to be inserted more lateral to the trochanteric tip (Synthes Inc.). Until now, it is unclear if nail introduction through these lateral entry sites with correspondingly bent nail systems induces higher strains in the femur than uniplane bent nails introduced through the conventional entry point at the piriform fossa.

The aim of this study was to determine the influence of these 3 insertion points along with their matched nail system designs on cortical bone strains and iatrogenic fractures and fissures during intramedullary nailing of femoral shaft fractures in a human cadaver model. Our hypothesis was that there are no differences between groups with regard to maximum bone surface strains and occurrence of iatrogenic fractures or fissures.

MATERIALS AND METHODS

Nail systems and experimental groups

Three experimental groups with different entry points were defined: a piriform fossa (PF) group, a tip of the greater trochanter (TT) group, and a lateral to the trochanteric tip (LT) group. In the PF group a standard uniplane bent nail was used with a curvature in the anterior–posterior (AP) plane to follow the curvature of the medullary canal [Synthes Inc., type: cannulated femoral nail (CFN), length: 440 mm, constant diameter: 12 mm, radius of curvature: 1500 mm, Fig. 1, PF]. In the TT group a nail with an additional proximal lateral bend in the frontal plane of 6 degrees was used [Synthes Inc., type: antegrade femoral nail (AFN), length: 380 mm, distal diameter: 12 mm, proximal diameter: 15 mm, radius of curvature: 1500 mm, Fig. 1, TT]. The nail is inserted in 90- degree rotation such that the handle is pointing anteriorly when the distal tip of the nail is inserted through the entry hole. During the insertion of the nail through the canal, it rotates toward its end position with the handle pointing laterally. An experimental nail with a helical bend over the entire length of the nail was developed based on the helical concept as published by Fernandez Dell'Oca[19] and was used in the LT group (Synthes Inc., type: prototype of the Lateral Femoral Nail, length: 400 mm, constant diameter: 12 mm, radius of curvature: 1100 mm, Fig. 1, LT). Similar to the AFN in the TT group, this nail is inserted in 90-degree rotation anteriorly through the entry hole. During insertion of the nail through the canal the nail rotates laterally to fit into the canal.

The prototype nail for the LT group was only available in 1 size (length of 400 mm and diameter of 12 mm). Nail lengths were the same within the respective groups but differed between groups due to the limited availability of cadaveric femurs of appropriate lengths to form 3 groups of 8 femurs each.

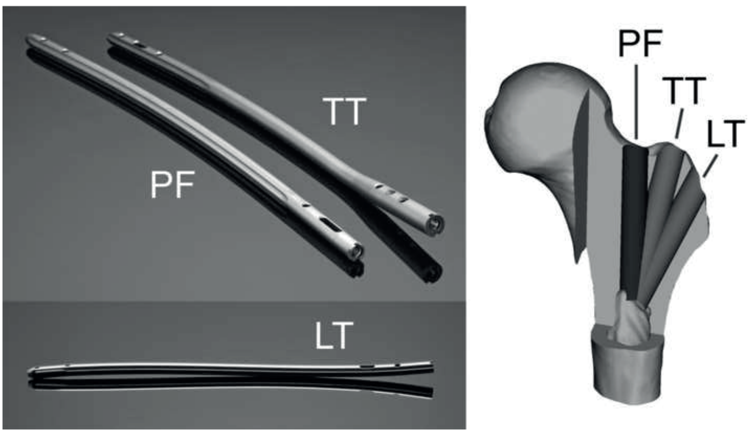

Figure 1. Cannulated femoral nail (PF), AFN (TT), and prototype of a helical nail (LT) with corresponding insertion paths.

Specimens

From a pool of fresh-frozen human cadaver femora without soft tissue coverage, 24 were used for biomechanical testing [16 male and 8 female, mean age 76 years (range 51–104 years)]. Biplanar radiographs were obtained to exclude bony abnormalities, to measure isthmus diameter, and to determine the entry points by using templates for the 3 different nail systems. Only femora with lengths between 400 and 460 mm and an isthmus diameter of 12 mm or less were selected, which were appropriate for treatment with nail sizes selected for the 3 groups. Bone mineral density (BMD) was determined in the cancelous bone of the femoral head by peripheral Quantitive Computer Tomography (Densiscan 1000, SCANCO Medical AG, Bassersdorf, Switzerland). All specimens had a BMD larger than 0.35 g/cm^3 and were neither osteopenic nor osteoporotic. BMD distribution did not differ between the groups with a sample size of 8 specimens each (BMD mean 6 SD: PF: 0.479 6 0.041 g/cm^3; TT: 0.455 6 0.033 g/cm^3; LT: 0.410 6 0.048 g/cm^3). The specimens were wrapped in saline-soaked gauze and stored at -28°C. Each femur was thawed at room temperature 24 hours before preparation.

Measurement equipment and variables

Two types of variables were measured in the experiments: intensities of hammer strikes required to insert the nail and bone surface strains during nail insertion.

Hammer strike intensities were measured by a standard sliding hammer (Synthes Inc., REF 357.250, weight: 1.2 kg), instrumented with a piezoresistive, uniaxial acceleration transducer (Type FA 101-A2, measurement range: 200 g, Disynet GmbH, Brüggen, Germany) and were subsequently categorized into "light," "medium," and "hard" strikes based on acceleration values. Categorization was done before the main study started by having the surgeon perform 20 hammer strikes in each of the categories light, medium, and hard, the intensities of which were judged subjectively by the surgeon. Based on this categorization the surgeon was provided with an optical signal using the voltage output of the accelerometer which was automatically integrated over time in the data acquisition system (ADwin-Gold, Jäger, Computergesteuerte Messtechnik GmbH, Lorsch, Germany). Computing the impulse by integrating the acceleration signal over time from every strike begin until strike end and multiplying this with the mass of the hammer, the categories were within the following impulse ranges: light: 0–1.2 kgm/s; medium: 1.2–2.4 kgm/s; and hard: 2.4-3.6 kgm/s. The number of strikes necessary to insert the nail was evaluated for each category.

To determine cortical bone strains during nail insertion, each femur was instrumented with 9 strain gage rosettes (Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany, SG Type: 3/120RY81-3-2M, Amplifier: MGCplus). Each rosette consisted of 3 single strain gages positioned in an angle of 45 degrees to each other on the polyamide carrier. Considering the anatomy of the femur with respect to the different nail systems, the rosettes were attached to regions where the strains were expected to be critical (Fig. 2). One rosette was attached to the posterior aspect of the femoral neck.

Two rosettes were attached to the posterior and anterior aspects of the greater trochanter, and 2 rosettes were applied medial and lateral of each entry point. In the TT and LT groups, 1 rosette was placed at the level of the expected impingement site on the medial aspect of the proximal cortex. The position of the predictable impingement point was measured for each bone in the TT and LT groups on the preoperative x-rays by using a special nail template for each group. For the PF group a standard position at a fixed distance to the lesser trochanter at about the height of the impingement sites of the LT and TT groups was defined for this strain gage location as no impingement point exists in the PF group. The last 3 rosettes were bonded to the distal diaphysis at about two-third of the femur length (posterior medial, posterior lateral, and anterior).

All data were recorded at a sampling rate of 1000 Hz using 2 synchronized data acquisition systems with 32 analog input channels in total with 16-bit resolution (ADwin-Gold, Jäger, Computergesteuerte Messtechnik GmbH).

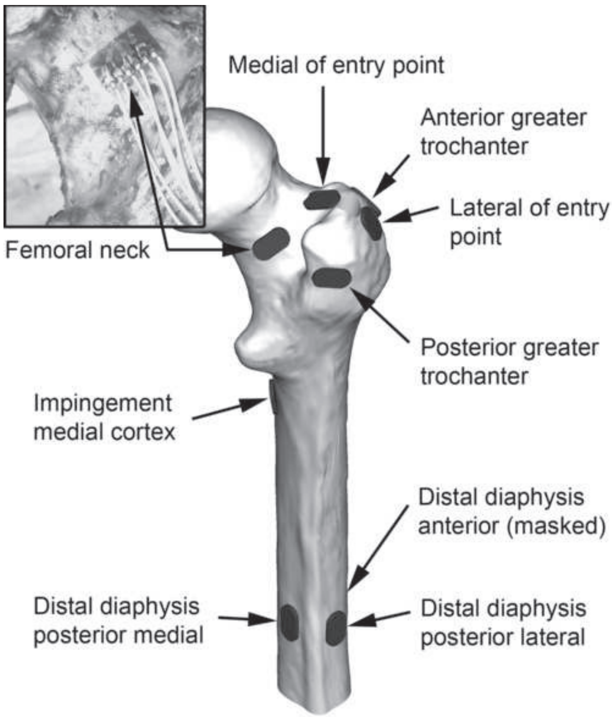

Figure 2. Illustration of the strain gage locations of a femur of the TT group. Upper left picture: example of a strain gage bonded to the femoral neck.

Preparation and nail insertion

A 10-mm hole was drilled in the center of the femoral head in an AP direction, and a 9.9-mm bolt was inserted into the head. To avoid head splitting, the head with the bolt in situ was embedded in PMMA (Polymethylmethacrylat, Beracryl, Troller AG, Fulenbach, Switzerland). The femur was oriented to simulate its position during surgery. The bolt was attached to a custom-made holding device and the femur shaft placed against a padded counter bearing (Fig. 3).

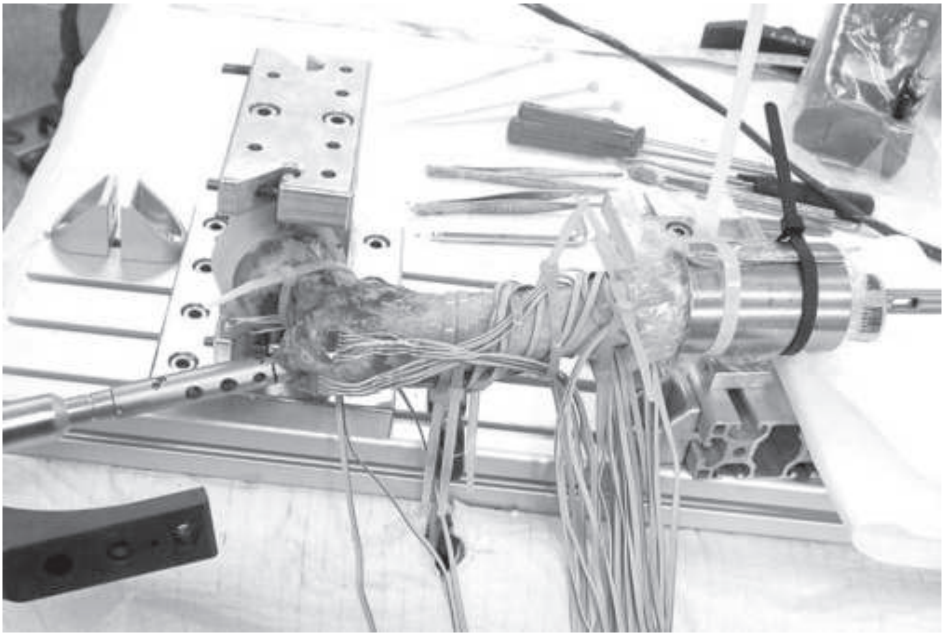

Figure 3. Experimental setup during nail insertion with strain gages attached to the femur.

Entry points were located at the piriform fossa for the PF group, at the trochanteric tip for the TT group, and at a point lateral to the tip of the greater trochanter for the LT group (Fig. 1). The entry points for the TT and the LT groups were identified using a custom-made template indicating the proper inclination of the entry path relative to the femoral canal and the lateral offset of the entry point relative to the canal axis on preoperative radiographs. In the clinical setting the pre- operative planning should be done similarly. A 2.8-mm K-wire was inserted at the entry site, and its alignment with the medullary canal was checked under fluoroscope control in AP and lateral–medial views. In the PF group the K-wire was positioned conventionally in line with the medullary canal. In the TT group the K-wire was inserted 6 degrees lateral to the central canal in the AP view and in line with the medullary canal in the lateral-medial view. In the LT group the 2.8-mm K-wire was placed 10 degrees lateral to the neutral femoral axis in the AP view and in line with the canal in the lateral view. The cortex was manually opened at the insertion point with a cannulated drill bit over the K-wire (13 mm for the PF and LT groups and 16 mm for the TT group). Medullary canals of all specimens were reamed up to 13 mm in increments of 0.5 mm using the SynReam system (Synthes Inc, Paoli, PA). A transverse osteotomy was performed at the distal third of the femur (distally to the distal diaphysis strain gages) to simulate a fracture. The distal fracture fragment was removed before the nail was inserted to avoid unrealistic peak strains which might have occurred by hammering the nail into an intact femur and which would not have resembled the clinical situation.

Data acquisition of strain values and hammer strikes was synchronously started. According to the manufacturer's protocol the nails were introduced by hand with the insertion handle until resistance was sensed by the surgeon. At that point, the sliding hammer was attached to the carbon fiber handle, and the insertion was completed with hammer strikes. Hammer strike intensities categorized as light, medium, and hard were also visually displayed to the surgeon to provide feedback during the insertion process. The strike intensities were kept by the surgeon in the category light as long as possible, but if the nail could not be driven any further, higher strike intensities were used to finish the insertion. In cases where the nails could be inserted completely by hand without hammering, strain values were recorded in the final position. Finally, the nails were locked proximally using standard locking with 4.8-mm locking bolts. All nail insertions were performed by 1 surgeon (C.A.M.) who was a surgical resident and had training in intramedullary femoral nailing. The occurrence of iatrogenic fractures or fissures as determined from visual inspection (instead of radiographic control) was documented. As opposed to a fracture with displacement, a fissure was defined to be an incomplete fracture with no displacement. Biplanar radiographs were taken postoperatively to check nail position in the medullary canal.

Data analysis and statistics

Global differences between the entry point groups with regard to the number of hammer strikes in each intensity level (light, medium, and hard) were analyzed with a nonparametric Kruskal–Wallis K-sample test. From the recordings of the 3 strain gages of each rosette, the maximum principal strain was calculated for each time point. For each rosette the highest value of the maximum principal strain during the insertion process was determined as the characterizing value for that location. For each strain gage location this value was analyzed for global differences between the entry point groups with a Kruskal–Wallis K-sample test. Comparisons between individual groups were performed using a Mann–Whitney U test with Bonferroni correction for number of group comparisons. The iatrogenic fracture and fissure occurrence in the 3 groups was analyzed using a chi-square test. All mathematical evaluations were performed using the MatLab software package (The Math Works, Version 6.5.0.180913a, Release 13). Statistical analysis was performed using SPSS for Windows (Version 14.0.1). For all statistical tests significance was defined as $P < 0.05$.

RESULTS

Hammer strikes

In the intensity category hard, only 2 hammer strikes were recorded for the whole test series, which occurred during insertion of an AFN in the TT group. For this femur a fracture located at the posterior aspect of the greater trochanter starting at the entry point of the nail was observed. With regard to the numbers of hammer strikes in the light- and medium-intensity categories, no significant differences were found between the 3 groups (light: $P = 0.287$ and medium: $P = 0.447$).

Surface strains

The maximum principal strains that occurred during the insertion of each of the tested specimens are shown in Figure 4 for each strain gage location and entry point (PF, TT, and LT). Most of the strain values are below 1600 μm/m, but in certain locations very high strains up to 4500 mm/m were also recorded. The strains at the impingement site of the nail at the medial cortex and the 3 distal diaphysis sites are below 1600 μm/m for all 3 groups. Only in 1 specimen of the PF group, a strain value of 2250 μm/m at the distal diaphysis anterior strain gage was measured, which might have been due to a mismatch of radius of curvature of the nail compared with that femur specimen. This finding is very similar for the strains at the femoral neck. They are mainly low except for 1 specimen in the LT group, which had a strain of 2100 μm/m. At the greater trochanter very low strains (below 1000 μm/m) were seen at the anterior aspect, and strains below 1600 μm/m were observed at the posterior aspect with 2 exceptions: 1 specimen each in the TT and LT groups had strains between 3000 and 3500 μm/m. The most frequent strain values above 1600 μm/m were seen near the nail entrance—predominantly on the medial side of the entry point and at the posterior greater trochanter. Medial to the entry point, 1 specimen of the LT group and 3 of the TT group showed strains around 4000 μm/m, whereas in the PF group 1 specimen had a strain value of about 3000 μm/m. Lateral to the entry point, 2 specimens of the TT group showed strains about 2200 μm/m. At this location the maximum strains were 1480 μm/m in the PF group and 1680 μm/m in the LT group. Statistical evaluation only revealed significant global differences between the entry point groups at the strain gage location lateral to the entry point ($P = 0.026$) and at the anterior greater trochanter ($P = 0.037$). At the lateral side of the entry point, the strains in the TT group were significantly higher than in the PF group ($P = 0.03$). At the anterior greater trochanter, the strains of the TT group were significantly higher than those in the LT group ($P = 0.03$). However, for these 2 locations, strain values were below 2200 μm/m. Although no statistical differences were found medial to the entry point and at the posterior greater trochanter, the number of femurs with high strains (close to or above 4000 μm/m) was higher for the groups with the lateral entry points.

Iatrogenic fractures and fissures

In the PF group there were no iatrogenic fracture or fissure (0/8, 0%), in the TT group there was 1 iatrogenic fracture and 3 fissures (4/8, 50%), whereas in the LT group 1 fissure (1/8, 12.5%) occurred. With regard to fracture and fissure occurrence, the difference between the PF and TT group was significant ($P = 0.021$, power = 0.50). Applying an unpaired t test for all specimens, there were no significant BMD differences between femurs with and without iatrogenic fractures or fissures ($P = 0.94$) (with: 0.446 ± 0.051 g/cm^3; without: 0.448 ± 0.050 g/cm^3). In the TT group the fissures started medially from the entry point at the trochanter–neck junction. The iatrogenic fracture started laterally from the entry

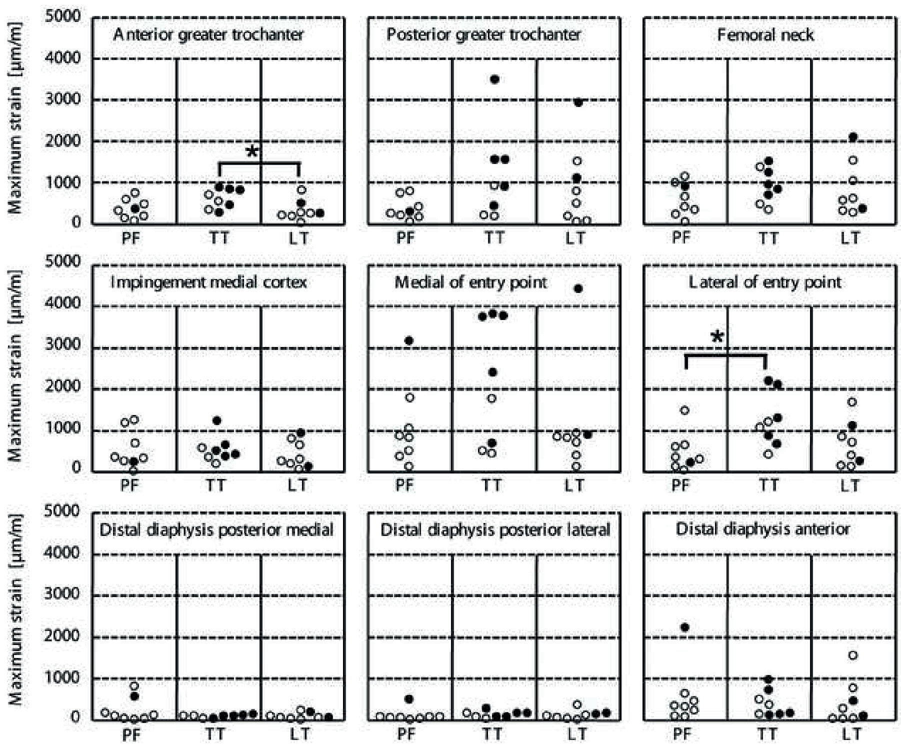

Figure 4. Maximum principal strains for all strain gage locations depending on entry point group. Significant differences between groups are indicated by stars. Data points of specimens with fissures or fractures are indicated by black symbols.

point through the greater trochanter, dislocating the complete posterior part of the greater trochanter. This fracture was rated as the most severe one and occurred for the specimen with the highest hammer strike intensities. In the LT group the fissure started at the medial side of the entry point. For this specimen, the highest strain value was recorded at that strain gage location (about 4500 μm/m). In Figure 4 strain data points of specimens with iatrogenic fissures and fractures are marked. At the locations with the highest strains (medial to the entry point and posterior greater trochanter) bones with iatrogenic fissures and fractures also had the highest strains.

DISCUSSION

Many investigations reported that from a mechanical point of view the piriform fossa is the preferable entry point for intramedullary nailing of a femoral shaft fracture, due to its perfect alignment with the medullary canal.[4,6,7] However, a more lateral placement of the entry point would be preferable with respect to a supine surgical approach and reduced soft tissue damage.[8]

Starr *et al.*[20] in a prospective randomized study found no differences between cephalomedullary nails inserted through trochanteric and piriform fossa entry portals with regard to incision length, duration of surgery, blood loss, reduction, ease of use, union rate, complication rate, or outcome. Further, in a prospective cohort study including 4 level 1 trauma centers, Ricci *et al.*[21] recently noted that nailing through the tip of the greater trochanter, especially in obese patients, required less operative and fluoroscopy time than nailing through the piriform fossa. Johnson *et al.*[16] reported that placement of the starting portal anterior, medial, or lateral to the axis of the medullary canal resulted in high stresses at the distal end of the proximal femoral component and a greater potential for bursting, if standard cloverleaf intramedullary nails were used. Additionally, they related clinical occurrences of iatrogenic fractures to a displaced starting position of the nail.[16] The reported complications can be attributed to the insertion of uniplane bent nails with only an AP curvature at entry points which were not in line with the axis of the medullary canal. Nonrigid implants, such as hollow and slotted nails, may absorb some strain caused by bending if a noncorresponding entry point is used. Rigid, closed-section nails will presumably not compensate this and may result in a higher risk of iatrogenic fractures. The motivation of the present study was therefore to compare surface strains and iatrogenic fracture occurrence of 2 closed-section nails with biplanar bends and lateral entry points relative to a uniplane bent closed-section nail introduced through the piriform fossa for the treatment of femoral shaft fractures.

We measured strains at various sites of the proximal femur. Unfortunately, no proximal strains have been reported so far for femoral nailing which would have allowed a comparison to our data. Aamodt *et al.*[22] published the only existing data on human in vivo femoral bone strains measured during daily activities including single leg stance and stair climbing. They measured maximum principal strains of 1500 μm/m in the proximal lateral aspect of the femur in 2 human beings during walking. Miller *et al.*[7] measured the strains generated at the superior aspect of the femoral neck while loading the femur until failure after creating a 14-mm entry hole at the piriform fossa. They recorded tensile strains of 2000 μm/m at a load of about 3 kN without causing any failure. Based on these findings, we consider strains of 2000 μm/m not to be problematic.

In our study we found low strains at the impingement point and at the distal diaphyseal site. Fissures or fractures at the distal site were therefore not seen for any of the systems.

Considerably higher strains between 2000 and 4500 μm/m were found mainly located at the posterior aspect of the greater trochanter and on the medial side of the entry point. As a consequence of these high strains, fissures or fractures were observed in the TT and LT groups starting at the entry point (Fig. 4).

Thin cortical walls are less capable of resisting strains than thicker cortical walls during nail insertion. Therefore, fissures are generated more easily in a thin cortex than in a thick cortex at the same hammer strike intensity. In the TT specimens reaming before nail placement had to be performed up to 16 mm (compared with 13 mm in the other specimens), leaving thin cortical walls (Fig. 5). This might explain the high incidence (3/8) of fissures in this group. The diameter of the nail of 15 mm proximally and thus the required reaming diameter may have influenced the incidence of high bone strains more than the insertion point itself. From this study it appears that the bigger the nail

Figure 5. Thin medial wall after reaming and AFN nail insertion resulting in a fissure medially.

diameter is, the bigger the reaming canal must be, the thinner the cortical walls are left, the more precise the entry point should be.

Given the same entry path relative to the axis of the femoral canal, thin cortical walls can also be due to a small greater trochanter, which is not unusual given the anatomical variations of the latter. In femurs with a small greater trochanter, thinner cortical walls are left by choosing lateral entry points. This was the case in the specimen of the LT group for which we recorded the highest strain in the study and for which we also observed a fissure.

The clinical relevance of the observed fissures around the nail entry site is questionable. They were only recognized in this experiment because the soft tissues were stripped of the specimens. In a clinical setting with a fluoroscopic view only, they would most likely have been overlooked. To our experience and knowledge, such fissures do not represent a clinical problem.

One specimen in the TT group sustained an iatrogenic fracture dislocating a part of the posterior wall of the greater trochanter. In retrospect, the entry path in this specimen was not chosen well (14 degrees instead of 6 degrees). The highest hammer strike intensities of the entire experiment were necessary to insert the nail in this specific specimen. To avoid this situation in a clinical setting it is more appropriate to enlarge the entry hole by reaming another 1–2 mm instead of using more force with the hammer.

From pilot experiments performed before this study, it was seen that choosing the entry point only based on the outer anatomy of the greater trochanter region easily leads to wrong entry path inclinations. Individual variations in the outer anatomy of the greater trochanter are recently recognized to influence entry point preciseness.[23] Additionally, the distance between the entry point and the medullary canal is longer for entry points at the greater trochanter than for the piriform fossa, which might make it more difficult to achieve a precise entry path. For the clinical setting, where the entry point is mainly determined by the surgeon's palpating finger and a C-arm, knowledge of these anatomic variations is important. We suggest that both the insertion angle of the K-wire and position of its entry path into the femoral canal should at least be checked radiographically in 2 planes and corrected if necessary.

With regards to limitations of the study we would like to state that we measured only periosteal or surface strains and not endosteal strains which might have been higher especially at locations where the nail was in contact with the intramedullary canal during insertion (e.g. impingement point). Measuring endosteal strains was not possible from a technical viewpoint as the strain gages could not be glued to the inner surface of the reamed canal. Furthermore, the study was not designed to investigate the influence of the insertion precision or insertion procedure upon bone strains. For the purpose of investigating the influence of the insertion precision, reaming should have been performed at defined offsets from the ideal entry path. With regard to precision we can only say that the entry path of the specimen for which we observed the fracture (TT group) was the most inaccurate of all insertions. For the purpose of investigating the influence of the insertion procedure, further insertion procedures should have been defined for each nail and then have been carried out in individual groups of femurs. Throughout the study the manufacturer's recommendations for insertion were followed for each nail as closely as possible.

The results of this investigation on the treatment of femoral shaft fractures have to be distinguished carefully from the treatment of reversed-type subtrochanteric fractures, as investigated by Ostrum *et al.*[24] For those fractures higher degrees of bending of the nail in conjunction with a lateral entry portal are not proposed due to the risk for varus deformities. If the fracture line, however, is located at the isthmus or lower, the risk for varus deformities is not an issue, but is replaced by an increased risk for iatrogenic fracturing of the intact proximal part of the femur.

In conclusion, 3 issues are important for intramedullary nailing of femur shaft fractures: anatomic safety, clinical ease, and biomechanical considerations. With regard to the first 2 issues, laterally based intramedullary nails have the advantage of an easier surgical approach and less iatrogenic damage only in supine nailing. From a biomechanical perspective, a precise starting hole and entry path are essential to avoid fractures or fissures at the entry portal. As in this study we observed more fractures and fissures in the lateral entry point groups as compared with the PF group, we would like to emphasize the importance of a precise entry point for these nails. Due to the anatomic variations of the greater trochanter, we recommend not to determine the insertion point based on anatomic landmarks alone but to also verify the insertion path radiologically in 2 planes. Furthermore, the diameter of the proximal part of the nail and thus the diameter of the entry hole may influence the occurrence of fractures or fissures. When these biomechanical considerations are kept in mind, the advantage of an easier surgical approach for supine antegrade intramedullary nailing of mid- to distal femoral shaft fractures with less iatrogenic damage to the neurovascular and muscular structures may justify the use of a nail designed with proximal bends specifically for a more lateral entry point.

REFERENCES

1. Bick EM. The intramedullary Nailing of Fractures by G. Kuntscher. Translation of article in Archiv fur Klinische Chirurgie, 200:443, 1940. *Clin Orthop Relat Res.* 1968;60:5-12.
2. Brumback RJ, Uwagie-Ero S, Lakatos RP, Poka A, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part II: Fracture-healing with static interlocking fixation. *J Bone Joint Surg Am.* 1988;70(10):1453-1462.
3. Brumback RJ, Reilly JP, Poka A, Lakatos RP, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part I: Decision-making errors with interlocking fixation. *J Bone Joint Surg Am.* 1988;70(10):1441-1452.
4. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg Br.* 1988;70(2):206-210.
5. Gausepohl T, Pennig D, Koebke J, Harnoss S. Antegrade femoral nailing: an anatomical determination of the correct entry point. *Injury.* 2002;33(8):701-705.
6. Harper MC, Carson WL. Curvature of the femur and the proximal entry point for an intramedullary rod. *Clin Orthop Relat Res.* 1987(220):155-161.
7. Miller SD, Burkart B, Damson E, Shrive N, Bray RC. The effect of the entry hole for an intramedullary nail on the strength of the proximal femur. *J Bone Joint Surg Br.* 1993;75(2):202-206.
8. Dora C, Leunig M, Beck M, Rothenfluh D, Ganz R. Entry point soft tissue damage in antegrade femoral nailing: a cadaver study. *J Orthop Trauma.* 2001;15(7):488-493.
9. Khan FA, Ikram MA, Badr AA, al-Khawashki H. Femoral neck fracture: a complication of femoral nailing. *Injury.* 1995;26(5):319-321.
10. Mileski RA, Garvin KL, Crosby LA. Avascular necrosis of the femoral head in an adolescent following intramedullary nailing of the femur. A case report. *J Bone Joint Surg Am.* 1994;76(11):1706-1708.
11. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip. *Injury.* 2005;36(11):1337-1342.
12. Bednar DA, Ali P. Intramedullary nailing of femoral shaft fractures: reoperation and return to work. *Can J Surg. J Can Chir.* 1993;36(5):464-466.
13. Danckwardt-Lilliestrom G, Sjogren S. Postoperative restoration of muscle strength after intramedullary nailing of fractures of the femoral shaft. *Acta Orthop Scand.* 1976;47(1):101-107.
14. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br.*1997;79(5):738-741.
15. Bain GI, Zacest AC, Paterson DC, Middleton J, Pohl AP. Abduction strength following intramedullary nailing of the femur. *J Orthop Trauma.* 1997;11(2):93-97.
16. Johnson KD, Tencer AF, Sherman MC. Biomechanical factors affecting fracture stability and femoral bursting in closed intramedullary nailing of femoral shaft fractures, with illustrative case presentations. *J Orthop Trauma.* 1987;1(1):1-11.
17. Johnson KD, Tencer A. Mechanics of intramedullary nails for femoral fractures. *Unfallchirurg.* 1990;93(11):506-511.
18. Lies A, Josten C, G M. Complications of intramedullary nailing and their prevention. *Zentralbl Chir.* 1993;118:342-350.
19. Fernandez Dell'Oca AA. The principle of helical implants. Unusual ideas worth considering. *Injury.* 2002;33 Suppl 1:SA1-27.

20. Starr AJ, Hay MT, Reinert CM, Borer DS, Christensen KC. Cephalomedullary nails in the treatment of high-energy proximal femur fractures in young patients: a prospective, randomized comparison of trochanteric versus piriformis fossa entry portal. *J Orthop Trauma*. 2006;20(4):240-246.
21. Ricci WM, Schwappach J, Tucker M, *et al*. Trochanteric versus piriformis entry portal for the treatment of femoral shaft fractures. *J Orthop Trauma*. 2006;20(10):663-667.
22. Aamodt A, Lund-Larsen J, Eine J, Andersen E, Benum P, Husby OS. In vivo measurements show tensile axial strain in the proximal lateral aspect of the human femur. *J Orthop Res.* 1997;15(6): 927-931.
23. Grechenig W, Pichler W, Clement H, Tesch NP, Grechenig S. Anatomy of the greater femoral trochanter: clinical importance for intramedullary femoral nailing. Anatomic study of 100 cadaver specimens. *Acta Orthop*. 2006;77(6):899-901.
24. Ostrum RF, Marcantonio A, Marburger R. A critical analysis of the eccentric starting point for trochanteric intramedullary femoral nailing. *J Orthop Trauma* 2005;19(10):681-686.

CLINICAL MODELS

Chapter 6

Functional outcome after antegrade femoral nailing: a comparison between trochanteric fossa versus tip of greater trochanter entry point

Chapter 7

Intramedullary nailing through the trochanteric fossa versus greater trochanter tip: prospective randomized study with in-depth functional outcome results

6

Functional outcome after antegrade femoral nailing: a comparison of trochanteric fossa versus tip of greater trochanter entry point

C.M. Ansari Moein, H.J. ten Duis, L. Oey, G. de Kort, W. van der Meulen, K. Vermeulen and Chr. van der Werken

J Orthop Trauma. 2011;25(4):196-201

ABSTRACT

Objectives: This study was performed to explore the relationship between entry point-related soft tissue damage in antegrade femoral nailing and the functional outcome in patients with a proximal third femoral shaft fracture.
Design: Retrospective clinical trial.
Setting: Level I university trauma center.
Patients: Seventeen patients with a high femoral shaft fracture treated with an antegrade femoral nail joined the study.
Intervention: Nine patients with an Unreamed Femoral Nail (UFN; Synthes, Bettlach, Switzerland) inserted at the trochanteric fossa and eight patients with a long Proximal Femoral Nail (PFN; Synthes) inserted at the tip of the greater trochanter.
Main Outcome Measurements: Pain, gait, nerve, and muscle function along with endurance.
Results: Five patients with a UFN had a positive Trendelenburg sign and a reinnervated superior gluteal nerve after initial injury of the nerve at operation. None of these findings occurred in the long PFN group ($P = 0.01$). Isokinetic measurements showed diminished abduction as well as external rotator function in the UFN group rather than in the long PFN group. Leg endurance was significantly lower in patients with a UFN.
Conclusions: Compared with the trochanteric fossa, femoral nailing through the greater trochanter tip may decrease the risk of damage to the superior gluteal nerve and intraoperative damage to the muscular apparatus of the hip region, resulting in some improved muscle function. Therefore, a lateral entry point may be a rational alternative for conventional nailing through the trochanteric fossa.

INTRODUCTION

Intramedullary nailing is well established for the treatment of fractures of the femoral shaft. The current entry point for most antegrade nails is the trochanteric fossa.[1-4] Well-recognized but rare complications of femoral nailing include iatrogenic fracture and fat embolism, but little attention is paid to the often persistent pain in the trochanteric region and loss of muscle strength and endurance in the upper leg after the fracture has healed.[5,6]

Percutaneous access to the trochanteric fossa is rather demanding and proper direction of the penetrating device in line with the intramedullary canal is essential.[7,8] Misdirection may result in violation of the subtrochanteric femoral cortex or even fracture of the femoral neck.[5]

Furthermore, this technique requires inevitable surgical dissection through the abductor and external rotator musculature of the hip. In addition, nail entrance through the trochanteric fossa bears some risk of iatrogenic injury of the medial circumflex femoral artery and superior gluteal nerve with subsequent vascular damage to the femoral head and paralysis of the gluteal muscles respectively.[9-13] These problems may ultimately result in reduced daily function for the patient and are associated with moderate pain, a discrete Duchenne limp, muscle weakness, and some loss of endurance.

Nail introduction through the tip of the greater trochanter appears to reduce the risk of damage to vascular and nervous structures and the abductor and external rotator muscle apparatus of the thigh.[13-17] Therefore, nails specifically designed for insertion through the tip of the greater trochanter have gained popularity.[18,19]

To date, adjacent soft tissue damage that can occur during antegrade femoral nailing and subsequently results in postoperative morbidity has not been quantified in a clinical setting. The aim of this retrospective study was to explore the relationship between nail entry point-related soft tissue damage and functional outcome in patients with a proximal third femoral shaft fracture treated with either a straight nail inserted through the trochanteric fossa or with a proximally bent nail inserted through the greater trochanter.

PATIENTS AND METHODS

We performed a retrospective study in a limited number of patients with proximal third (subtrochanteric) femoral shaft fractures (Orthopaedic Trauma Association 32A and 32B) treated with either an Unreamed Femoral Nail (UFN; Synthes, Bettlach, Switzerland) or a long Proximal Femoral Nail (long PFN; Synthes) from January 1997 to June 2002. To create an unbiased clinical setting, eligibility criteria included patients with the same sex, within the same age range, with comparable fracture types, and under the same medical and concomitant clinical circumstances. This resulted in a limited number of matched pair cohorts. Only patients with uneventful and completely healed fractures were included. We excluded patients with bilateral femoral shaft fractures, a pathologic fracture, previous, concomitant, or later fractures of the lower extremities, and/or older than 70 years of age. Patients carrying a pacemaker were also excluded from the study as a result of the inability to obtain a magnetic resonance image.

Operative procedure

All fractures could principally have been treated adequately with either a UFN or a long PFN; the original choice was determined by the preference of the surgeon on call. All patients were treated in the supine position using a similar technique. Before nail insertion, all fractures were reduced under image intensifier control on the fracture table with boot traction or distal femoral skeletal traction. After a short longitudinal skin incision approximately 5 cm cranial to the greater trochanter tip, the fascia layers were dissected sharply. Thereafter, the correct entry point was confirmed by Kirschner wire insertion under image intensifier control. Reaming of the proximal cortex was performed with a soft tissue protector. All nails were locked both proximally and distally.

Patient-reported outcome and clinical assessment

At mean follow-up of 26 months (22 months in the long PFN group and 30 months in the UFN group) after surgery, all patients had standard evaluation consisting of a questionnaire, physical examination, and the Harris hip score.[20] Participants were asked to quantify postoperative pain during daily activity on a visual analog scale[21] ranging from 0 (“no pain”) to 10 (“unbearable pain”). The Trendelenburg test[22] was performed and Duchenne limping was assessed at gait analysis.

Evaluation of muscle strength and endurance

Muscle strength and endurance in the hip abductor and external rotator muscle apparatus were determined isokinetically on a Cybex 6000 dynamometer (Cybex International Inc., Medway, Massachusetts) for comparison.[23] After an initial 5 minutes of limbering up, the patients performed five external and internal rotations as forcefully as possible at a fixed speed of 30° and 60° per second. After a rest, they performed 15 consecutive external and internal rotations at 120° per second. To evaluate the endurance, values of the first five sets of movements were compared with the last five during 120° per second test speed (endurance ratio = last five [Nm]/ first five [Nm]). In between each test, there was a 30-second rest. Subsequently, thigh abduction and adduction were performed in the same order of test speeds (five consecutive exercises at 30° and 60° and 15 exercises at 120° and the endurance ratio). Peak torque values (Nm) in the fractured limb were compared with the values obtained in the uninjured side and the difference was

Table 1. Patient-Reported Outcome, clinical assessment and EMG in the (A) UFN Group and (B) Long PFN Group

A

	Patient Number	Age (years)	Sex	Fracture Type	Trendelen-burg (0=nega-tive, 1= positive)	EMG Rein-nervation (0=no, 1 = in one or more muscles)	VAS-Pain (0 - 10)	Pain Inter-ference With Daily Activ-ity (No=0, Slight=1, Moder-ate=2, Severe=3)	Walking Distance (0= infi-nite)	Reduced Ability Inten-sive Exercise (no = 0, slight = 1 , moder-ate =2 severe = 3)	Walking Stairs (normal = 0, with some aid = 1, difficult = 2)	Post-operative Change of Profession	HHS
	1	18	M	32A	0	0	3	0	0	0	0	no	100
	2	27	M	32A	0	1	4	0	0	1	0	no	100
	3	46	M	32B	0	0	3	1	0	1	0	no	96
	4	38	M	32A	1	0	4	1	0	1	0	no	77
	5	45	M	32A	0	0	5	0	0	1	0	no	96
	6	49	M	32A	1	1	5	2	<2km	3	2	yes	68
	7	52	M	32B	1	1	6	2	<2km	1	0	no	87
	8	39	M	32B	1	1	6	3	<2km	3	2	yes	35
	9	51	M	32B	1	1	4	2	<2km	3	1	yes	79
Average (SD)		40,5 (11,5)					4,5 (1,1)						82,0 (18,9)

Table 1.
(continued)
B

	Patient Number	Age (years)	Sex	Fracture Type	Trendelen-burg (0= negative, 1= positive)	EMG Re-innervation (0= no, 1 = in one or more muscles)	VAS-Pain (0 - 10)	Pain Interference With Daily Activity (no = 0, yes = 1)	Walking Distance (0= infinite)	Reduced Ability Intensive Exercise (no = 0, slight = 1, moderate = 2, severe = 3)	Walking Stairs (normal = 0, with some aid = 1, difficult = 2)	Post-operative Change Of Profession	HHS
	1	62	M	32A	0	0	5	0	0	1	1	no	95
	2	35	M	32A	0	0	5	1	<2km	3	0	no	89
	3	58	M	32B	0	0	4	0	0	1	0	no	69
	4	45	M	32A	0	0	3	0	<2km	3	1	no	80
	5	46	M	32A	0	0	4	0	0	3	0	no	78
	6	67	M	32A	0	0	3	1	<2km	3	0	yes*	69
	7	34	M	32B	0	0	2	0	0	1	0	no	95
Average (SD)		48 (12,8)					3,3 (1,2)						89,8 (11,3)

* due to spinal injury
UFN, Unreamed Femoral Nail; PFN, Proximal Femoral Nail; M, male; EMG, electromyography; VAS, Visual Analogue Scale; HHS, Harris Hip Score; SD, standard deviation.

expressed as a percentage of the uninjured side. The percentage was considered negative when the peak torque was lower on the fractured side. Previously published data indicate that the reliability coefficient of isokinetic Cybex measurements varies between 0.80 and 0.99. [24,25]

Magnetic resonance imaging

Static magnetic resonance imaging (MRI) scanning was used to document postoperative soft tissue damage, fibrosis, or atrophy in the operated hip region and compared with the uninjured side.[26] The maximum muscle thickness (cm) of the abductors and external rotators was measured after which the difference in thickness between the operated and the control side was calculated. In addition, fibrosis in the muscles were documented and compared. To evaluate femoral head perfusion, dynamic MRI was carried out according to the method proposed by Konishiike *et al.*[27,28] A 1.0-Tesla superconducting scanner was used (Philips, Eindhoven, The Netherlands) with a two-dimensional fast low-angle shot with fat saturation. The paramagnetic contrast agent, gadolinium-diethylene-triamine penta-acetic acid (Gd-DTPA, 0.1 mmol/kg body weight), was injected into a brachial vein. The acquisition time for each image was 15 seconds. The region of interest was chosen in the image of the bilateral femoral heads. A dynamic curve was drawn in which the signal intensity of the region of interest in the femoral head was plotted against time.

Electrophysiological studies

Needle electromyography (EMG) from selected abductor muscles of the operated side (the gluteus maximus, medius and minimus, and the tensor fascia latae muscles) was carried out to assess the completeness of recruitment patterns and to look for evidence of ongoing denervation (fibrillation potentials and positive sharp waves) and/or reinnervation (reduction in number and increase in amplitude and duration of motor unit action potentials). To exclude radiculopathy and plexopathy as the underlying mechanism, limited nerve conduction studies were applied in both lower extremities. Antidromic sensory conduction studies were performed using surface recording electrodes for the sural and saphenous nerves. Hoffman reflex (H-reflex) measurement of the vastus medial and soleus muscles were performed with standard surface stimulation and recording technique.[29]

Statistics

The independent samples t test for comparison of the groups was used for nonparametric variables and the chi-square test for categorical variables. The Mann-Whitney test was used for skewed variables. *P* values less than 0.05 were considered significant. SPSS Version 14.0 (SPSS Inc, Chicago, IL) was used for all analysis.

RESULTS

A total of 17 patients were included in the study after written informed consent: nine male patients treated with a UFN with a mean age 40.5 years (range, 18–52 years) and eight male patients treated with a long PFN with mean age 48 years (range, 34–67 years). None of the implants had been removed.

Patient-reported outcome and clinical assessment

Table 1 shows the main outcome parameters. The differences between the groups were minimal. Some degree of residual pain was present in both groups of patients, but the differences were not statistically significant. The residual pain in both groups was predominantly localized to the gluteal region and the region of the surgical scar (five patients in the UFN and four in the long PFN group), in four patients (two in each group) in the entire upper leg and in two patients in the UFN group in the groin. The problems that occurred for the patients (in both groups) during prolonged walking always included muscle weakness and subsequent reduced endurance in the operated leg with additional limping. All patients in both groups had a hip range of motion equal to the opposite side.

The Trendelenburg sign was positive in five patients from the UFN group (56%) (Table 1A). In all patients with a long PFN, this sign was negative (0%). The difference in Trendelenburg sign between the groups was reached significance with a *P* value of 0.01.

Electromyographic studies

There were no signs of ongoing denervations in the examined muscles in either group. Five of the patients in the UFN group had an abnormal EMG with evidence of acute injury of the superior gluteal nerve directly after operation followed by reinnervation. In four of these patients, the reinnervated muscle was the tensor fasciae lata and in one patient both the gluteus maximus and gluteus minimus muscles were affected. In three patients with a long PFN, light abnormalities were seen during surface electrode measurements of the sural and saphenous nerves. Two of these patients were older than age 60 years. However, no patients treated with a long PFN had abnormal EMG findings (0%). As a consequence, the absence of reinnervation signs in the long PFN group was statistically significant with a *P* value of 0.01 using the chi-square test (Table 1A–B).

Magnetic resonance imaging

Comparison of static MRIs revealed no statistically significant differences. However, as can be seen in Table 2, the maximum thickness of the abductor and external rotator muscles was more reduced in the injured hip region in the UFN group than in the long PFN group. There was also more fat accumulation and fibrosis in the abductor apparatus

Table 2. Static Magnetic Resonance Imaging

	UFN (N=9)	Long PFN (N=8)
Abductor muscles*	-0.6(0.8)	-0.3(0.5)
External rotator muscles*	-0.9(0.7)	-0.2(0.5)
Fatting	3	2
Fibrosis abductor muscles	2	0
Fibrosis external rotator muscles	0	0

* Mean values of sum of differences of maximum muscle thickness (cm) with standard deviations.
A negative value was generated when the muscle volumes of the injured side were reduced.
UFN, Unreamed Femoral Nail; PFN, Proximal Femoral Nail

in the UFN group on the injured side than in the long PFN group. The dynamic MRIs could not reveal the state of perfusion in the bilateral femoral heads. There was no conclusion to be drawn from the dynamic findings.

Isokinetic studies

The values at 30°, 60°, and 120° per second were fairly similar for most parameters per patient; therefore, these values were averaged. The values for peak torque and endurance in the injured leg were moderately reduced during abduction and external rotation in both groups (Table 3). The difference in endurance during adduction, internal rotation, and external rotation was statistically significant. These endurance values were significantly lower in the UFN group.

DISCUSSION

Antegrade femoral nailing is regarded as the method of choice for treatment of most femoral shaft fractures.[1-3,8,9,30] The common entry point has been the trochanteric fossa for years, although this has been associated with complaints of pain, muscle weakness and limping, and with complications such as septic hip arthritis and avascular necrosis of the femur head. These reported impairments may be based on the nail entry point. The trochanteric fossa is located near the superior gluteal nerve innervating the abductor musculature as well as near branches of the medial femoral circumflex artery, which supply the femoral head.[9-11,20,21,31] Furthermore, the abductor and external rotator musculature are dissected on the way to the entry point. Facilitating a lateral entry at the greater trochanter tip seems to circumvent most of these risks. To our knowledge, no study has objectively evaluated superior gluteal nerve damage after femoral nailing in a clinical setting. Five of the patients treated with an UFN showed a Trendelenburg sign, and four of them had an abnormal EMG with evidence of reinnervation of the superior

Table 3. Percentage Change in Isokinetic Values on Injured Side (100% = Uninjured Side) for Function Parameters in the Two Patient Groups.

	UFN (N=9)	Long PFN` (N=8)	*P(<0,05)*
Abduction			
Average peak torque (SD)	-32.1 (16.0)	-18.6(12.8)	
Average endurance (SD)	-24.4 (17.7)	-4.8(8.1)	
Adduction			
Average peak torque (SD)	-24.3(9.5)	-8.4(6.4)	
Average endurance (SD)	-51.5(24.1)	-14.3(26.5)	0.001
Internal rotation			
Median peak torque (range)	-89.1(-10.3- -126.4)	-3.9(+9- -16.3)	0.002
Average endurance (SD)	-42.2(30.1)	+2.6(4.5)	0.001
External rotation			
Median peak torque (range)	-39.6(-28.6- -150)	-5.9(-2- -13.2)	
Average endurance (SD)	-10.4(13.3)	+3.8(6.2)	0.014

Averages for normal distribution and medians for not normal distribution and 95% confidence intervals.
Average and median = mean values for tests performed at 30º, 60º and 120º per second.
For normal distribution averages and standard deviation were calculated, otherwise median and range.
UFN, Unreamed Femoral Nail; PFN, Proximal Femoral; SD standard deviation

gluteal nerve. One additional patient showed reinnervation of the superior gluteal nerve on the EMG but no sign of Trendelenburg on physical examination. None of the patients treated with a long PFN had any evidence of damage to the superior gluteal nerve nor a positive Trendelenburg sign.

The anatomic course of the superior gluteal nerve has been documented in various anatomic reports.[13,15-17,32] Branches of the nerve are in the surgical field during the gluteal splitting approach to the trochanteric fossa as well as the greater trochanter tip. The average distance from the greater trochanteric tip to the lowest branch of the superior gluteal nerve, however, is 2,8 cm away in contrast to the nerve's location relative to the trochanteric fossa entry portal.[15] Therefore, using the greater trochanter tip as an entry point may reduce the risk of damage to these nerve branches.

Although one of the concerns about using the trochanteric fossa as the nail entry point in femur fractures is the probable reduction of strength and endurance in the operated leg, there are relatively few studies on muscle strength after nailing of femoral shaft fractures.[33-36] Most of these studies have measured isometric strength of the quadriceps and hamstrings. Few have evaluated isokinetic abduction function and we found no reports on external and internal rotation of the femur.[37] An isokinetic measurement allows measurement of muscle performance during limb movement.[23] Muscle performance is translated in peak torque and endurance.[24,25] It is common in isokinetic studies to perform movements in slow and fast speeds to evaluate function of the various types of muscle fibres. We found, however, that among our patients, the values obtained at 30°, 60°, and 120° were interchangeable and therefore we averaged the three values per patient. Emery *et al.* and van der Wees *et al.* have demonstrated that for knee flexors and extensors, the peak torque remains similar for slow and fast speeds.[24,38,39]

In this study, the majority of the patients in both UFN and long PFN groups had some reduced abduction peak torque as well as adduction strength at the operated side. Abduction endurance was reduced also in both groups with minimal differences between the groups. More striking differences were seen in internal and external rotation endurance; both were significantly reduced in the UFN group in comparison to the long PFN group. The latter finding can be explained from an anatomic point of view, that is, entering the femoral canal through the trochanteric fossa invariably damages the tendons of the external rotation muscles, which have their insertions in, or adjacent to, the trochanteric fossa.[15-17] Anatomic studies have also revealed damage to the gluteus medius and minimus muscles with nail insertion at the trochanteric fossa versus minimal damage to these muscles when using the tip of the greater trochanter. However, in this clinical setting, the abductor muscle strength was reduced in the UFN group as well as in the long PFN group.

Comparison of adjacent soft tissue damage with MRI between the two entry point groups did not show appreciable differences. However, reduced muscle volume and some fibrosis in the abductor apparatus were documented more often in patients treated with a trochanteric fossa entry portal. Our study was unable to critically evaluate bilateral femoral head perfusion using dynamic MRI. Two patients in the UFN group presented with postoperative pain in the groin, which may represent an intra-articular injury. The static MRI scans, however, did not reveal any femoral head abnormalities in any of the patients. Femoral head abnormalities may be better assessed with an MR arthrogram. Anatomic studies have revealed injury of the medial femoral circumflex artery when a nail is inserted through the trochanteric fossa.[15,40] Nevertheless, in the literature, rare cases have been reported of avascular necrosis of the femoral head after intramedullary nail insertion through the trochanteric fossa, especially in adolescents.[10,11]

Patients in both groups often described a fatigue pain associated with a limp that occurred after strenuous activities such as long-distance walking. Five patients in the UFN group exhibited a Trendelenburg sign before exercise and five patients in this group showed a reinnervated superior gluteal nerve at follow-up. Based on our findings, we presume that entrance through the trochanteric fossa is more likely to account for weakness, pain, and limping resulting from 1) injury to the gluteus medius and minimus muscles; 2) injury to the obturator externus muscle; or 3) injury to the superior gluteal nerve. We also surmise that entrance through the greater trochanter tip would account for some pain and limping predominantly resulting from the gluteal muscle injury.

Our goal was to objectively evaluate functional outcome after intramedullary nailing through the trochanteric fossa compared with a more lateral entry point, the greater trochanter tip, and to explore the relationship between the anatomic damage to adjacent soft tissues and the functional results in patients after intramedullary nailing through either entry portal. The retrospective nature of this study combined with a patient population evaluated by paired cohort matching resulted in a small sample size. These were very real limitations of our study.

In conclusion, more extensive follow-up is recommended with a larger sample size to reach more significant conclusions. However, based on the present data, femoral nail insertion through the greater trochanter tip appears to result in better postoperative hip function than when insertion of the nail is performed through the trochanteric fossa. Selecting a lateral entry point with the appropriate nail design may be considered a rational alternative to use of the trochanteric fossa.

REFERENCES

1. Winquist RA, Hansen ST, Jr., Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. 1984. *J Bone Joint Surg Am.* 2001;83-A(12):1912.
2. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg Br.* 1988;70(2):206-210.
3. Starr AJ, Hay MT, Reinert CM, Borer DS, Christensen KC. Cephalomedullary nails in the treatment of high-energy proximal femur fractures in young patients: a prospective, randomized comparison of trochanteric versus piriformis fossa entry portal. *J Orthop Trauma.* 2006;20(4):240-246.
4. Grechenig W, Pichler W, Clement H, Tesch NP, Grechenig S. Anatomy of the greater femoral trochanter: clinical importance for intramedullary femoral nailing. Anatomic study of 100 cadaver specimens. *Acta Orthop.* 2006;77(6):899-901.
5. Simonian PT, Chapman JR, Selznick HS, Benirschke SK, Claudi BF, Swiontkowski MF. Iatrogenic fractures of the femoral neck during closed nailing of the femoral shaft. *J Bone Joint Surg Br.*1994; 76(2):293-296.
6. ten Duis HJ. The fat embolism syndrome. *Injury.* 1997;28(2):77-85.
7. Ostrum RF, Marcantonio A, Marburger R. A critical analysis of the eccentric starting point for trochanteric intramedullary femoral nailing. *J Orthop Trauma.* 2005;19(10):681-686.
8. Russell TA, Mir HR, Stoneback J, Cohen J, Downs B. Avoidance of malreduction of proximal femoral shaft fractures with the use of a minimally invasive nail insertion technique (MINIT). *J Orthop Trauma.* 2008;22(6):391-398.
9. Benirschke SK, Melder I, Henley MB, *et al.* Closed interlocking nailing of femoral shaft fractures: assessment of technical complications and functional outcomes by comparison of a prospective database with retrospective review. *J Orthop Trauma.* 1993;7(2):118-122.
10. Astion DJ, Wilber JH, Scoles PV. Avascular necrosis of the capital femoral epiphysis after intramedullary nailing for a fracture of the femoral shaft. A case report. *J Bone Joint Surg.Am.* 1995;77(7): 1092-1094.
11. Orler R, Hersche O, Helfet DL, Mayo KA, Ward T, R G. Die avaskulare Huftkopfnekrose als schwerwiegende Komplikation nach Femurmarknagelung bei Kindern und Jugendlichen. *Unfallchirurg.* 1998;101:495-499.
12. Kenny P, O'Brien CP, Synnott K, Walsh MG. Damage to the superior gluteal nerve after two different approaches to the hip. *J Bone Joint Surg Br.*1999;81(6):979-981.
13. Perez EA, Jahangir AA, Mashru RP, Russell TA. Is there a gluteus medius tendon injury during reaming through a modified medial trochanteric portal? A cadaver study. *J Orthop Trauma.* 2007;21(9): 617-620.
14. Gardner MJ, Robertson WJ, Boraiah S, Barker JU, Lorich DG. Anatomy of the greater trochanteric 'bald spot': a potential portal for abductor sparing femoral nailing? *Clin Orthop Relat Res.* 2008; 466(9):2196-2200.
15. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue anatomy around the hip and its implications for choice of entry point in antegrade femoral nailing. *Clin Anat.* 2008;21(6): 568-574.
16. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip. *Injury.* 2005; 36(11):1337-1342.
17. Dora C, Leunig M, Beck M, Rothenfluh D, Ganz R. Entry point soft tissue damage in antegrade femoral nailing: a cadaver study. *J Orthop Trauma.* 2001;15(7):488-493.

18. Simmermacher RK, Bosch AM, Van der Werken C. The AO/ASIF-proximal femoral nail (PFN): a new device for the treatment of unstable proximal femoral fractures. *Injury.* 1999;30(5):327-332.
19. Ricci WM, Schwappach J, Tucker M, *et al.* Trochanteric versus piriformis entry portal for the treatment of femoral shaft fractures. *J Orthop Trauma.* 2006;20(10):663-667.
20. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am.* 1969;51(4):737-755.
21. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br.* 1997;79(5):738-741.
22. Hardcastle P, Nade S. The significance of the Trendelenburg test. *J Bone Joint Surg Br.*1985;67(5):741-746.
23. Markhede G, Grimby G. Measurement of strength of hip joint muscles. *Scand J of RehabilMed.* 1980;12(4):169-174.
24. Emery CA, Maitland ME, Meeuwisse WH. Test-retest reliabilty of isokinetic hip adductor and flexor muscle strength. *Clin J of Sport Med.* 1999;9(2):79-85.
25. Burnett CN, Betts EF, King WM. Reliability of isokinetic measurements of hip muscle torque in young boys. *Phys Ther.* 1990;70(4):244-249.
26. Pfirrmann CW, Chung CB, Theumann NH, Trudell DJ, Resnick D. Greater trochanter of the hip: attachment of the abductor mechanism and a complex of three bursae--MR imaging and MR bursography in cadavers and MR imaging in asymptomatic volunteers. *Radiology.* 2001;221(2):469-477.
27. Hirata T, Konishiike T, Kawai A, Sato T, Inoue H. Dynamic magnetic resonance imaging of femoral head perfusion in femoral neck fracture. *Clin Orthop Relat Res.* 2001(393):294-301.
28. Konishiike T, Makihata E, Tago H, Sato T, Inoue H. Acute fracture of the neck of the femur. An assessment of perfusion of the head by dynamic MRI. *J Bone Joint Surg Br.*1999;81(4):596-599.
29. Oh SJ. Electromyography in peripheral nerve injuries: when to consider it; what it can tell you. *Med Times.* 1980;108(6):94-98, 100.
30. Georgiadis GM, Olexa TA, Ebraheim NA. Entry sites for antegrade femoral nailing. *Clin OrthopRelat Res.* 1996(330):281-287.
31. Bednar DA, Ali P. Intramedullary nailing of femoral shaft fractures: reoperation and return to work. *Can J Surg.* 1993;36(5):464-466.
32. Ramesh M, O'Byrne JM, McCarthy N, Jarvis A, Mahalingham K, Cashman WF. Damage to the superior gluteal nerve after the Hardinge approach to the hip. *J Bone Joint Surg Br.*1996;78(6):903-906.
33. Bain GI, Zacest AC, Paterson DC, Middleton J, Pohl AP. Abduction strength following intramedullary nailing of the femur. *J Orthop Trauma.* 1997;11(2):93-97.
34. Danckwardt-Lilliestrom G, Sjogren S. Postoperative restoration of muscle strength after intramedullary nailing of fractures of the femoral shaft. *Acta Orthop Scand.* 1976;47(1):101-107.
35. Finsen V, Harnes OB, Nesse O, Benum P. Muscle function after plated and nailed femoral shaft fractures. *Injury.* 1993;24(8):531-534.
36. Damholt V, Zdravkovic D. Quadriceps function following fractures of the femoral shaft. *Acta Orthop Scand.* 1972;43(2):148-156.
37. Mira AJ, Markley K, Greer RB, 3rd. A critical analysis of quadriceps function after femoral shaft fracture in adults. *J Bone Joint Surg Am.* 1980;62(1):61-67.
38. Neumann DA, Soderberg GL, Cook TM. Comparison of maximal isometric hip abductor muscle torques between hip sides. *Phys Ther.* 1988;68(4):496-502.

39. Van der Wees PJ, Bobbert MF, J H. Ontwikkeling van een standaardprotocol voor isokinetische metingen aan de knie. *Geneesk Sport.* 1993;26:203-212.
40. Gautier E, Ganz K, Krugel N, Gill T, Ganz R. Anatomy of the medial femoral circumflex artery and its surgical implications. *J Bone Joint Surg Br.* 2000;82(5):679-683.

7

Intramedullary femoral nailing through the trochanteric fossa versus greater trochanter tip: a randomized controlled study with in-depth functional outcome results

C.M. Ansari Moein, H.J. ten Duis, P.L. Oey, G.A.P. de Kort, W. van der Meulen and Chr. van der Werken

J Trauma Emerg Surg. 2011;37(6):. 615 – 622

ABSTRACT

Purpose: In a level 1 university trauma center, an explorative randomized controlled study was performed to compare soft tissue damage and functional outcome after antegrade femoral nailing through a trochanteric fossa (also known as piriform fossa) entry point to a greater trochanter entry point in patients with a femoral shaft fracture.

Materials and methods: Nineteen patients were enrolled and randomly assigned to two nail insertion groups; ten patients were treated with an Unreamed Femoral Nail (UFN, Synthes, Solothurn, Switzerland) inserted at the trochanteric fossa and nine patients were treated with an Antegrade Femoral Nail (AFN, Synthes, Solothurn, Switzerland) inserted at the tip of the greater trochanter.

The main outcome measures were pain, gait, nerve and muscle function, along with endurance. Magnetic resonance imaging (MRI), electromyography (EMG), and Cybex isokinetic testings were performed at, respectively, 2 and 6 weeks and at a minimum of 12 months after surgery.

Results: The MRI and EMG showed, in both groups, signs of iatrogenic abductor musculature lesions (four in the UFN group and four in the AFN group) and superior gluteal nerve injury (five in the UFN group and four in the AFN group). The isokinetic measurements and the patient-reported outcomes showed moderate reduction in abduction strength and endurance, as well as functional impairment with slight to moderate interference with daily life in both groups, with no appreciable differences between the groups.

Conclusions: Anatomical localization of the entry point seems to be important for per operative soft tissue damage and subsequent functional impairment. However, the results of this study did not show appreciable differences between femoral nailing through the greater trochanter tip and nailing through the trochanteric fossa.

INTRODUCTION

The current standard for the operative treatment of patients with a femoral shaft fracture is intramedullary nailing.[1-5] Most of the available antegrade femoral nails are inserted through the trochanteric fossa. Nail insertion through the trochanteric fossa has several disadvantages for the surgeon as well as for the patient. Access to this entry point is demanding, especially in obese patients.[6,7] Nail entrance through the trochanteric fossa may increase the risk of iatrogenic injury of the medial circumflex femoral artery or superior gluteal nerve, with subsequent vascular damage to the femoral head or paralysis of the gluteal muscles, respectively.[8-11] Iatrogenic fractures of the femoral neck have been described during nailing through the trochanteric fossa.[12] In addition, this technique requires inevitable surgical dissection through the hip abductor and exorotator muscles and, last but not least, at implant removal, major surgical tissue dissection may cause considerable problems. The above outlined problems may, ultimately, result in reduced daily function accompanied by residual pain, stiffness, muscle weakness with discrete Duchenne limp, and some loss of endurance.[13-17]

In order to prevent these problems, nails with a proximal lateral bend, allowing insertion through the tip of the greater trochanter, have gained popularity.[18,19] Access to the greater trochanter tip appears to be easy and safe due to its anatomical localization.

Only a few studies have attempted to examine and compare the functional outcome of patients undergoing femoral nailing through the trochanteric fossa to those after trochanteric tip insertion.[6,17,20]

To date, no study has profoundly compared the probable soft tissue damage due to the nailing procedure and functional outcomes in a randomized setting with long-term follow-up.

This study was an explorative randomized controlled study to provide such a comparison. We hypothesized that a nail especially designed to use the greater trochanter tip as its entry point would result in less entry point-related soft tissue damage and, consequently, in better long-term functional outcome.

MATERIALS AND METHODS

Patients

Over a period of 2 years, adult patients (aged 18–65 years) with an isolated femoral shaft fracture (AO type 32A-C) who were to be treated by intramedullary nailing were recruited for an internal review board-approved randomized study. Patients were cared for at a level 1 university trauma center that acts as a regional referral center for complex orthopedic trauma. Patients with a pathological fracture, those suffering relevant pre-existing neurological/ vascular disease (i.e., Parkinson's disease, arterial occlusive disease), prior treatment for a femoral fracture, and those carrying a pacemaker were excluded. Inclusion was completed after written informed consent was given by the patient.

The patients were randomly assigned to two treatment groups through the use of envelopes: antegrade nailing with the Unreamed Femoral Nail through the trochanteric fossa (UFN group) and nailing with the Antegrade Femoral Nail through the greater trochanter tip (AFN group).

Implants

All nails were interlocking and made from titanium (Synthes, Solothurn, Switzerland). The UFN is straight in the frontal plane. Since the AFN is specifically designed to accommodate a trochanteric tip entry, it has a 6° proximal lateral bend in the frontal plane. This cannulated nail rotates 90° (such that the anterior bow is apex medial) at insertion. Once the nail is inserted beyond the impingement point on the medial cortex, it gradually derotates.

Operative technique

Operations were performed by the attending trauma surgeons. All patients were treated in the supine position using a similar technique. Prior to nail insertion, all fractures were reduced by closed means under image intensifier control on the fracture table with boot traction or distal femoral skeletal traction. After a short longitudinal skin incision approximately 5 cm cranial to the greater trochanter tip, the fascia layers were dissected sharply. Thereafter, the correct entry point was confirmed by K-wire insertion under image intensifier control. All nails were locked both proximally and distally.

Follow-up

Patients were followed up according to a standard protocol that called for, at a minimum, physical and radiographic examination at 6, 24, and 52 weeks. Apart from the standard follow-up, patients underwent magnetic resonance imaging (MRI) of the soft tissues around the hip at 2 weeks, electromyography (EMG) for the gluteal muscles at 6 weeks, and isokinetic hip muscle function testing along with patient-reported outcome and elaborate physical examination focusing on hip function at a minimum of 52 weeks status post-surgery.

Magnetic resonance imaging (MRI)

Static MRI was performed to document postoperative damage to the adjacent soft tissues around the entry points. Hematomas, fluid collections, edema, as well as lesions to the abductor and external rotator muscles were recorded.[21]

To evaluate femoral head perfusion, dynamic MRI was carried out according to the method proposed by Konishiike *et al.*[22,23] A 1.0-Tesla superconducting scanner was used (Philips, Eindhoven, the Netherlands) with a two-dimensional fast low angle shot with fat saturation. The paramagnetic contrast agent, Gd-DTPA (0.1 mmol/kg body weight) was injected into a brachial vein. The acquisition time for each image was 15 s. The region of interest was chosen in the image of the bilateral femoral heads. A dynamic curve was drawn in which the signal intensity of the region of interest in the femoral head was plotted against time.

Electrophysiological studies

Needle electromyography (EMG) from selected abductor muscles of the operated side (the gluteus maximus, medius, and minimus, and the tensor fasciae latae muscles) was carried out to assess the completeness of recruitment patterns and to look for evidence of ongoing denervation (fibrillation potentials and positive sharp waves) and/or re-innervation (reduction in the number and increase in the amplitude and duration of motor unit action potentials [MUAPs]). To exclude radiculopathy and plexopathy as the underlying mechanism, limited nerve conduction studies were applied in both lower extremities. Antidromic sensory conduction studies were performed using surface recording electrodes for the sural and saphenous nerves. Hoffman reflex (H-reflex) measurement of the medial vastus and soleus muscles were performed with standard surface stimulation and recording techniques.[24]

Patient-reported outcome and clinical assessment

At a minimum follow-up of 1 year, all patients had standard evaluation consisting of a questionnaire and physical examination. Participants were asked to quantify postoperative pain during daily activity, on a visual analog scale (VAS)[25] ranging from 0 ('no pain') to 10 ('unbearable pain'). The Trendelenburg test[26] was performed and Duchenne limping was assessed at gait analysis.

Evaluation of muscle strength and endurance

Along with the clinical assessments, muscle strength and endurance in the hip abductor and external rotator muscle apparatus were measured isokinetically on a Cybex 6000 dynamometer for comparison with the uninjured side.[27] After an initial 5 min of limbering up, the patients performed five external and internal rotations as forcefully as possible at a fixed speed of 30° and 60° per second. After a rest, they performed 15 consecutive external and internal rotations at 120° per second. To evaluate the endurance, values of the first five sets of movements were compared with the last five during a 120° per second test speed: ER (endurance ratio) = last five (Nm)/first five (Nm). In between each test, there was a 30-s rest. Subsequently, thigh abduction and adduction were performed in the same order of test speeds (five consecutive exercises at 30° and 60° and 15 exercises at 120° and the endurance ratio).

Peak torque values (Nm) in the injured limb were compared with the values obtained at the contralateral side and the difference was expressed as a percentage of the uninjured side. The percentage was considered to be negative when the peak torque was lower at the fractured side.

In the literature, the reliability coefficient of isokinetic Cybex measurements varies between 0.80 and 0.99.[28,29]

Statistics

The independent samples t-test for comparison of the groups was used for non-parametric variables and the Chi-square test was used for categorical variables. The Mann–Whitney test was used for skewed variables. *P*-values of less than 0.05 were considered to be significant. SPSS version 14.0 (SPSS Inc., Chicago, IL) was used for all analyses.

RESULTS

A total of 26 patients with an isolated femoral shaft fracture were eligible for the study, of whom 19 gave informed consent for participation and were enrolled in the study. Ten male patients were enrolled in the UFN group, with a mean age of 32.8 years (range 22–41 years), and nine patients were enrolled in the AFN group (eight males and one female; mean age 24.6, range 18–36 years). The mean follow up was 48 months (range 21–57 months). One patient in the UFN group withdrew and one patient in the AFN group was lost to follow-up, prior to their last follow-up visit.

Seven eligible patients were not enrolled in the study. Four declined to participate. Three were hemodynamically unstable and could not consent, of whom two had concomitant brain injury.

There were two Gustilo type I open fractures, one in each group. The other fractures were closed. All fractures were AO types 32 A and B in both groups, except one in the AFN group with type AO 32-C3.

Postoperative course

All fractures healed in both study groups without further surgical intervention. One patient in the AFN group developed a superficial wound infection that healed with conservative treatment. In five patients, two in the UFN group and three in the AFN group, prominent distal locking screws were removed because of pain in the knee region; nails were not removed.

MRI

Two weeks after surgery, MRI was performed. A hematoma in between the muscles in the operated region was seen in three patients in the UFN group and in four patients in the AFN group. In both groups, edema of the abductor muscles was documented in two patients.

In nine patients, four from the UFN group and five from the AFN group, iatrogenic lesions in the abductor muscles were seen (Tables 1, 2). In two of these patients, one from each group, atrophy was seen in the gluteus muscles. In one patient from the AFN group, an additional lesion in the hip joint capsule was found.

The dynamic magnetic resonance images did not reveal the state of perfusion in the bilateral femoral heads, so no conclusion could be drawn from these findings.

EMG

Ongoing denervation of the abductor muscles as a sign of (partial) superior gluteal nerve injury was seen in the examined muscles in nine patients, five in the UFN group and four in the AFN group (Tables 1, 2). In three patients (two in the UFN group and one in the AFN group), there was evidence of neurapraxia of branches of the gluteal superior nerve at operation, followed by re-innervation in parts of the abductor apparatus. During contraction, the recruitment was almost normal, except in one patient of the UFN group who showed reduced recruitment and atrophy of the glutei muscles. In this patient, no denervation was found in those muscles and it was considered as disused atrophy. The sensory conduction and Hoffmann reflex studies showed no asymmetry between the healthy leg and the operated leg.

Clinical assessment and patient-reported outcome

As can been seen in Tables 1 and 2, the majority of the patients in both groups reported some limitations for intensive daily activities (i.e., walking stairs, jogging), as well as reduced walking distance (< 2 km). The reported reasons for the experienced disabilities included limping, soreness, and weakness in the gluteal region. Only one patient (in the AFN group) reported pain in the trochanteric region as the interfering factor for reduced walking distance. The mean VAS score for pain for the UFN group was 4.6 (1.6), and for the AFN group, it was 3.7 (2.2).

At clinical assessment after a mean follow-up of 48 months, the Trendelenburg test was slightly positive in five patients in the UFN group, as well as in five patients from the AFN group. Furthermore, there were no cases of Duchenne limping at gait examination and the hip range of motion was symmetric in all patients.

Table 1. MRI, EMG and patient reported outcome in the UFN group.

	Patient Number	MRI Lesions (0=no, 1= in one or more muscles)	MRI Localisation Of Lesion In Muscle	EMG Denervation (0=no, 1= in one or more muscles)	EMG Localisation Of Neuromuscular Damage 6 Weeks Post Surgery	EMG Re-innervation (0=no, 1= in one or more muscles)	Reinnervation Localisation Of Neuromuscular Damage	Reduced Ability Intensive Exercise(No, Slight, Moderate) 4 years follow-up	Walking Distance (Infinite, Reduced < 2km) 4 years follow-up	Reason Reduced Walking Distance
	1	0		0		0		Slight	Infiinte	
	2	1	Gluteus maximus and medius	1	Gluteus maximus, medius and tensor fasciaelatae	1	Tensor fasicae latae muscle	Moderate	<2km	Weakness hip, limp
	3	0		0		0		Moderate	Infinite	
	4	1	Gluteus maximus and medius	1	Gluteus medius	0		Moderate	<2km	Weakness hip, limp
	5	1	Gluteus maximus and minimus	1	Tensor fasciae latae atrophy and gluteus minimus	0		Slight	<2km	Weakness hip, limp
	6	0		1	Tensor fasiae latae	0		-*	-*	-*
	7	1	Atrophy glutei muscles	0[1]		0[1]		Slight	< 2km	Soreness hip, limp
	8	0		1	Gluteus maximus, medius, minimus and tensor fasciae latae	1	Gluteus minimus and tensor fasciae latae	Moderate	<2km	Soreness hip region
	9	0		0		0		Slight	infiinte	
	10	0		0		0		No	infinite	
Total	10	4		5		2			5	

[1] EMG abnormality due to disused myopathy and atrophy of the gluteus medius and tensor fasciae latae muscles. * withdrew from the study.

Table 2. MRI, EMG and patient reported outcome in the AFN group.

	Patient Number	MRI Lesions (0=no, 1= in one or more muscles)	MRI Localisation of Lesion in Muscles 2 Weeks Post Surgery	EMG Denervation (0=no, 1= in one or more muscles)	EMG Localisation Of Neuromuscular Damage 6 Weeks Post Surgery	EMG Re-innervation (0=no, 1= in one or more muscles)	Reduced Ability Intensive Exercise(No, Slight, Moderate, Severe) 4 years follow-up	Walking Distance (infinte, reduced < 2km) 4 years follow-up	Reason Reduced Walking Distance
	1	1	Gluteus maximus and hip joint capsule	1	Glutei and tensor fasciae latae muscles	0	Slight	<2km	Weakness hip
	2	1	Gluteus medius	1	Glutei and tensor fasciae latae muscles	1	Moderate	<2km	Weakness hip and limp
	3	1	Gluteus medius	1	Gluteus medius and tensor fasciae latae	0	Moderate	<2km	Weakness hip and limp
	4	1	Gluteus medius	0		0	Moderate	<2km	Pain and soreness
	5	1	Atrophy of gluteus medius	1	Gluteus medius and tensor fasciae latae	0	Slight	<2km	Weakness hip and limp
	6	0		0		0	No	infinite	
	7	0		0		0	No	infinite	
	8	0		0		0	Slight	<2km	Weakness hip and limp
	9	0		0		0	-*	-*	-*
Total	9	5		4		1		6	

* lost to follow-up

Muscle-strength testing

Isokinetic measurements were performed at a mean follow-up of 48 months. Since the values at 30°, 60°, and 120° per second were fairly similar per patient, these values were averaged. The peak torque and endurance in the injured leg were found to be moderately reduced for abduction and adduction in both groups (Table 3). There were no statistically significant differences between the groups in any of the parameters. For the external and internal rotation experiments, there was a trend for a slight benefit of the AFN group.

Furthermore, the endurance ratio for all of the exercises was consistently decreased in the injured leg compared with the contralateral side in both groups.

Table 3. Percentage change in isokinetic values on injured side (100% = uninjured side) for function parameters in the two patient groups.
Averages and standard deviation per group and 95% confidence intervals.

	UFN (n = 9)	AFN (n = 8)
Abduction		
Peak torque	-36.4 (16.0)	-23.5 (35.7)
Endurance	-47.2 (15.1)	-32.0 (12.3)
Adduction		
Peak torque	-7.1(9.5)	-43.9(6.4)
Endurance	-34.1(24.1)	-60.6(26.5)
Internal rotation		
Peak torque	-100.6(65.7)	-88.7(46.1)
Endurance	-117.2(4.5)	-47.6(24.1)
External rotation		
Peak torque	-76.0 (26.6)	-31.7 (18.1)
Endurance	-98.4 (35.3)	-13.6 (27.2)

DISCUSSION

Although many authors have discussed residual pain and hip abductor weakness after antegrade intramedullary nailing of the femur as a recognized impairment, there are scant objectively measured data that objectify the neuromuscular damage and subsequent functional weakness. Recent articles have postulated that nail introduction through the standard entry point, the trochanteric fossa (also known as piriform fossa), may be the cause for the documented functional impairments.[16,17,30,31] Opening the medullary canal through the trochanteric fossa jeopardizes the glutei and exorotator muscles, as well as the superior gluteal nerve.[9-11,32] Direct damage to these structures may result in postoperative weakness of the hip abductors. Furthermore, rare cases of femoral head avascular necrosis and septic arthritis have been described after trochanteric fossa nailing, due to damage to the deep branch of the medial femoral circumflex artery and to adverse penetration of the hip joint during the procedure.[8,33] Therefore, nails allowing a more lateral entry point—tip of the greater trochanter—have (re)gained popularity [18-20], as an attempt to make nail introduction easier and to limit the risk of damage to the adjacent soft tissues during nailing. This study, however, did not show any differences between the two entry points with regards to superior gluteal nerve injury, abductor muscles injury, hip abductor muscle function, and long-term functional outcome.

Two weeks after surgery, early soft tissue damage was visualized with MRI. Regardless of the entry point, in half of the patients, abductor muscle injury directly inflicted by nail insertion was documented. Strikingly, in two of these patients, one in each nail group, signs of atrophy of the gluteus muscles was visible already 2 weeks after surgery. Furthermore, no lesions of the external rotator muscles were seen in the UFN group, while anatomical studies have revealed definite damage to the external rotator muscles and tendons when entering the femur at the trochanteric fossa.[9,10] However, it seems possible that there were some small tendinal lesions in the direct proximity of the nail entrance, which could not be identified due to small implant artefacts at the entry point.

Electrophysiology testing at 6 weeks status post-surgery showed comparable results; in approximately half of the patients in both the UFN and AFN groups, signs of ongoing denervation were found in the gluteus muscles. In a minority of these patients, re-innervation of parts of the abductor apparatus had already occurred. This implies that the initial damage of surgery to some branches of the superior gluteal nerve had been neurapraxia, which is reversible in a small number of cases. None of the patients had profound or extended nerve injuries, since the nerve conduction study which was performed in this investigation showed no abnormality in the operated extremity.

After a mean follow-up of 4 years, the majority of the patients in both groups had some degree of weakness, limping, and residual pain in the gluteal region and reduced walking distance (<2 km), with slight to moderate interference with activities of daily life.

The combination of the MRI, EMG, and patient-reported outcomes has a two-fold implication; in patients with reported postoperative functional impairment, both directly inflicted damage to the gluteus muscles as well as direct damage to the superior gluteal nerve at operation may cause abductor muscle atrophy and subsequent limitations many years after the operation.

Comparison of the isokinetic muscle function tests revealed some strength reduction in the abductor apparatus in both groups at 4 years follow-up, with no appreciable differences between the groups. The isokinetic tests also revealed reduced endurance in the investigated muscle groups in both groups. Interestingly, both muscle strength and endurance in the external rotator muscle groups were decreased in the trochanteric fossa group compared to the greater trochanter group. This clinical finding was as expected from the previous anatomical studies on this topic.[9,10]

The isokinetic muscle function tests, along with the MRI and EMG findings, were compatible with the patient-reported outcome in our study, as well as the self-reported outcomes described in previous reports.[16,17,25,30,34] Promising results were the uneventful fracture healing and uneventful postoperative course in both nailing groups. Other studies have underlined the equally high union rates and low complication rates in both nailing procedures. [6,20]

Antegrade femoral nailing through the currently described entry points has recognized disadvantages for the patient, sometimes resulting in some permanent functional limitations. Nail introduction results in musculotendinous damage to the adjacent gluteus muscles as well as potential neurovascular damage due to the proximity of the entry point to the superior gluteal nerve and the medial femoral circumflex artery. The results of our study did not support the superiority of one nail system with regards to neuromuscular damage and long-term functional results. However, this study had an explorative character and was performed in a limited group of patients. For the generalization of these results, this limitation has to be kept in mind.

Although the greater trochanter tip entry seems to be a logical solution for preventing neuromuscular damage to the adjacent soft tissues during nailing, the operating field remains narrow. Probably, an even more lateral entry point than the greater trochanter tip may have advantages in this respect. Currently, the choice of entry point is probably best decided on the basis of familiarity of the surgeon with the used nail system.

REFERENCES

1. Sage FP. The second decade of experience with the Kuntscher medullary nail in the femur. *Clin Orthop Relat Res*. 1968;60:77-85.
2. Winquist RA, Hansen ST, Jr., Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. 1984. *J Bone Joint Surg Am*. 2001;83-A(12):1912.
3. Brumback RJ, Reilly JP, Poka A, Lakatos RP, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part I: Decision-making errors with interlocking fixation. *J Bone Joint Surg Am*. 1988;70(10):1441-1452.
4. Gibbons CL, Gregg-Smith SJ, Carrell TW, Murray DW, Simpson AH. Use of the Russell-Taylor reconstruction nail in femoral shaft fractures. *Injury*. 1995;26(6):389-392.
5. Stockenhuber N, Schweighofer F, Bratschitsch G, R. S. UFN-system. Eine methode der minimal-invasiven chirurgischen Versorgung von Oberschenkelschaftfrakturen. *Langenbecks Archiv Chir*. 1996;381:267-274.
6. Starr AJ, Hay MT, Reinert CM, Borer DS, Christensen KC. Cephalomedullary nails in the treatment of high-energy proximal femur fractures in young patients: a prospective, randomized comparison of trochanteric versus piriformis fossa entry portal. *J Orthop Trauma*. 2006;20(4):240-246.
7. Tucker MC, Schwappach JR, Leighton RK, Coupe K, Ricci WM. Results of femoral intramedullary nailing in patients who are obese versus those who are not obese: a prospective multicenter comparison study. *J Orthop Trauma*. 2007;21(8):523-529.
8. Astion DJ, Wilber JH, Scoles PV. Avascular necrosis of the capital femoral epiphysis after intramedullary nailing for a fracture of the femoral shaft. A case report. *J Bone Joint Surg Am*. 1995;77(7): 1092-1094.
9. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue anatomy around the hip and its implications for choice of entry point in antegrade femoral nailing. *Clin Anat*. 2008;21(6): 568-574.
10. Ansari Moein CM, Verhofstad MH, Bleys RL, van der Werken C. Soft tissue injury related to choice of entry point in antegrade femoral nailing: piriform fossa or greater trochanter tip. *Injury*. 2005; 36(11):1337-1342.
11. Kenny P, O'Brien CP, Synnott K, Walsh MG. Damage to the superior gluteal nerve after two different approaches to the hip. *J Bone Joint Surg Br*. 1999;81(6):979-981.
12. Simonian PT, Chapman JR, Selznick HS, Benirschke SK, Claudi BF, Swiontkowski MF. Iatrogenic fractures of the femoral neck during closed nailing of the femoral shaft. *J Bone Joint Surg Br*. 1994; 76(2):293-296.
13. Danckwardt-Lilliestrom G, Sjogren S. Postoperative restoration of muscle strength after intramedullary nailing of fractures of the femoral shaft. *Acta Orthop Scand*. 1976;47(1):101-107.
14. Bednar DA, Ali P. Intramedullary nailing of femoral shaft fractures: reoperation and return to work. *Can J Surg*. 1993;36(5):464-466.
15. Benirschke SK, Melder I, Henley MB, *et al*. Closed interlocking nailing of femoral shaft fractures: assessment of technical complications and functional outcomes by comparison of a prospective database with retrospective review. *J Orthop Trauma*. 1993;7(2):118-122.
16. Archdeacon M, Ford KR, Wyrick J, *et al*. A prospective functional outcome and motion analysis evaluation of the hip abductors after femur fracture and antegrade nailing. *J Orthop Trauma*. 2008;22(1):3-9.

17. Ansari Moein C, ten Duis HJ, Oey L, *et al*. Functional outcome after antegrade femoral nailing: a comparison of trochanteric fossa versus tip of greater trochanter entry point. *J Orthop Trauma*. 2011;25(4):196-201.
18. Simmermacher RK, Bosch AM, Van der Werken C. The AO/ASIF-proximal femoral nail (PFN): a new device for the treatment of unstable proximal femoral fractures. *Injury*. 1999;30(5):327-332.
19. van Doorn R, Stapert JW. The long gamma nail in the treatment of 329 subtrochanteric fractures with major extension into the femoral shaft. *European J Surg*. 2000;166(3):240-246.
20. Ricci WM, Schwappach J, Tucker M, *et al*. Trochanteric versus piriformis entry portal for the treatment of femoral shaft fractures. *J Orthop Trauma*. 2006;20(10):663-667.
21. Pfirrmann CW, Chung CB, Theumann NH, Trudell DJ, Resnick D. Greater trochanter of the hip: attachment of the abductor mechanism and a complex of three bursae - MR imaging and MR bursography in cadavers and MR imaging in asymptomatic volunteers. *Radiology*. 2001;221(2): 469-477.
22. Konishiike T, Makihata E, Tago H, Sato T, Inoue H. Acute fracture of the neck of the femur. An assessment of perfusion of the head by dynamic MRI. *J Bone Joint Surg Br*. 1999;81(4):596-599.
23. Hirata T, Konishiike T, Kawai A, Sato T, Inoue H. Dynamic magnetic resonance imaging of femoral head perfusion in femoral neck fracture. *Clin Orthop Relat Res*. 2001(393):294-301.
24. Oh SJ. Electromyography in peripheral nerve injuries: when to consider it; what it can tell you. *Med Times*. 1980;108(6):94-98, 100.
25. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br*.1997;79(5):738-741.
26. Hardcastle P, Nade S. The significance of the Trendelenburg test. *J Bone Joint Surg Br*. 1985;67(5): 741-746.
27. Markhede G, Grimby G. Measurement of strength of hip joint muscles. *Scand J Rehabil Med*. 1980; 12(4):169-174.
28. Burnett CN, Betts EF, King WM. Reliability of isokinetic measurements of hip muscle torque in young boys. *Phys Ther*. 1990;70(4):244-249.
29. Emery CA, Maitland ME, Meeuwisse WH. Test-retest reliabilty of isokinetic hip adductor and flexor muscle strength. *Clin J Sport Med*. 1999;9(2):79-85.
30. Helmy N, Jando VT, Lu T, Chan H, O'Brien PJ. Muscle function and functional outcome following standard antegrade reamed intramedullary nailing of isolated femoral shaft fractures. *J Orthop Trauma*. 2008;22(1):10-15.
31. Kapp W, Lindsey RW, Noble PC, Rudersdorf T, Henry P. Long-term residual musculoskeletal deficits after femoral shaft fractures treated with intramedullary nailing. *J Trauma*. 2000;49(3):446-449.
32. Dora C, Leunig M, Beck M, Rothenfluh D, Ganz R. Entry point soft tissue damage in antegrade femoral nailing: a cadaver study. *J Orthop Trauma*. 2001;15(7):488-493.
33. Orler R, Hersche O, Helfet DL, Mayo KA, Ward T, R G. Die avaskulare Huftkopfnekrose als schwerwiegende Komplikation nach Femurmarknagelung bei Kindern und Jugendlichen. *Unfallchirurg*. 1998;101:495-499.
34. Bain GI, Zacest AC, Paterson DC, Middleton J, Pohl AP. Abduction strength following intramedullary nailing of the femur. *J Orthop Trauma*. 1997;11(2):93-97.

GENERAL DISCUSSION

Chapter 8
Discussion and concluding remarks

Chapter 9.1
English summary

Chapter 9.2
Dutch summary
(Nederlandse samenvatting)

8 Discussion and concluding remarks

Intramedullary nailing is the standard of care in the treatment of femoral fractures[1-7]. The technique has been subject to constant change and refinement throughout the decades. The standard entry point in antegrade nailing has been the trochanteric fossa (also known as the piriform fossa) since the 1980s[5, 8-11]. However, the choice of the entry point is of paramount importance for a successful nailing procedure and has been subject to discussion in literature[11-14]. The trochanteric fossa is in line with the femoral canal and facilitates entrance of a rigid intramedullary nail. It has postoperative advantages concerning load-bearing capacities. On the other hand, the localisation of the trochanteric fossa may be quite demanding, especially in obese patients. Wiggling through the hip soft tissues on the way to the trochanteric fossa may be a difficult manoeuvre. Moreover, the abductor muscles and neurovascular apparatus of the hip are in direct vicinity of the surgical field[14-16]. Many authors report suboptimal functional outcome with some residual pain and loss of endurance in daily living as recognized impairment[17-19].

The suboptimal postoperative clinical findings may have their origin in intraoperative anatomical lesions near the nail entry site. A shift of the entry point to lateral, i.e. the tip of the greater trochanter as already mentioned by Gerhard Küntscher in the 1940s, or even lateral to the greater trochanter tip seems to be a logical step to avoiding peroperative damage to the adjacent soft tissues[20]. During the last decade, new nail designs have entered the market to facilitate such a lateral entry point (Proximal Femoral Nail (Antirotation), Trochanteric Femoral Nail, Gamma Nail) with the same rigid nail and load-bearing characteristics as the standard straight femoral nail, but with a modified proximal lateral bend[21,22]. Using the greater trochanter tip as entry point has shown acceptable post-operative results in very proximal, per- and intertrochanteric fractures[21-23]. In theory, using a lateral entry for femoral shaft fractures should have postoperative advantages as well. Yet, objective measurements of the neurovascular and muscular status of the operated region in relation to the reported functional impairments are too scarce to be conclusive.

This thesis focuses on the anatomical, mechanical and clinical implications of a standard trochanteric fossa entry point compared to a lateral entry point at the greater trochanter tip.

Anatomical models

The soft tissues in the hip region that are directly at risk in the operation zone or can be damaged in any antegrade nailing procedure are documented in cadaver studies (chapters 3 and 4). The abductor muscles, m. tensor fasciae latae and the mm. glutei medius and minimus have their insertion sites on the greater trochanter and therefore their tendons are equally at risk during both procedures. These structures were damaged in both nailing procedures as expected, but the soft tissue damage was predominantly tendinous and minor in the lateral approach, whereas lesions were predominantly muscular and larger with longer diameter in the standard approach. The external rotator muscles, the obturator externus and internus muscles and the gemelli muscles, on the other hand, have their insertion exactly at the trochanteric fossa and consequently are always at risk during the standard procedure. In three of the five specimens these tendons were damaged during the Unreamed Femoral Nail (UFN) procedure.

The superior gluteal nerve (SGN) has a diverse course and is frequently documented in literature. In most of our specimens the nerve distribution was according to the spray pattern described by Jacobs *et al.*[24] The spray pattern has a distinct inferior branch that passes narrowly across the gluteus minimus muscle on to the tensor fasciae latae muscle. In the anatomical dissections, the inferior branch of the nerve was always in the 'danger zone', i.e. within 5 cm of the track of the nail and thus always at risk during both procedures. Postoperative dissections of the specimens that were blindly operated showed no lesions of the nerve in both nailing procedures. However, the inferior branch of the nerve was within 5mm distance to the upper end of the nailing instruments in two cases in the Antegrade Femoral Nail (AFN) and the UFN group. In other words, the nail had just brushed past the inferior branch of the SGN in these two cases in both entry point groups.

The vascularisation of the femoral head seems to be composed of anastomoses between the deep branch of the medial femoral circumflex artery (MFCA)[16], the inferior gluteal artery, the obturator artery and to a lower extent the lateral femoral circumflex artery. The deep branch of the MFCA has its course just across the trochanteric fossa itself and was damaged in four of the five specimens of the piriform fossa (UFN) group. Since the MFCA does not seem to be the sole blood supplier for the femoral head, the clinical consequences of compromising its deep branch may not be substantial.

Finally, the capsula reflecta of the hip joint was evaluated. The hip joint capsule is within a few millimeters distance to the trochanteric fossa, and always at risk of penetration. In one case in the UFN nailings, the joint capsule was actually penetrated. Therefore, even if reported only once, the occurrence of septic arthritis after nailing in adults may be a complication of the trochanteric fossa as entry portal[25].

Hence, from our anatomical studies we can conclude that there might be some benefits in choosing the greater trochanter tip as lateral nail entry, especially with regards to damage to the deep branch of the MFCA along with risk of penetration of the hip joint capsule. To a lower extent, the risk of elaborate damage to the abductor muscles and tendons seem to diminish with a lateral entry portal at the greater trochanter tip.

Mechanical model

Choosing a lateral entry point because of its assumed anatomical advantages seems an appropriate decision. However, entering the femoral canal from a laterally situated entry point needs a different geometrical and mechanical approach, in order to prevent further complications. Complications due to misalignment of either nail or entry point with the femoral canal are mentioned frequently in literature, e.g. compromising the medial femoral cortex and iatrogenic fracture of the femoral neck. In other words, an eccentric entry point may be associated with high bone strains and even induce iatrogenic fractures[26-28].

We performed a safety study on entry point related cortical bone strains, which is described in Chapter 5. Three entry points with congruent nail designs were compared; the trochanteric fossa (piriform fossa) with the Cannulated Femoral Nail (CFN); the greater trochanteric tip with a prototype Antegrade Femoral Nail; and an entry point lateral to the greater trochanter tip with a helical shaped nail, a prototype helical nail (Lateral Femoral Nail (LFN), Synthes, Bettlach, Switzerland). The helical properties in combination with the proximal lateral bend of this prototype were especially designed to facilitate an entrance to the femoral canal quite lateral from the trochanteric tip (Figure 1).

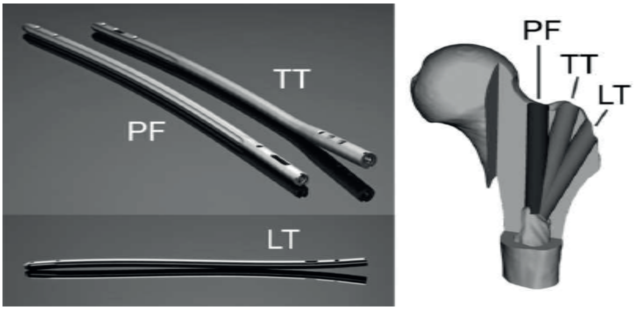

Figure 1. Cannulated Femoral Nail (Piriform Fossa/Trochanteric Fossa), Antegrade Femoral Nail (Trochanter Tip) and prototype of a Helical Nail (Lateral to Trochanter tip) with corresponding insertion paths.

The greater trochanter tip group showed the highest surface strain values, especially in the region near the entry point, with a range between 2000 and 4500 μm/m. Aamodt *et al.* published the only available data on surface strains on the femur measured during daily load bearing activity (walking, single leg stance and stair climbing)[28]. Their maximum principal strains were 1500 μm/m on the proximal lateral aspect of the femur during walking. An investigation by Miller *et al.*[10] measured tensile strains of 2000 μm/m on the superior aspect of the femoral neck after creating an entry hole at the trochanteric fossa, under an experimental load of 3 kN, without causing fissures or failure. The highest strain values (> 2000 μm/m) in our study were seen in four specimens of the greater trochanter tip entry group; in these cases fissures occurred at the medial aspect of the tip of the greater trochanter and one fracture occurred in the greater trochanter massive. The value of these measured strains and fissure occurrence is not quite certain for the clinical situation. In clinics, many muscles and their tendons cover the greater trochanter as well as the medial wall of the tip of the trochanter, probably serving as protection against dislocation of small fissures.

On the other hand, not only the entry point itself matters. The proximal diameter of the nail is important as well since this dictates the diameter of the reamer needed to create an appropriate nail entrance in the femur. The larger this nail and reamer diameter, the less bone is left and the bigger the risk for iatrogenic fissures or fractures. From a functional perspective especially the medial cortex and its abductor insertion are relevant. So a lateral insertion point combined with a small nail diameter would be optimal. Although the straight UFN and CFN have the smallest diameter, their drawback is the trochanteric fossa entry point. The nails that are designed to be introduced at the trochanter tip vary in diameter. For example an Antegrade Femoral Nail (AFN) needs a 14, 16 or even 18 mm entry depending on the diameter at the level of the shaft. For the PFN(A) the proximal entry is 17 mm irrespective of the nail diameter. The Lateral Femoral Nail (LFN; i.e. the commercially available successor of the Helical Nail) requires a proximal entry of 15 mm for nails with a diameter up to 12 mm and an entrance of 17 mm for the larger ones. In the LFN more bone stock is left medially from the femoral entry due to its more lateral insertion point, thus reducing the risk of fissures.

Not only the entry point and the diameter used to open the medullary canal are important, the length of the nail, the location of the fracture and the amount of intra-medullary reaming can also affect the strain on the proximal femur. The nail seeks for its optimal fit into the medullary canal. If it fits tightly over a long distance at the level of the isthmus, a considerable chance occurs that the nail does not perfectly fit proximally and the proximal femur needs to give way. In a patient with a fracture at or above the isthmus, the fracture will be able to absorb this small mismatch. But this is not the case in fractures distal to the femur. Our femurs were cut below the isthmus, mimicking a distal 1/3 femoral shaft fracture. The clinical relevance of such proximal fissures can be limited if the nail is locked into the femoral neck and head (recon locking). This type of locking stabilizes such iatrogenic fissures (or fractures) at the level of the greater trochanter because the load is transmitted to the implant proximal to these fissures.

The handling of the CFN and the Helical Nail seemed smoother and more comfortable than of the AFN, which was partly quantified by the number and intensity of hammer strikes necessary in each nailing procedure. We have to bear in mind that the circumstances were experimental and that femurs were completely stripped from their soft tissues, including the periost.

In conclusion, our findings indicate that a nailing procedure through the greater trochanter tip with a nail with the current geometric properties as the AFN seems to have some mechanical drawbacks, compared to the standard nailing procedure through the trochanteric fossa. Furthermore, according to this study, a helical shaped nail which allows the use of an even more lateral entry point, seems to be promising, considering its handling ease and the moderate surface strains during the nailing procedure. Although not specifically tested, the proximal nail diameter seems a relevant factor that affects the capacity of the proximal femur to absorb strains.

Clinical models and applications

Permanently diminished endurance and residual pain in the operated leg are two main complaints at follow-up in patients treated with nails entered at the trochanteric fossa[29-31]. The clinical studies described in Chapters 6 and 7 compare the functional outcome between the standard nailing procedure at the trochanteric fossa and renewed nailing procedure at the laterally situated greater trochanter tip. Furthermore, these studies attempt to find anatomical and functional explanations for the reported complaints after surgery. The retrospective study described in Chapter 6, tested outcomes in high femoral, subtrochanteric fractures. Very mild differences were noticed in favour of the greater trochanter tip entry point, regarding abductor muscle power and endurance during the Cybex dynamic testings. More prominent differences were revealed in the EMG findings, showing signs of re-innervation of the SGN in half of the patients treated with a UFN. In the long PFN group no signs of SGN damage were seen. The mild differences in permanent muscle function at the Cybex testings between the UFN and long PFN groups seem explicable since the SGN had re-innervated after an extensive follow-up period of average two years.

The randomized controlled trial described in Chapter 7 was a study on clinical outcome after treatment of isolated midshaft fractures. It presents data similar to the retrospective study with regards to residual pain, abductor muscle function and endurance after extensive follow-up of four years, i.e. no appreciable differences between the two nailing groups. Both studies failed to survey the perfusion status of the femoral head, probably due to an insufficiency in the dynamic MRI protocol. Nevertheless, there were no clinical signs of femoral head ischemia after several years follow-up, which seems compatible with the anatomical findings in Chapter 3; the blood supply of the femoral head seems to depend on multiple anastomoses and not merely on one deep branch of the MFCA.

Two striking results in the randomized controlled study were the atrophy in the abductor muscles on the two weeks post-operative MRI findings in two patients from both nailing groups and the SGN injury in half of the patients in both nailing groups. In light of the earlier described anatomical dissections these findings require further remarks.

In the cadaver studies, the abductor apparatus was equally at risk and damaged in both nailing procedures in the anatomic dissections, with predominantly tendinous lesions in the greater trochanter tip group and muscular lesions in the trochanteric fossa group. In clinical practice, equally extensive lesions in the abductor apparatus were recorded in both groups as well in the postoperative MRI shortly after operation. On the long-term MRIs recorded in Chapter 6, the amount of fatty and fibrous tissue was also equal for both groups. Both findings seem to be congruent with the functional measurements at the Cybex testings. Furthermore, in the anatomic dissections the inferior branch of the SGN showed a variable course in the cadaver studies and was equally at risk because of the narrow operation 'window' (danger zone of 5 cm from the greater trochanter tip), while in some specimens the incision just brushed near the nerve branches within 5 mm distance. It seems plausible that in clinics, the operating field is indeed very narrow, as foreseen in the anatomical studies (Figure 2 A,B). Therefore, the revealed intraoperative damage to the SGN in the UFN as well as the AFN procedure may not be quite surprising.

The extensive nerve injury in the AFN group is in contrast to no nerve injury in the long PFN group, while both nailing procedures have the same entry point at the greater trochanter tip. An explanation for this contrast may be sought in the different the study sizes and study designs.

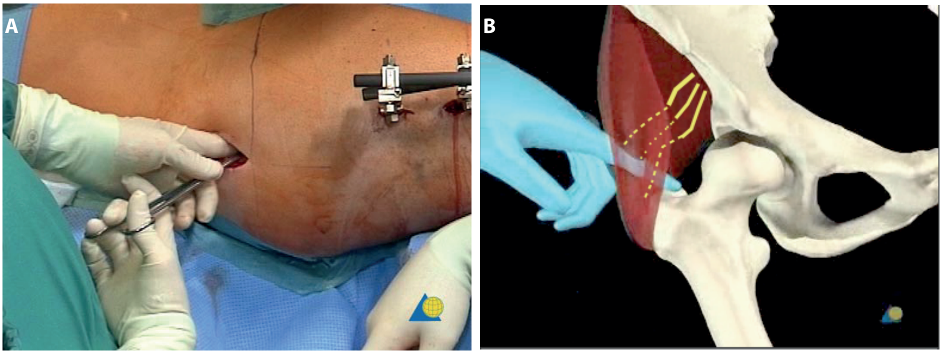

Figure 2. At palpation of the entry point the greater trochanter tip as well as the trochanteric fossa, some dissection through the medial gluteal muscle is required (surgeon's view, A). Hence branches of the superior gluteal nerve (in yellow) are at risk. (schematic reproduction operation field, B).

The randomised trial was conducted on isolated femoral **midshaft** fractures and the nail systems used were the UFN and the prototype AFN (Synthes). The study described in Chapter 6 was conducted on **proximal** (subtrochanteric) fractures and reported a retrospective survey. In the randomised setting described in Chapter 7, the surgeon on call did not have the opportunity to select a nail system suiting his comfort or experience, while in the included cases of our study in Chapter 6, the operation type and nail system were chosen by virtue of the experience and comfort of the surgeon on call. Moreover, the prototype AFN used in the randomised trial was a rather new device at the time of the study, especially for management of midshaft fractures. It seems plausible that clinical discomfort may have had some influence on the soft tissue handling at operation and subsequently induced a higher risk of damaging a vulnerable structure as the SGN branches.

Nevertheless, despite the differences in intraoperative nerve injury in the retrospective and randomised studies, the long term muscle function measured on the Cybex dynamometer and patient reported disabilities including pain did not vary considerably between the nailing groups in both studies. The average peak torques in the UFN group and long PFN group for abduction and adduction seem to be in line with the measurements for the UFN and AFN groups in the randomised trial. As for endurance, there seems to be a slight difference between the two study results in favour of the long PFN.

In conclusion, our anatomical and clinical studies showed that the amount of anatomical damage along with the suboptimal functional results were generally quite similar for both evaluated nailing procedures.

Therefore, the greater trochanter tip may be, although lateral to the trochanteric fossa, yet not lateral enough to avoid complete risk of damage to the abductor and neurovascular apparatus.

Our biomechanical study outlined in Chapter 5, comprised not only the trochanteric fossa and greater trochanteric tip entry portal, but also a new entry hole lateral to the greater trochanter tip (Figure 3). An entry point even more lateral to the greater trochanter tip requires however a new congruent nail design as the outlined experimental helical shaped nail.

Based on the results of our in-depth studies, it seems plausible that a new generation nail design with an even more lateral entry point than the greater trochanter tip may produce the optimal functional outcome that we pursue in antegrade femoral nailing. Currently, the helical shaped nail Lateral Femoral Nail (part of the Synthes Expert™ nailing system) is implemented in many clinics worldwide. Further clinical investigations on the helical shaped nail applying the same in-depth methods and outcome parameters as described in this thesis are desirable to determine the optimal functional outcome in patients with a femoral shaft fracture.

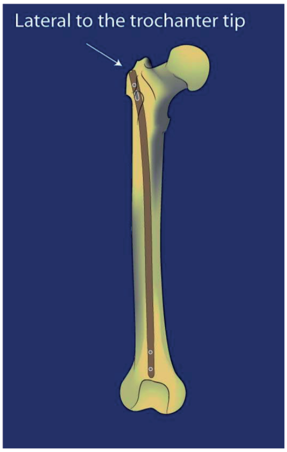

Figure 3. Entry point lateral to the greater trochanter tip with congruent nail properties.

REFERENCES

1. Burwell HN. Internal fixation in the treatment of fractures of the femoral shaft. *Injury.* 1971;2(3): 235-244.
2. Kempf I, Grosse A. L'apport due verrouillage dans l'enclouage centro-medullaire des os longs. *Rev Chir Orthop Reparatrice Appar Mot.* 1978;64:635-651.
3. Kuntscher G. The technique of medullary nailing of fractures. *Clin Orthop.* 1968;60:105-112.
4. Bick EM. The intramedullary Nailing of Fractures by G. Kuntscher. Translation of article in Archiv fur Klinische Chirurgie, 200:443, 1940. *Clin Orthop Related Res.* 1968;60:5-12.
5. Christie J, Court-Brown C, Kinninmonth AW, Howie CR. Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg Br.* 1988;70(2):206-210.
6. Brumback RJ, Uwagie-Ero S, Lakatos RP, Poka A, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part II: Fracture-healing with static interlocking fixation. *J Bone Joint Surg Am.*1988;70(10):1453-1462.
7. Brumback RJ, Ellison TS, Poka A, Bathon GH, Burgess AR. Intramedullary nailing of femoral shaft fractures. Part III: Long-term effects of static interlocking fixation. *J Bone Joint Surg Am.* 1992;74(1): 106-112.
8. Winquist RA, Hansen ST, Jr., Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. 1984. *J Bone Joint Surg Am.* 2001;83-A(12):1912.
9. Harper MC, Carson WL. Curvature of the femur and the proximal entry point for an intramedullary rod. *Clin Orthop Relat Res.* 1987(220):155-161.
10. Miller SD, Burkart B, Damson E, Shrive N, Bray RC. The effect of the entry hole for an intramedullary nail on the strength of the proximal femur. *J Bone Joint Surg Br.* 1993;75(2):202-206.
11. Gausepohl T, Pennig D, Koebke J, Harnoss S. Antegrade femoral nailing: an anatomical determination of the correct entry point. *Injury.* 2002;33(8):701-705.
12. Georgiadis GM, Olexa TA, Ebraheim NA. Entry sites for antegrade femoral nailing. *Clin Orthop Relat Res.* 1996(330):281-287.
13. Starr AJ, Hay MT, Reinert CM, Borer DS, Christensen KC. Cephalomedullary nails in the treatment of high-energy proximal femur fractures in young patients: a prospective, randomized comparison of trochanteric versus piriformis fossa entry portal. *J Orthop Trauma.* 2006;20(4):240-246.
14. Benirschke SK, Melder I, Henley MB, *et al.* Closed interlocking nailing of femoral shaft fractures: assessment of technical complications and functional outcomes by comparison of a prospective database with retrospective review. *J Orthop Trauma.* 1993;7(2):118-122.
15. Orler R, Hersche O, Helfet DL, Mayo KA, Ward T, R G. Die avaskulare Huftkopfnekrose als schwerwiegende Komplikation nach Femurmarknagelung bei Kindern und Jugendlichen. *Unfallchirurg.* 1998;101:495-499.
16. Gautier E, Ganz K, Krugel N, Gill T, Ganz R. Anatomy of the medial femoral circumflex artery and its surgical implications. *J Bone Joint Surg Br.* 2000;82(5):679-683.
17. Bain GI, Zacest AC, Paterson DC, Middleton J, Pohl AP. Abduction strength following intramedullary nailing of the femur. *J Orthop Trauma.* 1997;11(2):93-97.
18. Damholt V, Zdravkovic D. Quadriceps function following fractures of the femoral shaft. *Acta Orthop Scand.* 1972;43(2):148-156.
19. Mira AJ, Markley K, Greer RB, 3rd. A critical analysis of quadriceps function after femoral shaft fracture in adults. *J Bone Joint Surg Am.* 1980;62(1):61-67.
20. Kuntscher G. The technique of medullary nailing of fractures. *Clin Orthop.* 1968;60:105-112.

21. Simmermacher RK, Bosch AM, Van der Werken C. The AO/ASIF-proximal femoral nail (PFN): a new device for the treatment of unstable proximal femoral fractures. *Injury.* 1999;30(5):327-332.
22. van Doorn R, Stapert JW. The long gamma nail in the treatment of 329 subtrochanteric fractures with major extension into the femoral shaft. *Eur J Surg.* 2000;166(3):240-246.
23. Ricci WM, Schwappach J, Tucker M, *et al.* Trochanteric versus piriformis entry portal for the treatment of femoral shaft fractures. *J Orthop Trauma.* 2006;20(10):663-667.
24. Jacobs LG, Buxton RA. The course of the superior gluteal nerve in the lateral approach to the hip. *J Bone Joint Surg Am.*. 1989;71(8):1239-1243.
25. Orler R, Hersche O, Helfet DL, Mayo KA, Ward T, R G. Die avaskulare Huftkopfnekrose als schwerwiegende Komplikation nach Femurmarknagelung bei Kindern und Jugendlichen. *Unfallchirurg.* 1998;101:495-499.
26. Johnson KD, Tencer A. Mechanics of intramedullary nails for femoral fractures. *Unfallchirurg.* 1990; 93(11):506-511.
27. Ostrum RF, Marcantonio A, Marburger R. A critical analysis of the eccentric starting point for trochanteric intramedullary femoral nailing. *J Orthop Trauma.* 2005;19(10):681-686.
28. Aamodt A, Lund-Larsen J, Eine J, Andersen E, Benum P, Husby OS. In vivo measurements show tensile axial strain in the proximal lateral aspect of the human femur. *J Orthop Res.* 1997;15(6): 927-931.
29. Danckwardt-Lilliestrom G, Sjogren S. Postoperative restoration of muscle strength after intramedullary nailing of fractures of the femoral shaft. *Acta Orthop Scand.* 1976;47(1):101-107.
30. Dodenhoff RM, Dainton JN, Hutchins PM. Proximal thigh pain after femoral nailing. Causes and treatment. *J Bone Joint Surg Br.* 1997;79(5):738-741.
31. Lies A, Josten C, G M. Complications of intramedullary nailing and their prevention. *Zentralbl Chir.* 1993;118:342-350.

9.1 Summary (English)

Chapter 1 offers an introduction and background on the subject and objectives of this thesis.

Intramedullary nailing has a long and interesting history that dates back, at least, to the 16th century. Modern intramedullary techniques were developed by Küntscher in Germany during the 1940s and were originally met with much scepticism. Despite these early doubters, intramedullary nailing has become the standard of care for the treatment of femoral shaft fractures.

Entry point determination for antegrade nailing of the femur has been subject for discussion since the advent of Küntscher's nail. He recommended the greater trochanter tip entry for his semi-rigid nail system. Later, the entry point was shifted to central, at the trochanteric fossa (piriform fossa), in order for a straight and rigid intramedullary nail to be inserted in line of the femoral canal. A rigid intramedullary nail has advantages above a semi-rigid nail in respect of full weight bearing possibilities and fracture stability. In the clinical situation however, the functional outcome after full rehabilitation remains suboptimal after treatment with a straight nail through the trochanteric fossa; with permanent residual pain, loss of endurance and some limping. Presumably, the initially recommended lateral entry point at the greater trochanter tip seems to have advantages above the central entry point at the trochanteric fossa in respect of risk of intra-operative damage to the soft tissues in the direct vicinity of the entry point.

In this dissertation the qualities of the two entry points are tested and outlined in experimental and clinical settings; the risk and amount of adjacent soft tissue damage during the operating procedure are documented (Chapter 3 and Chapter 4), mechanical properties in terms of cortical bone strains and iatrogenic fractures are dealt with in the second part of the thesis (Chapter 5) and the third part concerns in-depth clinical outcome measurements (Chapter 6 and Chapter 7).

Chapter 2 offers a review on the anatomical terminology of the existing entry points in the proximal region of the femur. The nomenclature in surgical articles is sometimes inconsistent and prone for misunderstanding. The Nomina Anatomica and Gray's Anatomy mention the deep depression at the base of the femoral neck as the trochanteric fossa, while in surgical literature this location is defined differently as the piriform fossa. The anatomical textbooks define the greater trochanter tip as one entity, while in surgical literature the greater trochanter tip is inconsistently also mentioned as piriform fossa. In order to be consistent and avoid misunderstandings, we propose the central entry point which is in line with the medullary canal to be called the trochanteric fossa and the lateral entry point at the greater trochanter tip to maintain its proper name.

Anatomical models (Chapter 3 and Chapter 4)

The soft tissues around the entry locations of the antegrade femoral nail, the abductor and internal rotator muscles of the leg and their neurovascular apparatus, are susceptible to damage during the operating procedure. Chapter 3 concerns the topographical dimensions of the soft tissues in the hip region in relation to the trochanteric fossa (piriform fossa) and the greater trochanter tip. Anatomical dissections were performed in ten fresh human cadavers. The hip abductor muscles (m. tensor fasciae latae, mm. glutei and m. piriformis) were in the direct vicinity of both entry points. The superior gluteal nerve, which innervates the m. gluteus medius, showed a variable track but was always within the 5 cm danger zone near the greater trochanter tip and trochanteric fossa. The vascularisation of the femoral neck seems to be supplied by an anastomotic network between the deep branch of the medial femoral circumflex artery (MFCA), the lateral femoral circumflex artery and the obturator artery. However, the deep branch of the MFCA enters the hip joint capsule at the trochanteric fossa and is always at risk when using the trochanteric fossa as entry point. Subsequently, the hip joint capsule is also at risk during penetration of the trochanteric fossa. These findings were confirmed in the experimental study described in Chapter 4. In ten other fresh human cadavers closed nailing through trochanteric fossa (nail: Unreamed Femoral Nail) and through the greater trochanter tip (nail: Antegrade Femoral Nail) was executed as in clinics. This implicates that the surgery is performed through a small incision that does not allow identification of the functional structues. The iatrogenic injury to various structures of each procedure was assessed. The gluteus medius muscle was damaged more vigorously during the UFN procedure than with the AFN. The MFCA was often damaged with the UFN nailing, while it was not damaged in any of the AFN nailings. Furthermore, the lower branch of the superior gluteal nerve was always intact in both groups, but more often in the operating danger zone of the UFN than the AFN.

The anatomical studies show that the neurovascular structures and the abductor muscles are damaged and at risk during both procedures, but (the risk of) damage may be more elaborate when using the trochanteric fossa as entry point.

Mechanical model (Chapter 5)

In literature frequent complications like femoral neck fractures and compromising the medial cortex just below the lesser trochanter have been described as a result of eccentric reaming. A lateral entry point, like the greater trochanter tip, seems to need a new congruent nail design in order to prevent collateral bone damage of the nailing procedure.

The study described in Chapter 5 aimed to determine the strains on the bone produced during nailing through different entry points. Nailings were performed in 24 human femurs without soft tissue coverage. The inserted nails were congruent with the entry point used: the CFN (Cannulated Femoral Nail) for the trochanteric fossa; the AFN for the greater trochanter tip; and a new helical shaped nail (prototype Lateral Femoral Nail; LFN) for an entry point even lateral to the greater trochanter tip. The AFN produced the highest cortical strains, especially on the trochanteric cortex around the entry point. There were some iatrogenic fissures and one fracture around the entry point in the AFN group. The clinical relevance of these findings may not be quite clear. Yet, the helical shaped nail and the cannulated femoral nail showed favourable results concerning cortical strain and handling ease in this experimental setting with femurs stripped from their soft tissues. This might be due to the anatomical location of the entry point, but also the diameter of the proximal part of the nail is a factor influencing the ability of the bone to absorb high strains. The AFN has a larger diameter than both the CFN and prototype LFN.

Clinical models (Chapter 6 and Chapter 7)

The clinical implications of an eccentric entry point at the greater trochanter tip are evaluated.

Chapter 6 offers a retrospective comparison of clinical outcome in patients with a subtrochanteric fracture treated with a UFN or with a long Proximal Femoral Nail (PFN). The main outcome measures were patient reported (residual pain, endurance, walking distance etc.) and tested with EMG (mm. glutei innervation through the superior gluteal nerve), with MRI (muscle atrophy and femoral head perfusion) and with dynamic muscle function tests (peak torque and endurance). The most striking result of this study was the re-innervation sign in the superior gluteal nerve on the EMG in half of the patients with a UFN. The functional and patient reported outcomes as well as MRI did no reveal substantial differences between both groups.

Chapter 7 concerns a prospective randomised controlled trial in which patients with an isolated femoral midshaft fracture were included and treated with a UFN or an AFN. The long-term clinical outcome was measured with in-depth tools (EMG, dynamic muscle function, MRI) and patient reported outcome measurements. The results did not reveal appreciable differences between the patient groups. Moreover, the superior gluteal nerve showed signs of re-innervation in both groups on the EMG and on the MRI's some atrophy was seen in the abductor muscles of both patient groups.

Chapter 8 reflects on the objectives and findings in this dissertation. In conclusion, we have seen that from an anatomical point of view, a lateral entry point renders some modest advantages above the standard entry point. However, in clinics the operating window remains narrow and the risk of damage to adjacent soft tissues remains equally high in nailing through the trochanteric fossa or through the greater trochanter tip. The clinical and functional postoperative results are equal as well. Hence, the ideal entry point seems yet to be defined. An entry point even more lateral to the greater trochanter tip seems to meet the anatomical and mechanical needs for a successful long-term functional outcome in antegrade nailing.

9.2 Dutch summary (Nederlandse samenvatting)

Hoofdstuk 1 geeft een inleiding en achtergrondinformatie over het onderwerp en het doel van deze dissertatie. De geschiedenis van de mergpenosteosynthese gaat terug tot tenminste de 16^{e} eeuw. Moderne intramedullaire technieken zijn ontwikkeld door Küntscher in Duitsland in de 40er jaren van de vorige eeuw en werden aanvankelijk met scepsis ontvangen. Desondanks is de intramedullaire pen de standaard behandeling geworden voor femur(schacht)fracturen. Sinds de komst van de Küntscherpen is de entreeplaats voor de antegrade mergpenosteosynthese onderwerp van discussie. Küntscher beval de trochanter punt aan als entree voor zijn semi-rigide pensysteem. Later werd de entreeplaats naar mediaal verplaatst op de fossa trochanterica (fossa piriformis), om zo een rechte rigide pen in te kunnen brengen in het verlengde van het mergkanaal. Een rigide pen heeft voordelen ten opzichte van een semi-rigide pen, vanwege de volledige belastbaarheid en fractuurstabiliteit. Echter, in de klinische praktijk zijn de functionele resultaten na een osteosynthese met een rechte pen, ingebracht via de fossa trochanterica, suboptimaal na volledige revalidatie; residu pijn, permanent verminderd uithoudingsvermogen en enigszins mankend looppatroon. Vermoedelijk biedt de eerder aanbevolen laterale entreeplaats op de trochanterpunt voordelen ten opzichte van de centrale fossa trochanterica ten aanzien van het peroperatieve risico op weke delen schade in de directe omgeving van de entreeplaats.

In dit proefschrift worden de kenmerken van beide entreeplaatsen onderzocht in experimentele en klinische onderzoeken. Het risico op en de mate van weke delen schade tijdens de operatie worden gedocumenteerd in hoofdstukken 3 en 4. De mechanische eigenschappen met corticale botbelasting en iatrogene fracturen worden behandeld in het tweede gedeelte van dit proefschrift (hoofdstuk 5). Het derde gedeelte betreft onderzoeken met klinische uitkomstmaten (hoofdstukken 6 en 7).

Hoofdstuk 2 is een overzicht van de terminologie van de bestaande entreeplaatsen van het proximale femur. De nomenclatuur in de chirurgische literatuur is soms inconsistent en biedt ruimte voor misverstanden. In de Nomina Anatomica en Gray's Anatomy wordt de diepe groeve aan de basis van de femurhals de fossa trochanterica genoemd, terwijl deze locatie in de chirurgische literatuur de fossa piriformis genoemd wordt. De anatomische tekstboeken definiëren de trochanter major als een entiteit met verschillende spieraanhechtingen, terwijl in de chirurgische literatuur de locatie op de trochanter major ook soms als fossa piriformis wordt geduid. Om inconsistenties en misverstanden te voorkomen, stellen wij voor om de centrale entreeplaats die in het verlengde van het femurkanaal ligt, de fossa trochanterica te noemen, en de laterale entreeplaats als de tip van de trochanter major te blijven noemen.

Anatomische modellen (Hoofdstuk 3 en Hoofdstuk 4)

De weke delen rondom de entreeplaats van de antegrade mergpen, in het bijzonder de spieren die zorgen voor abductie en interne rotatie - inclusief hun neurovasculaire structuren - zijn kwetsbaar voor chirurgische schade toegebracht tijdens de operatie. Hoofdstuk 3 behandelt de topografische dimensies van de weke delen in de heupregio in relatie tot de fossa trochanterica (fossa piriformis) en de trochanter major. In tien verse humane cadavers werden dissecties verricht. De heupabductoren (m. tensor fasciae latae, mm. glutei en de m. piriformis) bevonden zich in de directe omgeving van beide entreeplaatsen. De nervus gluteus superior bleek een variabel beloop te hebben waarbij de onderste tak zich altijd direct in de gevarenzone van de trochanter major top en de fossa trochanterica bevond. De vascularisatie van de femurkop wordt verzorgd door een anastomotisch netwerk tussen de diepe tak van de a. circumflexa femoris medialis, de a. circumflexa femoris lateralis en de a. obturatoria. De diepe tak van de a. circumflexa femoris medialis penetreert het gewrichtskapsel direct ter plaatse van de fossa trochanterica en is derhalve altijd in gevaar bij de fossa trochanterica entree. Daarnaast bevindt het kapsel van het heupgewricht zich eveneens in dit gebied, waardoor het eenvoudig geopend kan worden wanneer de fossa trochanterica wordt gebruikt als entreeplaats voor een mergpen.

Deze bevindingen werden bevestigd in de experimentele studie zoals beschreven in Hoofdstuk 4. In tien andere verse humane cadavers werden gesloten mergpenosteosyntheses uitgevoerd via de fossa trochanterica (pen: Unreamed Femoral Nail) en de trochanter major tip (pen: Antegrade Femoral Nail), zoals in een klinische situatie. De iatrogene schade aan de verschillende anatomische structuren is vastgelegd. De m. gluteus medius werd meer en vaker beschadigd bij het inbrengen van een UFN dan van een AFN. The a. circumflexa femoris medialis bleek vaak beschadigd door een UFN en in het geheel niet door een AFN. De onderste tak van de n. gluteus superior is bij alle osteosyntheses intact gebleven, maar bevond zich vaker in de gevarenzone bij de UFN, dan bij de AFN.

De anatomische studies laten zien dat de neurovasculaire structuren en de abductorspieren in beide procedures beschadigd kunnen raken. Maar het gevaar op beschadiging is groter wanneer de fossa trochanterica gebruikt wordt als entreeplaats.

Mechanisch model (Hoofdstuk 5)

Iatrogene complicaties door mechanische oorzaken, zoals femurnekfracturen en beschadigingen van de mediale cortex als gevolg van recht boren, zijn in de literatuur beschreven, naast de weke delen schade wat kan resulteren in suboptimale functionele resultaten. Een eccentrische entreeplaats voor mergpennen, lateraal boren via de trochanter major tip, zou de weke schade kunnen limiteren, maar lijkt wel een nieuw ontwerp van de mergpen te vragen om iatrogene cortex schade tijdens de operatie te voorkomen.

De experimentele studie beschreven in Hoofdstuk 5 heeft tot doel om de stress te meten waaraan het proximale femur bloot staat tijdens het inbrengen van een mergpen via verschillende entreeplaatsen. In 24 humane femora die van hun weke delen waren ontdaan, zijn verschillende mergpennen ingebracht. De mergpennen waren zodanig ontworpen, dat zij congruent waren met de beoogde entreeplaatsen. Een rechte pen (Cannulated Femoral Nail) voor de fossa trochanterica; een 6° gebogen (AFN) voor de trochanter major tip; een 10° gebogen, helixvormige pen (prototype LFN) pen voor een entreeplaats lateraal van de trochanter major tip. De AFN produceerde de hoogste corticale stress, met name op het trochanter massief. Er ontstonden drie iatrogene fissuren en één fractuur in de AFN groep, alle rondom de entreeplaats. De helixvormige en rechte femurpen produceerden de laagste corticale druk en hadden het grootste gebruiksgemak in deze experimentele setting. De klinische relevantie van deze experimentele bevindingen staat echter niet vast.

Klinische studies (Hoofdstuk 6 en Hoofdstuk 7)

In Hoofdstuk 6 zijn de resultaten beschreven van een retrospectieve studie naar de klinische uitkomst van patiënten met een subtrochantaire fractuur behandeld met een UFN en zij die geopereerd zijn met een lange PFN. De voornaamste parameters waren door de patiënt gerapporteerde uitkomsten (residu pijn, uithoudingsvermogen, loopafstand etc.), onderzocht met EMG (mm. glutei innervatie door de n. gluteus superior), met MRI (spieratrofie en femurkopperfusie) en met dynamisch spierfunctie onderzoek (‘peak torque’ en uithoudingsvermogen). De meest opvallende bevinding waren de tekenen van re-innervatie van de n. gluteus superior zoals te zien op het EMG bij de helft van de patiënten behandeld met een UFN. De functionele, patiënt-gerapporteerde en MRI uitkomsten lieten geen grote verschillen zien tussen beide groepen.

Hoofdstuk 7 beschrijft een prospectief gerandomiseerd onderzoek waarin patiënten met een geïsoleerde midschacht femurfractuur werden behandeld met een UFN of AFN. De lange termijn uitkomst werd gemeten met EMG, dynamische spierfunctie-onderzoek, MRI en patiëntgerapporteerde uitkomstmaten. Er bleken geen substantiële verschillen tussen de groepen te zijn. Bovendien was er in beide groepen re-innervatie van de n. gluteus superior en atrofie van de abductor spieren te zien.

Hoofdstuk 8 reflecteert op de doelen en bevindingen van deze dissertatie.

Concluderend heeft een laterale entreeplaats enkele bescheiden voordelen ten opzichte van de standaard entreeplaats in de fossa trochanterica vanuit een anatomisch perspectief. Desalniettemin blijven de anatomische marges nauw en daardoor het risico op beschadiging van de omliggende weke delen bij beide entreepunten hoog. De ideale entreeplaats lijkt nog te moeten worden gedefinieerd. Een entreeplaats nog lateraler dan de trochanter major tip lijkt aan de anatomische en mechanische behoeftes te voldoen om ook op de lange termijn een succesvol functioneel resultaat van een osteosynthese met een antegrade femurpen te bieden.

APPENDIX

Acknowledgements

ACKNOWLEDGEMENTS

Throughout the years of course many colleagues, friends and family members, have contributed in many ways to finalising this thesis; from the first intention, through the hard work of data retrieving, to the last word on paper.

I would like to thank all who have been at my side in these years.

In particular I have to thank the following persons:

Prof. dr. Christiaan van der Werken, who initiated this research program and gave me the opportunity to learn, to grow and to experience the epi-centre of trauma research at the AO Institute in Davos.

Prof. dr. Henk Jan ten Duis, who admitted me to the surgery training program and showed confidence in me for further clinical training.

Prof. dr. Michiel Verhofstad, who stood beside me throughout these years with bright ideas and patience.

Prof. dr. Erik Hoencamp, for his inspiring and incessant support.

Prof. dr. H.J. Stam, prof. dr. J.A.N. Verhaar and prof. dr. L.P.H. Leenen for judging the manuscript and their valued input.

David and Eduard, my brothers, for their unconditional devotion and love.

My mother and father who have been the driving and inspiring force behind all my decisions and actions in life.

Entry Point Related Outcome in Antegrade Femoral Nailing

experimental and clinical studies

Chloé Mahsima Ansari Moein is born in Tehran, Iran as the eldest child in the family. As her father is an international judge, the family moved between various countries whilst Chloé grew up, and she attended several international schools. Chloé spent her high school years in The Hague, the Netherlands, attending the Christelijk Gymnasium Sorghvliet. She embarked upon her medical studies at the Catholic University of Leuven (Belgium) before studying at the University of Utrecht, School of Medicine. After graduating from medical school Chloé started as a clinical researcher at the Department of Surgery of University Medical Centre Utrecht. Furthermore she worked as a researcher at the AO-Research Institute in Davos, Switzerland. The AO-Research Institute is a world-renowned research environment which provided Chloé with unparalleled experience and a strong foundation for her further development. The research she conducted during these years resulted in her thesis. In 2004 she started her training in general surgery at the Department of Surgery, University Medical Centre of Groningen. After two years Chloé continued her training in psychiatry at Parnassia Academy in The Hague.

Since 2012 Chloé has been working as a psychiatrist and is the founder and Medical Director of PsyQ International Mental Health Services, which has locations in The Hague, Eindhoven and Amsterdam.

Chloé is married to Patrice Grabietz. Together they have two children.