OLLI VÄISTÖ

Intramedullary Nailing of Tibial Shaft Fracture

With special attention given
to anterior knee pain

■

UNIVERSITY OF TAMPERE

UNIVERSITY
OF TAMPERE

To Hannele, Emilia and Oskari

CONTENTS

1. LIST OF ORIGINAL PUBLICATIONS

This study is based on the following original publications, referred to in the text by their Roman numerals (I–IV)

I Väistö O, Toivanen JAK, Kannus P, and Järvinen MJ (2004): Anterior knee pain and thigh muscle strength after intramedullary nailing of tibial shaft fractures: a report of 40 consecutive cases. J Orthop Trauma 18: 18–23.

II Väistö O, Toivanen JAK, Paakkala T, Järvelä T, Kannus P, and Järvinen MJ (2005): Anterior knee pain after intramedullary nailing of a tibial shaft fracture: an ultrasound study of the patellar tendons of 36 patients. J Orthop Trauma 19: 311–316.

III Väistö O, Toivanen JAK, Kannus P, and Järvinen MJ (2007): Anterior knee pain and thigh muscle strength after intramedullary nailing of a tibial shaft fracture: an 8-year follow-up of 28 consecutive cases. J Orthop Trauma 21: 165–171.

IV Väistö O, Toivanen JAK, Kannus P and Järvinen MJ (2008): Anterior knee pain after intramedullary nailing of fractures of the tibial shaft: an 8-year follow-up of a prospective, randomized study comparing two different nail-insertion techniques. J Trauma 6: 1511–1516.

Articles I–IV have been reprinted in this thesis with permission from Wolters Kluwer Health, the *Journal of Orthopaedic Trauma* (I – III) and the *Journal of Trauma: Injury, Infection and Critical Care* (IV).

2. ABBREVIATIONS

ACL   Anterior cruciate ligament

AKP   Anterior knee pain

AP   Always pain (one group in study III)

AO/ASIF   Arbeitsgemeinschaft für Osteosynthesefragen / Association for the
            Study of Internal Fixation

BMI   Body mass index

CP   Compartment pressure

CS   Compartment syndrome

DBP   Diastolic blood pressure

ΔP   Delta pressure (DBP – CP)

FES   Fat embolism syndrome

HO   Heterotopic ossification

IMN   Intramedullary nail

IPBSN   Infrapatellar branch of the saphenous nerve

LTI   Lateral trochlear inclination

MRI   Magnetic resonance imaging

NP   Never pain (group in study III)

NSAID   Non-steroidal anti-inflammatory drug

PTA   Paratendinous approach

PNP   Pain, no pain (group in study III)

Q angle   Quadriceps angle

ROM   Range of movement

SP   Neurotransmitter substance P

SPSS   Statistical Package for the Social Sciences

TEE   Transesophageal echocardiogram

TTA   Transtendinous approach

UTN   Unreamed tibial nailing

9

VAS   Visual analogue scale

3. ABSTRACT

A tibial shaft fracture is a common trauma, especially amongst young and middle-age people. Its prevalence is lower amongst children and older people. During the last few decades, locking intramedullary (IM) nailing has become a popular method for treating closed tibial shaft fractures and, during the last few years, also for treating open tibial shaft fractures. The use of IM nailing in the treatment of tibial shaft fractures has the following advantages: closed reduction and preservation of the periosteal blood supply, the possibility of early mobilisation of the knee and ankle joint, the ease with which the limb can be observed postoperatively, a lower prevalence of wound infections, good biomechanical stability of the cortical bone, good possibility for bone union, and a faster recovery and return to work.

One common complication after IM nailing of a tibial shaft fracture is anterior knee pain (AKP), which may be an important handicap for the patient. The pain usually appears a few months after the nailing procedure. The incidence of AKP varies from 10% to 86% in different studies. The aetiology of AKP after IM nailing is multiple. Trauma-induced tissue damage, inappropriate methods of nailing, anatomical changes in the knee due to IM nailing, and the presence of the nail have been proposed. However, the exact aetiology of this common postoperative problem is still unknown.

In this study, it became evident that AKP cannot be reduced when the paratendinous approach is used instead of transtendinous incision, as there were AKP patients in both groups. No morphology changes were found to occur in the patellar tendon region of the patients with AKP in the ultrasonographic investigation, and there were no differences in the power Doppler measurements in the region of the scar or patellar tendon between the study groups. Three years after the IM nailing, there was a clear deficit in the thigh muscle strength of the operated leg when it was compared with the non-operated leg of patients with

11

AKP. This difference decreased during the further long-term follow-up, and, at the time of the second examination, there were significant differences only between the strength of the extensor muscles in the operated and non-operated legs. The strength deficit was greater for the patients who still had AKP. After 8 years of follow-up, the AKP had disappeared for most of the patients, or it showed only reduced intensity in the remaining patients.

In this study, there was more AKP amongst the female than the male patients. This finding should be taken into account during postoperative rehabilitation. Some patients seem to benefit from thigh muscle rehabilitation after the operation. Such rehabilitation may reduce the incidence of AKP after IM nailing of tibial shaft fractures and thus make the return to work easier.

The treatment of tibial shaft fractures with locked IM nailing is effective; patients can return to work earlier than after conservative cast treatment. Almost all patients can return to their previous work and pretraumatic level of activity. With respect to AKP, it seems that young and physically active patients may benefit from IM nail removal. In general, fear of postoperative chronic AKP should not restrict the use of IM nails in the treatment of tibial shaft fractures. AKP is rarely severe, and it does not hinder daily living or reduce the quality of life. In addition, in the long term, AKP usually disappears.

4. TIIVISTELMÄ

Säärimurtuma on yleinen vamma varsinkin nuorilla ja keski-ikäisillä aikuisilla. Sen esiintyvyys on selvästi pienempi lapsilla ja vanhuksilla. Viimeisten parin vuosikymmenen aikana salpausydinnaulauksesta on tullut suosittu metodi sääriluun umpimurtumien ja viime vuosina myös avomurtumien hoidossa. Ydinnaulauksen etuina ovat murtuma-alueen pysyminen suljettuna ja periosteaalisen verenkierron säilyminen, mahdollisuus varhaiseen nivelten mobilisointiin, raajan postoperatiivisen tarkkailun helppous, vähäiset haavakomplikaatiot, luun kannalta hyvä mekaaninen tuki ja hyvä luutumistodennäköisyys sekä potilaan nopea työkyvyn palautuminen.

Yleinen komplikaatio sääriluun murtuman ydinnaulauksessa on polven etuosan kipu, joka aiheuttaa usein myös alaraajan toimintakyvyn heikkenemistä. Kipu ilmaantuu muutamien kuukausien kuluttua operaatiosta. Polven etuosan kivun insidenssi on vaihdellut 10 %:sta 86 %:in. Ydinnaulauksen jälkeisen polven etuosan kivun etiologia on moninainen ja osin epäselvä. Sen syyksi on esitetty mm. vamman aiheuttamaa kudosvauriota, ydinnaulausmenetelmiä, ydinnaulauksen aiheuttamia anatomisia muutoksia polvessa ja ydinnaulan läsnäoloa. Mitään yhtä selkeästi varmaa etiologista syytä polvikivulle ei ole löytynyt.

Tässä tutkimuksessa todettiin, ettei naulan sisäänvientitavalla ole merkitystä sääriluun ydinnaulauksen jälkeiseen polven etuosan kipuun. Polvikipua esiintyi potilailla, joilla naulaus oli tehty polvilumpiojänteen lävitse tai polvilumpiojänteen vierestä. Polvikipuisten potilaiden polvilumpiojänteen alueella ei ollut ultraäänitutkimuksessa poikkeavia löydöksiä, eikä polvilumpiojänteen ja arven seudussa ollut verenkierrossa eroa doppler-tutkimuksessa polvikipuisten tai kivuttomien välillä. Polvikipuisilla potilailla oli heikkoutta polven lihasvoimissa kolme vuotta naulauksen jälkeen. Lihasvoimien puoliero tasoittui kahdeksassa vuodessa, mutta polvikipuisilla eroa oli edelleen

polven ojentajavoimissa. Kahdeksan vuoden seurannan jälkeen polvikipu oli hävinnyt suurelta osalta potilaita kokonaan ja vähentynyt lopuiltakin potilailta. Naisilla esiintyi ydinnaulauksen jälkeen selvästi enemmän polvikipua, mikä on syytä huomioida naulauksen jälkeistä kuntoutusta sunniteltaessa. Naiset saattaisivat hyötyä ohjatusta fysioterapiasta ja tehostetusta kuntoutuksesta. Aktiivinen reisilihaskuntoutus postoperatiivisesti saattaa vähentää polvikivun esiintyvyyttä ja helpottaa potilaiden kuntoutumista työkykyisiksi.

Ydinnaulaus on säärimurtuman tehokas hoitomuoto. Potilaat toipuvat työkykyisiksi nopeammin kuin konservatiivisen hoidon jälkeen. Lähes kaikki palaavat entiseen työhönsä varsin nopeasti ja saavuttavat murtumaa edeltävän suoritustasonsa.

Nuoret ja fyysisesti aktiiviset potilaat saattavat hyötyä ydinnaulan poistosta ajatellen polven etuosan kivun häviämistä ja kuntoutumista. Polven etuosan kipu säärimurtuman ydinnaulauksen jälkeen ei ole estä polven ydinnaulaukselle. Kipu on yleensä suhteellisen lievää, se ei haittaa merkittävästi päivittäistä elämää eikä huononna elämänlaatua. Lisäksi polven etuosan kipu häviää suurelta osalta potilailta ajan kuluessa.

5. INTRODUCTION

The tibial shaft is the commonest site of long bone fractures due to its superficial location. Tibial shaft fractures usually involve young or middle-age people. Closed reduction and cast immobilization have previously been regarded as the standard treatment for low-energy tibial shaft fractures (Charnley 1963, Nicoll 1964, Haines et al. 1984, Sarmiento et al. 1984). However, during recent decades, the use of intramedullary locking nails (IMLN) has become more populae, and many studies have shown that the outcome of treatment of a tibial shaft fracture with locked intramedullary (IM) nailing is superior to that of cast treatment (Ekeland et al. 1988, Alho et al. 1990, Court-Brown et al. 1990, Hooper et al. 1991, Bone et al. 1997, Court-Brown et al. 1997, Keating et al. 1997b, Karladani et al. 2000, Toivanen et al. 2001). Several complications have been described after IM nailing, and one of the commonest problems associated with tibial nailing is chronic anterior knee pain. Its incidence has been reported to be as high as 86% (Katsoulis et al. 2006).

After surgery, complaints of anterior knee pain exacerbated by walking, kneeling, squatting, and stair climbing are common (Ekeland et al. 1988, Sarmiento et al. 1989, Hernigou et al. 2000). Same kind of anterior knee pain has also been reported after the reconstruction of a ruptured anterior cruciate ligament (Järvelä et al. 2004). Ligament instability, retropatellar fat necrosis and irritation, meniscal and cartilage damage, gait changes, tendinosis, and inadequate neuromuscular rehabilitation have been suggested as possible causes. In addition, deficits in thigh muscle strength have been reported after IM nailing of a tibial shaft fracture (Nyland et al. 2001). However, the exact aetiology of this common postoperative problem (anterior knee pain) after tibial IM nailing is still unknown.

The purpose of this prospective randomized study was to evaluate whether there is a difference in the prevalence of chronic anterior knee pain after

two different surgical approaches. In addition, an attempt was made to determine whether there is an association between sonographic changes in the patellar tendon and the occurrence of chronic anterior knee pain, as well as whether there is an association between chronic anterior knee pain and thigh muscle weakness in patients with a nailed tibial shaft fracture.

6. REVIEW OF LITERATURE

6.1 Anatomy of the lower leg

The tibia, the second largest bone of the skeleton, is located on the anteromedial side of the leg. The tibia supports most of a person's weight. It articulates with the condyles of the femur superiorly and the talus inferiorly. The shaft of the tibia is approximately triangular in the tranverse section, and it has medial, lateral, and posterior surfaces. Muscles are attached to its lateral surfaces (Moore 1992).

There are no standard radiological landmarks that separate the metaphysis and the diaphysis. The proximal and distal segments of long bones are defined by a square whose sides are the same length as the widest part of the epiphysis in question (Figure 1). The diaphyseal segments are contained between the proximal and distal segments (Müller et al. 1990).
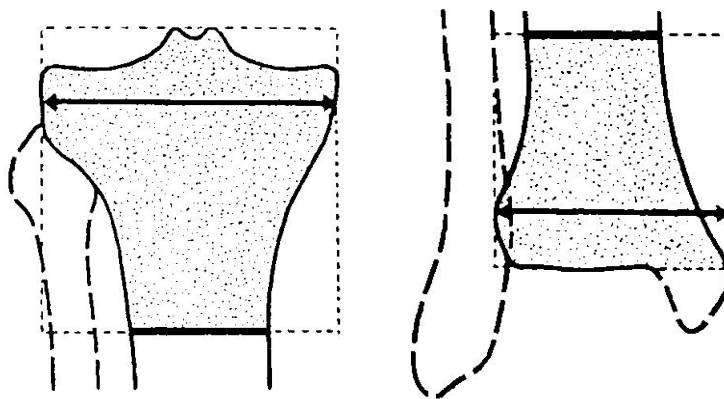
Figure 1. The proximal and distal segments of the tibia. (Müller et al. 1990). Reprinted with the permission of Springer-Verlag.

The diaphysis of the tibia is usually divided into proximal, middle, and distal thirds. The shaft of the tibia is the narrowest at the junction of its middle and inferior thirds, which is the most frequent site of fracture (Moore 1992, Martens et al. 1981). Because of its location, the tibia is exposed to frequent injury; it is the most commonly fractured long bone. Because one third of the tibial surface is subcutaneous throughout most of its length, open fractures are commoner in the tibia than in any other long bone (Canale et al. 2003). The IM canal of the tibia is generally triangular. The isthmus of the canal is short, usually extending for approximately 6 cm (Hicks et al. 1995). The prominent tibial tuberosity is located at the anterior border of its upper section, and the patellar ligament is attached to the upper portion of the tibial tuberosity.

The cross-section of the fibula is roughly triangular. It has medial, lateral, and posterior surfaces that are separated by anterior, interosseal, and posterior borders. The fibula is mainly for the attachment of muscles, but it also provides stability to the ankle joint. The fibula enables the tibia to withstand some bending and twisting. Without fibular support, tibial fractures would occur more frequently (Moore 1992).

The sharp interosseal border of the fibula provides a surface for the attachment of the interrosseal membrane, which plays an important role as a stabilizing structure in the leg.

The deep fascia of the leg, the crural fascia, forms an incomplete covering for the muscles of the leg, and it separates four compartments of the lower leg. The anterior compartment contains the tibialis anterior, extensor hallucis longus, extensor digitorum longus, and peroneus tertius muscles. This compartment is primarily responsible for dorsiflexion of the foot and ankle. In distal thirds, near the ankle, the tendons of the tibialis anterior and extensor hallucis longus muscles are close to the tibia and may be damaged by an open fracture or by a prominent callus formation that appears during the healing of a fracture. The common peroneal nerve is the smaller, lateral, terminal branch of the sciatic nerve, and it originates from the sciatic nerve in the thigh and divides into the superficial and deep branches between the peroneus longus and fibular neck. The deep peroneal nerve descends between the tibialis anterior and

extensor digitorum muscles at the upper portion of leg and is located between the tibialis anterior and extensor hallucis longus muscles in the lower part of the leg.

The lateral compartment contains the peroneal group, the peroneus brevis and peroneus longus muscles. This compartment is primarily responsible for plantar flexion and eversion of the foot. The superficial peroneal nerve runs between the peroneus muscles and the extensor digitorum muscle, and it perforates the fascia of the distal half of the leg and terminates as the medial and intermediate dorsal cutaneus nerves of the foot.

The superficial posterior compartment contains the triceps surae (the gastrocnemius, the soleus, the popliteus and the plantaris muscles). These muscles serve primarily as flexors of the knee and as plantar flexors of the foot.

The deep posterior compartment contains the tibialis posterior, the flexor digitorum longus, and flexor hallucis longus muscles. These muscles are involved in plantar flexion of the foot and toes. The tibialis posterior muscle also inverts the foot and provides stability for the ankle joint. The sciatic nerve divides into tibial and the common peroneal nerve at varying levels after the branch of nerve to the biceps femoris muscle. The posterior tibial nerve is the major neurological structure in this compartment, and it descends along the anterior side of the soleus muscle. It consists of muscular, articular, sural, calcaneal, and medial and lateral plantar main branches (Netter 1987).

The blood supply to the tibial shaft is derived from the nutrient artery and the periosteal vessels. The nutrient artery arises from the posterior tibial artery as it enters the posterior tibial cortex, distal to the soleal line at the middle third. The artery may be damaged in segmental fractures, which devascularize the shaft downstream from the nutrient artery. The periosteal vessels derive from the anterior tibial artery as it courses down the interosseal membrane. Approximately one third of the blood supply to the tibial shaft comes from periosteal vessels (Rhinelander 1987). The blood supply of the tibia is also generously supplied by the vessels entering from the periphery into the regions of the epiphyseal–metaphyseal area; these vessels anastomose with vessels from the diaphyseal area (Nelson et al. 1960).

6.2   Epidemiology of tibial shaft fractures

The commonest cause of tibial diaphyseal fractures in most areas is road-traffic accidents, and the most difficult tibial fractures occur in motorcyclists—over 60% of all such tibial fractures are open (Court-Brown and McBirnie 1995. Sports injuries (usually football) are the second commonest cause of tibial fractures in Great Britain, but the fractures are relatively benign, including a high percentage of isolated tibial injuries without a fibular fracture, most being AO type A. Overall 76.5% of tibial fractures are closed fractures, and they occur typically amongst young people. In addition, skiing accidents are often the cause of tibial shaft fractures, at least in Switzerland (Grütter et al. 2000). Amongst elderly people, a simple fall is usually the mechanism for a tibial shaft fracture.
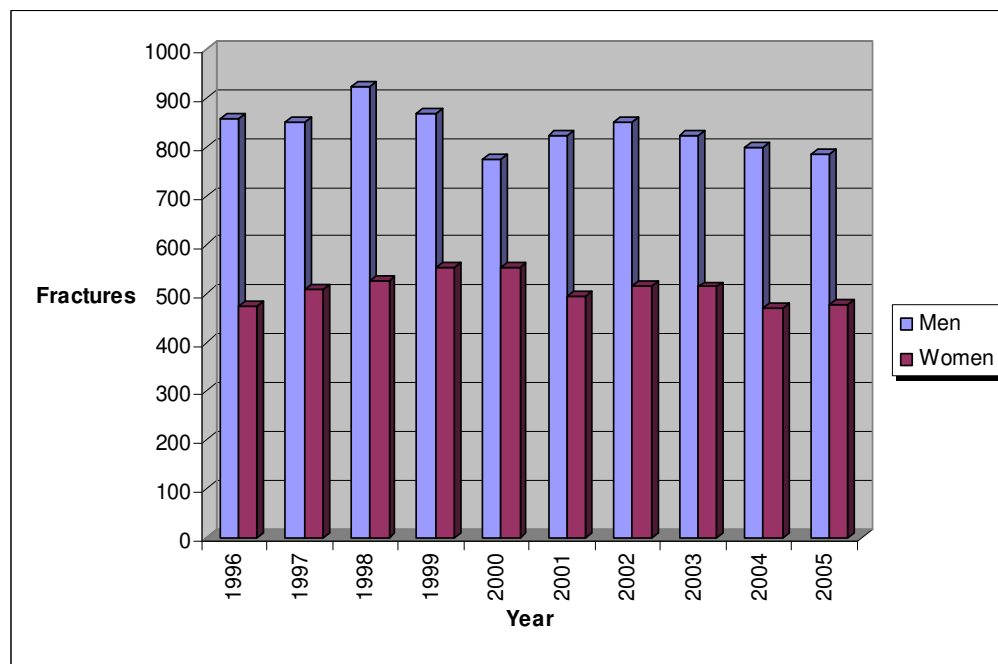
Figure 2. Number of tibial shaft fractures occurring amongst men and women from 1996 to 2005 in Finland (data from the National Institute for Health and Welfare (Terveyden ja Hyvinvoinnin laitos)).

Between 1996 and 2005, altogether 13 455 hospital-treated tibial shaft fractures received hospital treatment in Finland (data from the National Institute

for for Health and Welfare (Terveyden hyvinvoinnin laitos)). There were 8363 men and 5092 women with a tibial shaft fracture. The incidence of the fractures is shown in Figure 2. In addition, in other societies, tibial shaft fractures occur predominantly amongst men. For example, in Switzerland, the number of fractures is over two times greater amongst men than amongst women (Grütter et al. 2000, Court-Brown and Brydone 2007).

The rates of tibial shaft fractures are greatest for both the young (15 to 34 years) and the elderly (over 70 years) (Singer et al. 1998). The peak incidence of tibia fractures was found for young men and also for elderly women, and diaphyseal fractures have become increasingly commoner, reaching an incidence equal to or even greater than that of young men. In the 42-month material gathered by Williams et al. (1995), the age range of the patients varied from 14 to 74 years, with a mean age of 31 years.
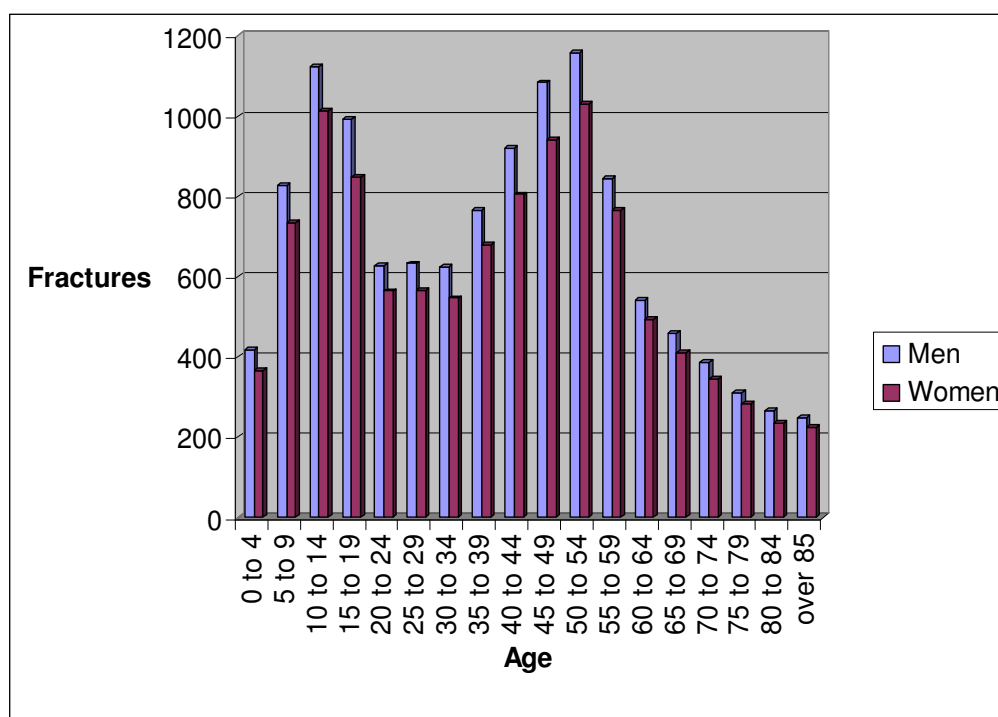
Figure 3. Distribution of patients sustaining a tibial shaft fracture in different age groups and treated in a hospital in Finland between 1996 and 2005 (data from the National Institute for Health and Welfare (Terveyden ja Hyvinvoinnin laitos)).

Amongst the Finnish population, tibial shaft fractures occur the most frequently in the age groups of 10 to 20 years and 45 to 55 years (Figure 3). In

elderly groups over 60 or 65 years of age, the incidence of tibial shaft fractures is similar between men and women.

Sarmiento et al. (1995, USA) observed that spiral fractures, distal third fractures, and low-energy fractures were commoner amongst women than amongst men, and transverse, middle-third fractures and high-energy fractures occurred more often amongst men.

The choice of treatment for tibial shaft fractures has changed during the past decade, IM nailing having become more popular due the good results obtained as regards functional outcome. The incidence of IM nailing is increasing in hospitals in Finland (Figure 4). In 1997, 381 tibial shaft fractures were treated with IM nailing, whereas, in 2005, the corresponding number was 671.
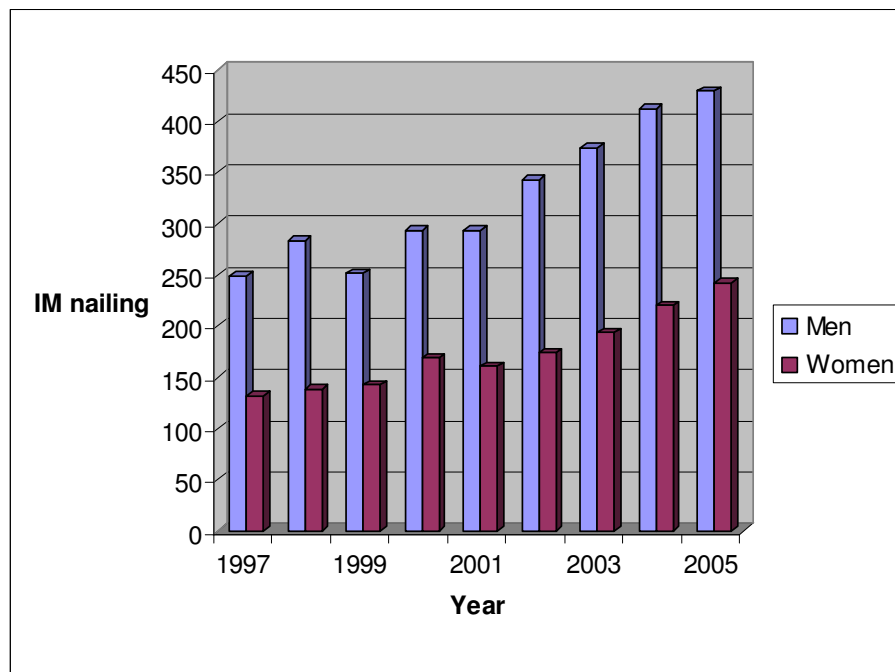
Figure 4. Intramedullary (IM) nailing procedures performed in Finnish hospitals between 1997 and 2005 (data from the National Institute for Health and Welfare (Terveyden ja Hyvinvoinnin laitos)).

The number of hospitalization days needed after the IM nailing of a tibial shaft fracture has varied between 6 and 9 days during the last decade, the mean being 7.2 days (7.3 for men and 7.1 for women) for 1997 to 2005. The mean hospitalization days are shown in Figures 5 and 6.
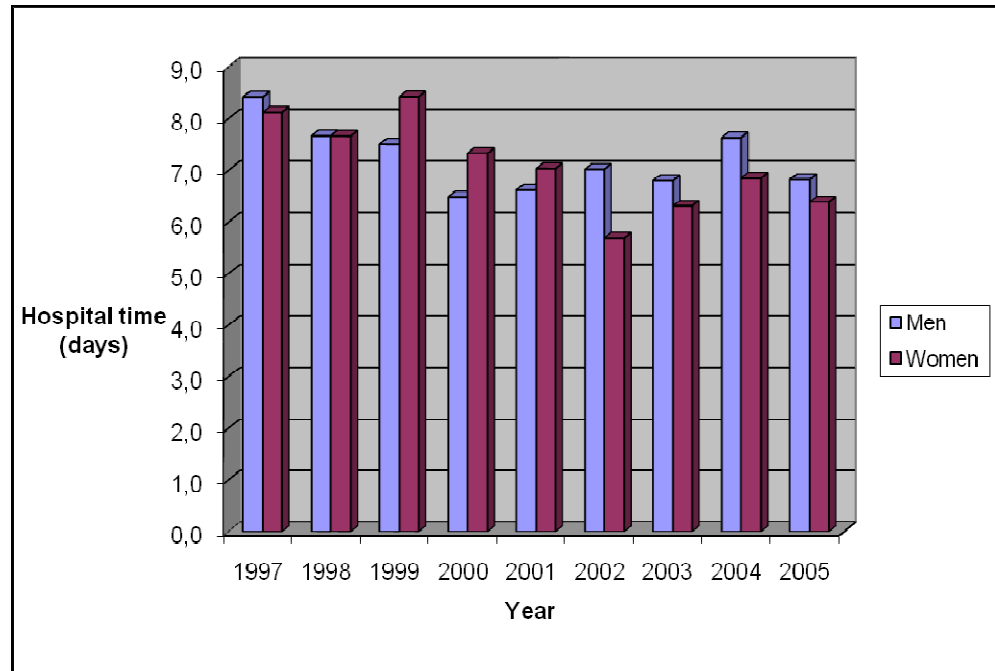
Figure 5. Mean hospitalization days after IM nailing of tibial shaft fractures amongst men and women 15 years or older in Finland from 1997 to 2005 (data from the National Institute for Health and Welfare (Terveyden ja Hyvinvoinnin laitos)).
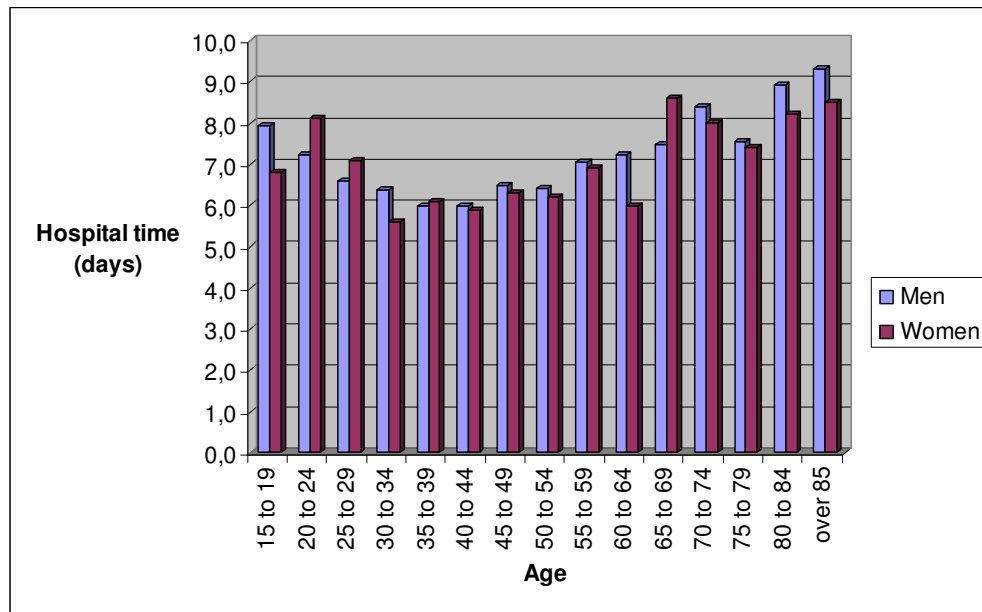
Figure 6. Mean hospitalization days by age group after IM nailing of tibial shaft fractures in Finland between 1997 and 2005 (data from the National Institute for Health and Welfare (Terveyden ja Hyvinvoinnin laitos)).

There seems to be a trend towards older people staying longer in the hospital than middle-aged and young people (Figure 6). It also seems that young people (15 to 29 years of age) stay longer in the hospital than middle-aged people.

6.3 Classifications of tibial shaft fractures

The classification of the extent and type of a tibial shaft fracture and its associated soft-tissue injuries facilitates the determination of optimal treatment. The classification also allows surgeons to monitor their results and to speak a common language with other surgeons when comparing results. In addition, the classification assists the prognosis in that patients can be told what to expect with the results. It also provides a basis for evaluating new treatment modalities.

6.3.1   Classification of a fracture associated soft-tissue injury

Oestern and Tscherne (Tscerne and Gotzen 1984) developed a four-grade system for classifying closed fractures. Grade 0 fractures result from indirect injury to the limb and cause minimal soft-tissue damage, a simple fracture pattern. Grade 1 fractures are caused by a low- or moderate-energy mechanism that causes superficial abrasion or contusion, a mild fracture pattern. Grade 2 fractures are caused by direct trauma to the limb, and they involve deep abrasion accompanied by skin or muscle contusion, a severe fracture pattern. Grade 3 fractures are accompanied by extensive skin contusion or a crush injury, severe damage to underlying muscle, and they may also cause subcutaneous avulsion (Appendix 1).

Open tibial shaft fractures are generally classified according to the three-graded system published by Gustilo and Anderson (1976). The classification used for the prognosis and fractures should be employed in the operating room at the time of initial debridement. Grade 1 fractures are those with a skin lesion smaller than 1 cm, the wound is clean, and there is a simple bone fracture with minimal comminution. Grade 2 fractures have a larger skin lesion than 1 cm but no extensive soft-tissue damage; there is minimal crushing and moderate comminution and contamination. Grade 3 fractures have extensive skin damage with muscle and neurovascular involvement, comminution of the fractures, and instability. Gustilo et al. (1984) divided Grade 3 into three subgroups according to the severity of the wound. Grade 3A fractures have extensive laceration of soft tissue, usually larger than 10 cm, with periosteal coverage. Grade 3B fractures have extensive lesioning of soft tissues with periosteal stripping, and they usually require exposed bone to be replaced with a local or free flap as a cover. They are typically injuries caused by a high-speed vehicle accident or a gunshot or can be any open fracture caused by a farm accident or any open fracture with accompanying vascular injury requiring repair. In addition, all exposed fractures with arterial damage that must be repaired for limb salvage fall into the category of Grade 3C (Appendix 2).

Gustilo and Anderson (1976) reported that the prognosis of fractures graded 1 or 2 is significantly better than that of Grade 3 injuries (Appendix 2).

25

6.3.2   Classification of skeletal injury

The classification developed by the AO/ASIF group (Arbeitsgemeinschaft für Osteosynthesefragen / Association for the Study of Internal Fixation) is generally used to assess a configuration of a fracture with skeletal injury (Müller 1990). The classification divides tibial shaft fractures into nine groups according to increasing severity on the basis of morphological complexity and the difficulty of treatment and prognosis.

There are the following three main groups: simple (A), wedge (B), and complex (C). A simple fracture with two fragments is characterized by a single cortical disruption involving at least 90% of the circumference of the bone. In a wedge fracture, there is always some contact between the main fragments after reduction, and, after the reduction of the fracture, the length and alignment of the bone is usually restored. There is no contact between the main fragments after reduction in a complex fracture. Each of these main groups has three subgroups that represent morphological criteria reflecting direct and indirect impact.

Also each group of simple (A) or wedge (B) fractures has three subgroups according to the presence or absence of a fibular fracture and its location. Complex spiral fractures are subdivided on the basis of the number of intermediate fragments (two, three, or more). Complex segmental fractures are subdivided according to the presence of additional wedge fragments or an additional segmental fracture. Complex irregular fractures are subdivided according to the number of intermediate fragments and the extent of fracture comminution.

The AO classification provides information about skeletal trauma and does not take into account the severity of soft-tissue injury. Data obtained by Court-Brown and McBirnie 1995) that there is a reasonable correlation between the basic AO classification and both the Tscherne and the Gustilo classifications, although a much larger study would be required to test the correlation with the 27 AO groups. In addition, it has been shown that the AO system provides an anatomical classification that is useful for audits (Newey et al. 1993). On the other hand, it can be an unnecessarily complex system and often falls short of playing a useful role in the planning of management.
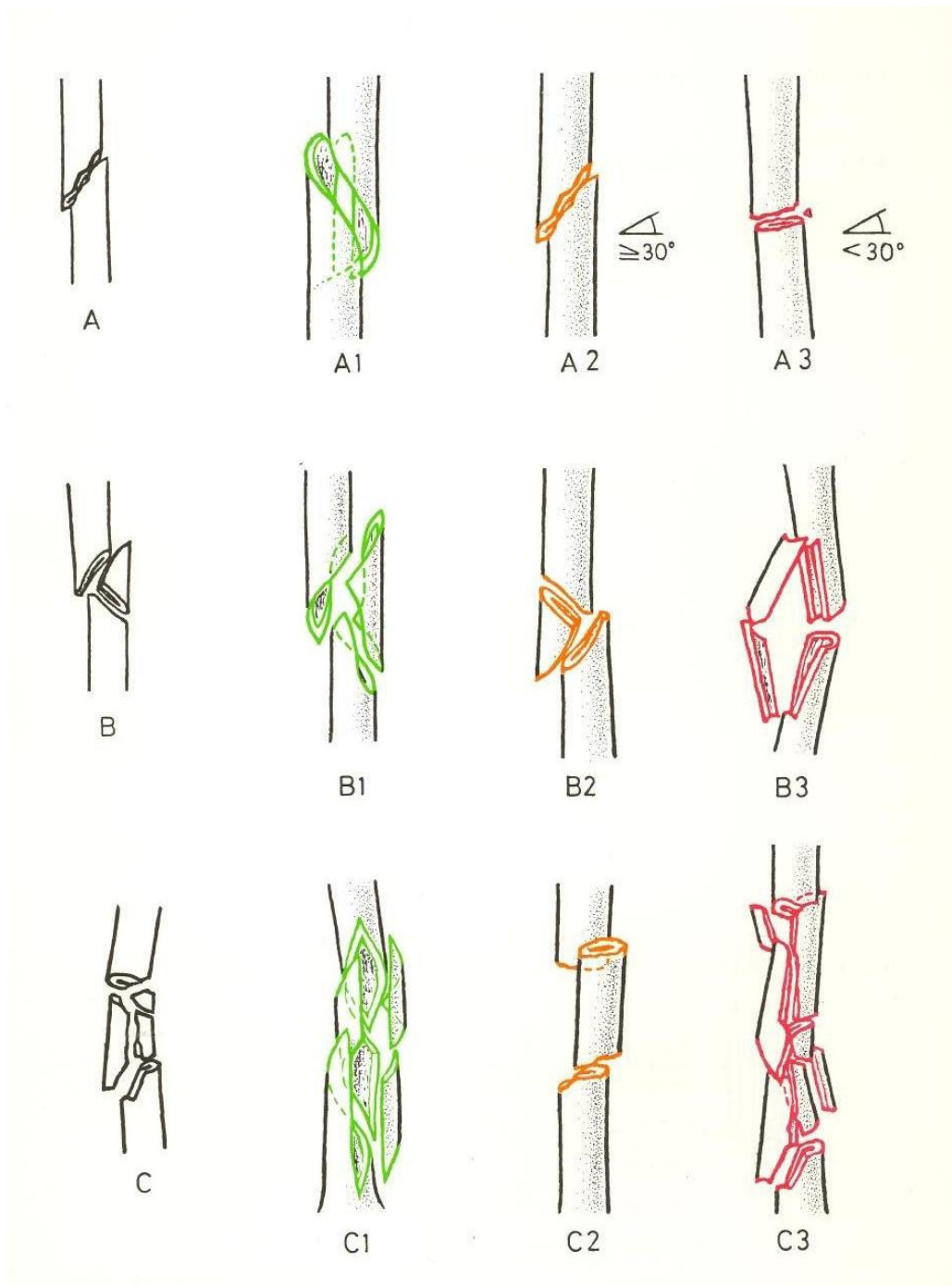
Figure 7. The AO/ASIF classification of long bone fractures (Müller et al. 1990, reprinted with the permission of Springer-Verlag).

6.4   Treatment of tibial shaft fractures

Initially, all tibial shaft fractures should be stabilized with a long posterior splint with the knee in 10–15° flexion and the ankle flexed at 90°. In addition, the principles of R.I.C.E. (rest, ice, compression, elevation) reduce the pain and swelling after trauma. Admission to a hospital may also be necessary for pain control and close monitoring for the compartment syndrome (CS). The goal of fracture treatment of the tibial shaft in adults is to restore the anatomy and regain function as quickly as possible.

Orthopaedic opinion is often cyclic, and in no area of orthopaedic endeavour is this better seen than in the management of a fractured tibia. Most fractures of the tibia will heal if treated by non-operative means—this fact is undeniable. Watson-Jones and Coltart (1943) have stated that "if immobilized long enough, all fractures will eventually heal" (Schazker and Marvin 1987). In 1936, Böhler recommended that all major tibial fractures be treated with skeletal traction for 3 weeks, followed by a weight-bearing plaster cast until healing is complete. However, Watson-Jones and Coltart (1943) clearly showed that traction had a deleterious effect on the rate of union. In addition, surgical management was increasingly recommended for the treatment of tibial shaft fractures at the beginning of the last century. Hey Groves (1992) introduced IM nailing of long bones, which was popularized by Küntscher in the 1940s (Küntscher 1940). He also performed the first IM nailing on a Finnish patient on August 25th, 1942, in Kemi, while completing his military service during World War II (Lindholm 1980).

6.4.1   Casting versus IMN in closed tibial shaft fractures

The standard treatment for most closed fractures of the tibial shaft consists of closed reduction and cast immobilisation (including functional bracing). This method has proved to be generally successful and offers reliable healing without the risks inherent in any operative procedure (Böstman 1986, Nicoll 1964, Sarmiento et al. 1984, Watson-Jones et al. 1943, Sarmiento et al.

1989, Sarmiento and Latta 2004). However, a sustantial of patients has had less than satisfactory outcomes with closed treatment (Jensen et al. 1977, Trafton 1988).

IM nailing with metal nails was introduced after World War I, but it was Küntsher who promoted the use of reaming, and it was his "detensornagel" that stimulated interest in locked IM nailing of long bone fractures, as mentioned previously. In 1986, Klemm and Börner (1986) documented the results that they had obtained for the reamed IM nailing of 401 tibial fractures. They presented their results according to an analysis of patient function and showed that almost 95% of their patients had an angular deformity of less than 5 degrees (62.5% had normal radiographic alignment), no or slight loss of knee or ankle motion, and less than 2 cm of muscle atrophy. Only 5.7% of their patients had worse results. Twenty (5%) of their patients developed complications, with an infection rate of 2.2% and a 1.1% incidence of non-union. These remarkable results led to many other studies of the use of reamed IM nailing in the treatment of closed and open tibial fractures. Closed IM nailing has gained popularity during the last decade.

Many studies have compared cast management with the IM nailing of tibial shaft fractures, and functional outcome after IM nailing is better compared with cast treatment (Alho et al. 1992, Bone et al. 1997, Karladani et al. 2000, Karladani et al. 2001b, Toivanen et al. 2001). There were clearly more malunions and delayed unions with cast treatment than with IM nailing, and also patients' durations of sick leave were shorter after IM nailing (Puno et al. 1986, Toivanen et al. 2001). In addition conservative treatment with long-leg casting has been shown to result in prolonged joint immobilisation, restricted ambulation, and extended rehabilitation requirements to regain a preinjury level of function (Trafton 1988, Hooper et al. 1991, Alho et al. 1992, Bone et al. 1997, Karladani et al. 2000, Toivanen et al. 2001).

Busse et al. (2005) also reported that, from an economic standpoint and from both a governmental and societal point of view, reamed IM nailing is the treatment of choice for closed and open Grade I tibial shaft fractures. Toivanen et al. (2000) compared the relative costs of cast treatment and IM nailing of closed and Gustilo type I open (A1, A2, A3, and B1 categories of the Orthopaedic Trauma Association) fractures. They found that the overall cost of

cast management was about 50% greater than the cost of IM nailing. It would seem that not only does IM nailing give better results than cast or brace management in displaced closed adult tibial fractures, but it is also more cost-effective.

6.4.2   External fixation versus IMN in open tibial shaft fractures

In recent years, there has been a greater acceptance of the use of IM nailing also in the treatment open tibial shaft fractures. Earlier it was believed that external fixation is safer for severe open tibial shaft fractures because the vasculature of the tibia is better preserved. The blood supply to the tibia comes mainly from a nutrient artery (as mentioned earlier, in the page 19), and it is highly unlikely that the tibial nutrient artery would survive a high-energy injury. The endosteal blood supply of the tibia is already compromised, and nailing significantly worsens the situation.

Many studies have directly compared the two methods of management (Holbrook et al. 1989, Schandelmaier et al. 1995, Henley et al. 1998, Shannon et al. 2002). Tornetta et al. (1994) compared external fixation and unreamed IM nailing in Gustilo type IIIb fractures and showed that, not only was the union faster, but the joint motion was better in the IM nailing group. Some studies have also shown that reamed IM nailing of type IIIa and IIIb fractures decreases the rates of non-union and malunion (Tu et al. 1995, Kaftandziev et al. 2006). In a prospective randomized study, Henley et al. (1995) showed that the prevalence of deep traumatic wound infections after IM nailing was 7%, and the prevalence of such infections after external fixation was 11%. In their study, no difference was found in the time to union between two groups. For the Grade I to III open fractures, the higher incidence of non-union and surgical procedures performed to promote union after external fixation indicated that IM nailing is superior to external fixation in the treatment of most open tibial fractures (Swanson et al. 1990, Alberts et al. 1999). In a study by Alberts et al. (1999) there was also faster union after IM nailing, and the infection rate was equal in both groups. There was a significantly shorter union time with IM nailing than with external fixation for Gustilo type IIIb fractures, and no difference of infection, malunion,

or refracture was found (Schandelmaier et al. 2002). The major difference between the two techniques was improved hindfoot function and a longer walking distance in the nailed group.

Bråten et al. (2004) compared the use of an external fixator with locked IM nailing for closed and Grade I and II open fractures of the tibial shaft. Their results were comparable in most respects in that unprotected weight-bearing was achieved earlier after IM nailing, but anterior knee pain occurred more frequently after the nailing. The results have also been good with the use of external fixation for closed tibial fractures (De Bastiani et al. 1984). Interlocked tibial nailing provides greater stiffness for axial compression and torsion than the use of an external Ilizarov frame (Hasenboehler et al. 2006).

Overall, unreamed tibial nailing (UTN) reduced the incidence of reoperations, superficial infections, and malunions when it was compared with the use of external fixators (Bhandari et al. 2000a). Early internal fixation is safe and has several benefits. Available evidence supports the current trend towards the earlier coverage and closure of open fracture wounds (Okike et al. 2006). In addition, a high rate of infection occurs if secondary IM nailing has to be performed (Tornetta et al. 1994). The timing of secondary nailing is important to avoid infection. Recently, a large prospective series of open tibial shaft fractures treated with immediate IM nailing without reaming showed that UTN appears to be safe and effective in the treatment of open tibial fractures (Kakar et al. 2007b).

6.4.3   Reamed versus unreamed IM nailing of tibial shaft fractures

In the early 1950s, Küntscher introduced IM reaming. This procedure permitted the use of nails, which more accurately fit the diaphyseal portion of the medullary canal and has led to improved fixation. For many years, conventional (with reaming, without interlocking) IM nailing was considered to be dangerous for severely open fractures. The risk of IM infection was considered to be too high in relation to the advantages gained with nailing (Müller et al. 1992). The question arose of whether reaming had a deleterious effect on bone circulation in severe open fractures. Klein et al. (1989) studied the acute effect of reaming on

bone circulation by comparing unreamed nailed and reamed nailed beagle tibias. They showed that intact dog tibias were largely able to compensate for the lack of medullary circulation through periosteal circulation. The reamed bones showed large deficits of blood circulation 7 hours after reaming and nailing. These results prove that cortical circulation is preserved to a good degree by unreamed nailing. The next year they showed that reaming of the canine tibia results in damage to 70% of the cortical vasculature, whereas there was damage to only 31% if UTN was used (Klein et al. 1990). Reichert et al. (1995) investigated the acute vascular response to IM reaming and showed that, 30 minutes after reaming, there is no change in cortical blood flow, but the periosteal flow increases sixfold. When Hupel et al. (2001) compared limited and standard reaming with unreamed nailing, they found no difference in the new bone formation or the mineral apposition rate 11 weeks after surgery on canine tibia. In addition, Utvåg et al. (1998) failed to show that the degree of reaming significantly affected the healing pattern of bone in an animal model. Schemitsch et al. (1994) found that it took 6 weeks for sheep tibial cortex to revascularize after the stabilization of a spiral fracture with the use of UTN, but 12 weeks were needed if reamed tibial nailing (RTN) was used. In a later experiment using the same animal model, they did not find any difference in the new bone formation in sheep tibiae treated with reamed or unreamed nails (Schemitsch et al. 1998). Lindström et al. (1998) reported that, in simple tibial fractures, their measured changes in local tissue perfusion variables were more a reflection of the injury mechanism itself than of the effect of reaming and IM nailing.

An increase in temperature may also negatively influence a healing fracture. Giannoudis et al. (2002) showed that the increase in temperature that occurs during reaming is greater with narrow medullary canals. They suggested that the generation of heat with reaming is a problem in medullary canal cavities of 8 mm or less. Significant differences have been found in comparisons of the peak pressures of reamed and unreamed nailing of the tibia, and it was possible to manipulate the IM pressure using the surgical method of nail insertion (Heim et al. 1993). Ram insertion gave rise to very low pressures when it was compared with fast manual insertion.

The temperature may also increase if an incorrect technique is used for reaming or the reamers are not sharp enough. The use of a tourniquet will have a negative influence on the cooling effect of the blood flow in the medullary canal of the tibia.

Fairbank et al. (1995) compared the biomechanical stability of UTN with RTN in compression and torsion in their cadaver study. They showed that UTN may not afford the same stability as RTN and indicated that the difference may be due to an increased incidence of infection or non-union in clinical situations. Laboratory studies indicate more rapid revascularisation of the IM blood supply after the insertion of small-diameter nails without reaming. On the other hand, reaming causes a compensatory increase in the extraosseal blood supply, and this increase may benefit callus formation. Reaming also has a "bone graft" effect on a fracture site. Bhandari et al. (2008) found a possible benefit for reamed IM nailing in patients with closed fractures, but there was no difference between the methods as regards open fractures. Animal experiments have produced much information and data that suggest that IM reaming has harmful effects, but it is not clear whether these findings are clinically relevant.

Many clinical studies have compared the results of reamed and unreamed nailing in the tibia. Most surgical interest has focussed on the open fractures associated with significant soft-tissue damage, despite the fact that a beneficial effect would be expected for reaming in low-energy closed fractures with associated minor soft-tissue damage. A meta-analysis (Bhandari et al. 2000b) of the literature concerning reaming of the femur and tibia concluded that reaming is beneficial and that it reduces the rates of non-union and implant failure in comparison with non-reamed nailing. In addition, the Finnish Current Care Unit (Finnish unit producing evidence-based treatment guidelines for the Finnish Medical Society Duodecim) concluded that reaming is the primary method for use in most cases. The same kind of results was also obtained later (Forster et al. 2005). Reaming of the tibia during IM nailing does not add a significant amount of time to tibial nailing procedures. Crist et al. (2009) found that it took an average of 7 minutes and constituted 5% or less of the total surgical time and 4% or less of the time spent in the operating room.

6.4.4   Expandable IM nailing of tibial shaft fractures

Expandable nails were created to retain the advantages of large-diameter nails and improve torsional stability and avoid the biological disadvantages of reaming and inserting tight-fitting large-diameter IM nails.

The expandable nail is a sealed stainless-steel tube consisting of four longitudinal rectangular bars connected by four thinner metallic membranes. The nail is introduced into the medullary canal in its collapsed form, which allows easy, less traumatic insertion. Once in its proper position, it is expanded gradually with physiological saline solution using a manual hand-operated pump. The surrounding steel membrane slowly expands under the guidance of an image intensifier and pressure barometer control. During the expansion, the outer bars of the nail and the stainless steel connecting membrane conform to the individual shape of the medullary canal (Ben-Galim et al. 2007).

The benefits of the expandable nail seem to be the shorter operative time needed and the fewer peroneal complications, because there is no need to insert interlocking screws (Bekmezci et al. 2005, Steinberg et al. 2006). The expandable nail is not the choice for proximal third fractures or distal third fractures of the tibial shaft (Steinberg et al. 2006). In addition, the expandable nail may not provide adequate stability in fractures with fragments greater than 50% (Bekmezci et al. 2005). Expandable nailing is an unreamed procedure. It can be safely used for patients with chest injuries, and also there is no damage to the endosteal microcirculation of the diaphyseal cortex, which may benefit bone union (Fortis et al. 2008).

Smith et al. (2006) carried out a prospective study on the expandable nailing of tibial and femur diaphyseal fractures. They had to terminate their work due to the high complication rate (shortening and a tendency for some stable fractures to become less stable during nail expansion); an unplanned return trip to the operating room was necessary for 16.5% of their patients because of postoperative shortening. They found that expandable nails cannot be used predictably even in stable fracture patterns, and locked IM nailing is more appropriate and reliable than the insertion or an expandable nail. In addition, for rotationally unstable fractures (A2 and A3 diaphyseal fractures), interlocked

nails have been found to provide increased stability over expandable nails (Blum et al. 2005).

6.4.5   New methods of treatment

Recently, a couple of studies have been carried out on new methods or choices of IM nail treatment for tibial shaft fractures. Lin (2006) studied the effectiveness of completely round nails in contrast to that of conventional locked nails with surface grooves. Completely round nails have the advantage of high mechanical strength and low manufacturing cost and could effectively treat tibial fractures.

Another study compared unlocked nailing of tibial shaft fractures. Lee et al. (2008) showed that the use of unreamed unlocked tibial nails (with an above-knee cast for 4 weeks) is a simple and effective method, especially in the treatment of middle-third fractures. In addition, traditional interlocked nailing provided stable fixation without cast immobilisation, which helped the patients to return to work more easily 6 months after their surgery.

Recently, IM nails have been developed that allow fracture or osteotomy sites to be compressed at the time of fixation. With the use of cadaveric and composite bones, it has been shown that IM nail compression increases the torsional stability of tibiae with mid-shaft osteotomy better than conventional dynamised IM nails do, because IM nails create more osteotomy site compression than the application of body weight to tibiae with dynamised IM nails (Brown et al. 2007).

6.5   Complications after IM nailing of tibial shaft fractures

Open tibial shaft fractures are the most complication prone. Complications attributable to tibial shaft fractures may be related to primary trauma, the fracture itself, or the management of the fracture. Complications that compromise the final result develop for two thirds of patients (Waddell and

Reardon 1983, Koval et al. 1991), and late complications such as deep infection etc. tend to be more serious than early ones. In addition, tibial fractures may result in social deprivation (Court-Brown and Brydone 2007). Lottes stated in 1952 that, in their series of over 500 nailings, they had experienced " . . . every known type of complication."

The reoperation rate for closed and open tibil shaft fractures varies between 17% and 50% (Harris and Lyons 2005). The reoperation rate was found to increase as the severity of contamination increased (Harris and Lyons 2005), and three predictors of reoperation are an open fracture, a transverse fracture pattern, and a postoperative fracture gap (Bhandari et al. 2003).

6.5.1   Malunion

One of the most important requirements of the use of IM nailing for tibial shaft fractures is that it can retain fracture fragments in an acceptable alignment throughout the course of the treatment. In general, progress in operative treatment and with implants has reduced the incidence of malunion with respect to tibial shaft fractures. It seems that the lowest overall frequency of malunion has been achieved with the use of locked IM nailing (Court-Brown et al. 1990, Kyrö 1997, Coles and Gross 2000). Acceptable postoperative alignment has been reported to be 5 to 10 degrees of varus–valgus and 10 to 20 degrees of rotation (Boucher et al. 2002).

Malunion rates have been reported to be 0% to 49% after IMLN treatment of tibial shaft fractures (Bone and Johnson 1986, Alho et al. 1990, Court-Brown et al. 1990, Koval et al. 1991, Coles and Gross 2000, Boucher et al. 2002, Milner et al. 2002). The commonest types of axial malunion of at least 5 or 6 degrees are varus deformity and recurvature deformity after IM nailing of a tibial shaft fracture. A potentially serious, but often underappreciated complication of the IM nailing procedure is rotational malreduction. In addition to introducing cosmetic problems, torsional deformities may lead to lower extremity arthrosis and other functional complications (Kyrö 1997, Puloski et al. 2004). Malrotation is seldom reported, the incidence for large studies ranging from 0% to 6% (Alho et al. 1990, Blachut et al.1997, Kyrö 1997).

Van Der Schoot et al. (1996) found a statistically significant relationship between tibial malalignment and degenerative changes in the knee and ankle. Varus tibial deformity has been shown to be tolerated less because subtalar joint motion may be insufficient to permit a plantigrade foot during stance (Mechrefe et al. 2006b). In addition, Puno et al. (1991) attained more severe clinical results in the face of greater degrees of ankle malalignment and statistically significantly higher percentages of good and excellent results with less malalignment.

There is a complex relationship between tibial fracture malunion and poor outcome, and a symptomatic patient may show improvement if the deformity is corrected (Mechrefe et al. 2006b).

6.5.2 Delayed union and non-union

The tibia is second only to the scaphoideum with respect to the incidence of delayed unions and non-unions (Epps 1994). In the literature, delayed union is designed at 12 to 30 weeks after a tibial shaft fracture, 20 weeks being the most commonly cited cutoff time (Oni et al. 1988, Uhlin and Hammer 1998, Coles and Gross 2000). The predictive factors for compromised fracture healing are excessive comminution, excessive initial displacement, and an open wound (Nicoll 1964, Böstman 1986, Dickson et al. 1994).

The determination and time criteria for non-union vary in the literature. Nicoll (1964) has defined non-union as a condition in which, in the opinion of the surgeon, the fracture would not unite with further conservative treatment. Keating et al. (1997a) defined clinical union as the ability to bear full weight with no pain at the site of the fracture, and radiographic union was defined as evidence of bridging of three of the four cortices in standard anteroposterior and lateral radiographs. Many authors have considered non-union to be a stage in which no signs of union can seen at six months and there is no further progression in the consolidation process during three consecutive months (Nicoll 1964, Rosenthal et al. 1977, Helfet et al. 1992, Epps 1994).

The vascular status at the time of injury affects the outcome of a fracture. A concomitant vascular injury increases non-union rates by threefold

(Mechrefe et al. 2006a). Smoking and nicotine slow fracture healing and contribute to delayed union and non-union and weaker callus formation. In addition, the use of some drugs (non-steroidal anti-inflammatory drugs, calcium channel blockers, steroids) is a risk factor for non-union (Altman et al. 1995, Castillo et al. 2005, Gullihorn et al. 2005, Kyrö et al. 1993, Mechrefe et al. 2006a, Schmitz et al. 1999). Tang et al. (2006) found that the average time to union was 8.7 months for smokers and 6.3 months for non-smokers (p = 0.09).

The final status of a non-united fracture is the formation of pseudoarthosis. The diagnosis of non-union is made at varying times, ranging from 12 to 39 weeks (Coles and Gross 2000). Non-union has been reported for 0% to over 17% of closed or open tibial shaft fractures after IM nailing (Alho et al. 1990, Anglen and Blue 1995, Bone et al. 1997, Blachut et al. 1997, Keating et al. 1997b, Larsen et al. 2004, Wood 2006).

6.5.3   Refracture

The optimal strength of the tubular bone is not restored until 1 year after the fracture of a long bone in adults (Frankel and Johnson 1968). After IM nail stabilisation, the refracture or broken nail usually occurs with non-union, deep infection, or full weight-bearing (Wiss and Stetson 1995, Court-Brown et al. 1996, Blachut et al. 1997, Keating et al. 1997b, Garcia-Lopez et al. 1998). Mechanical failure is commoner with unreaming IM nailing, as discussed earlier.

As tibial IM nailing became the preferred treatment for tibial shaft fractures, the removal of tibial nails has become commoner. There are a few case reports of tibial fractures during nail removal (Takakuwa et al. 1997, Dewey at al. 1999, Im and Lee 2003) and refractures of the tibial shaft have also occurred during the removal of IM nail (Seebauer et al. 2009). The fractures all occurred in patients who had relatively late removal of a slotted nail (ACE Medical Company nail), approximately 20 months after the nailing, and the delay probably allowed more healing and bone formation around the nail and within the slot (Takakuwa et al. 1997). The same opinion was also expressed in the

1970s (Lottes 1974). A younger age of a patient was found to be associated significantly with the difficulty of nail removal (Im and Lee 2003).

Nail-related problems also include the breakage of interlocking screws or the nail. In the absence of cortical contact, compressive loads are transferred to the interlocking screws and result in four-point bending of the screws (Bong et al. 2007).

Broken hardware, especially screws, is commonest when small-diameter nails are used, the reported prevalence being as high as 40% (Cole and Latta 1992). The rate of screw failure was 59% when a single distal screw had been used but only 5% with the use of two screws (Kneifel and Buckley 1996). Additional locking of the screw close to the diaphyseal osteotomy site reduces strain at the osteotomy site and improves torsional stability (Sayana et al. 2006).

6.5.4   Infection

Soft tissue lesions are the essential risk factors as regards the infection of tibial fractures (Edwards 1965). The incidence of postoperative infections is lower for closed tibial fractures than for open fractures (Jenny et al. 1994). The infections are usually evident during the first month after surgery, the majority being recognized during the first 7 days (Gustilo and Anderson 1976). The overall incidence of deep infection was more than 10% a few decades ago, whereas nowadays it occurs in only 0% to 4% of closed and Grade I open tibial shaft fractures (Alho et al. 1990, Court-Brown et al. 1990, Jenny et al. 1994, Watson 1994, Blachut et al. 1997, Bone et al. 1997, Keating et al. 1997b, Larsen et al. 2004, Court-Brown 2004). Tang et al. (2006) investigated closed tibial shaft fractures (42 A to C) and showed that the rate of infection for open versus closed reductions was higher but not statistically different. Open reduction seemed to have a minimal risk of infection. In addition, these authors showed that, when compared with an infection rate of 2.7% for their smoking group, their non-smoking group had an infection rate of 1.2% (p > 0.05). The deep infection rate for open tibia fractures treated with UTN has been reported to be 0–2% for type I fractures, 4–7% for type II fractures, 7–11% for type IIIA fractures, and up to 17% for type IIIB fractures (Harris et al. 2005).

Salam et al. (1991) identified a significantly higher incidence of postoperative wound induration and erythema with the use of a tourniquet use than without tourniquet use (20% versus 0%, $p < 0.05$) as regards plating tibial fractures. Petrisor et al. (2005) reviewed a case series of patients who developed postoperative infection after reamed IM nailing of tibial shaft fractures to investigate the possible causes of infection. In a closed-fracture group, 43.8% of the patients were considered to have developed infection because of inappropriate fasciotomy closure, exchange nailing, or thermal necrosis.

Some deep infections after reamed IM nailing are avoidable; attention must be paid to correct reaming, exchange nailing, and fasciotomy closure in closed fractures. In addition, in open fractures, marginal flap necrosis should be actively treated and not left to granulate (Petrisor et al. 2005).

6.5.5   Compartment syndrome

The complication that should concern every physician treating a tibial shaft fracture is compartment syndrome (CS). CS is a condition in which increased tissue pressure in a closed fascial space stops capillary perfusion and leads to ischaemia and neuromuscular damage (Matson et al. 1980, Bourne and Rorabeck 1989). The usual causes of CS include haematoma and soft-tissue swelling. A closed tibial fracture is one of the conditions most frequently associated with the development of CS (Tornetta et al. 1996). For awake and cooperative patients, subjective criteria for making the diagnosis include pain, changes in sensation and motor function, and turgor of the compartment (Kakar et al. 2007a).

CS occurs after both closed and open tibial fractures, the prevalence ranging from 0% to 18% after a tibial shaft fracture (Alho et al. 1990, Bone et al. 1997, Keating et al. 1997b, Court-Brown et al. 1990, Finkemeier et al. 2000, Larsen et al. 2004). It has been suggested that IM nailing causes CS, but McQueen et al. (1990) monitored 67 tibia fractures treated by reamed IM nailing and showed no evidence of an increased incidence of CS. The same kind of results was attained in the prospective, randomized study of Nassif et al. (2000). An experimental study on sheep reported that the IM pressure increased as much

as 10-fold during reaming (Wozasek et al. 1994). Hupel et al. (1998) showed that IM reaming of the canine tibia increased circulation to the surrounding muscles considerably, and elevated perfusion was still evident 11 weeks after the nailing. The elevated perfusion may have had a beneficial effect on the fracture healing.

Longitudinal traction during surgery tightens the fascia and thereby decreases compartment volume and increases compartment pressure (CP) (Tischenko and Goodman 1990, Kutty et al. 2005, Kakar et al. 2007a). In addition, haemorrhagic shock decreases the mean arterial pressure and can be an important factor in the development of a CS, particularly in a multiply injured patient (Tornetta et al. 1996). For the same reasons, a tourniquet should not be used for a patient who has a tibial shaft fracture and is at risk of CS or thermal injury.

Some researchers have advocated fasciotomy on the basis of compartment pressures ranging from 30 to 45 mmHg because this level is considered to approximate the critical occlusion pressures of intra-compartment microvasculature (Mubarak et al. 1976, Mubarak et al. 1978, Rorabeck et al. 1981). Lately, it has been shown that ΔP (diastolic blood pressure [DBP] – CP) is a more sensitive indicator of CS, measurements of < 30 mmHg being diagnostic of a muscle at risk. Preoperative DBP is a good indicator of postoperative DBP in most patients, and intra-operative DBP is significantly lower (average 18 mmHg, $p < 0.05$) (Kakar et al. 2007a). When a surgeon decides whether to perform a fasciotomy or awaken the patient and perform serial examinations or CP measurements, he or she should recognize that the intra-operative ΔP may be lower than the ΔP once the patient is awakened .

The treatment of CS consists of early surgical decompression. Regardless of the method used, it decreases the incidence of permanent neurological sequelae (Rorabeck and Macnab 1975, Rorabeck 1984, Georgiadis 1995, Tornetta et al. 1996). If fasciotomy is performed within 24 hours of the onset of clinical symptoms and signs, a good result is almost always achieved (Rorabeck 1984).

6.5.6 Peripheral nerve injury

The reported incidence of neurological complications after tibial nailing varies, involving mainly the peroneal nerve. The incidence of neurological deficit varies from 0% to 30% (Kellam 1985, Bone and Johnson 1986, Klemm and Börner 1986, Koval et al. 1991, Robinson et al. 1999). Williams et al. (1995) reported a new lesion of the common peroneal nerve or its divisions in 19 of 102 (19%) patients after their operation, and there was no statistical correlation between common peroneal lesions and the type of fracture, degree of trauma, time of operation, use of tourniquet, or use of traction during surgery.

Often the mechanism of peroneal nerve damage in tibial fracture nailing is indirect, the damage being caused by leg traction or CS. Stabilization of the leg in the 90/90 position can place pressure on the peroneal and tibial nerves (Koval et al. 1991, Sarangi and Karachalios 1993). The peroneal insult is often transient, and function usually recovers completely within 6 months (Klemm and Börner 1986, Koval et al. 1991, Williams et al. 1995). Weakness of the extensor hallucis longus is the commonest feature of peroneal nerve injury (Robinson et al. 1999). The affected patients are younger than other patients, their mean age being 25.6 years (18 to 33 years, $p = 0.003$) (Robinson et al. 1999).

Direct peroneal nerve damage in relation to the proximal locking screw seems to be very rare (Hems and Jones 2005, Drosos et al. 2006). Drosos et al. (2006) reported a case of partial peroneal nerve damage caused by a long oblique proximal locking screw. Removal of the screw led to gradual improvement in nerve function and complete resolution at 1 year.

6.5.7 Deep venous thromboses and pulmonary embolisms

The reported incidence of deep venous thrombosis after IM nailing of a tibial shaft fracture is low, varying from 0% to 6% (Blachut et al. 1997, de Santos de la Fuente et al. 1998, Uhlin and Hammer 1998, Larsen et al. 2004). The incidence of pulmonary embolism is also low, varying from 0% to 2% (Batten et al. 1978, Anglen and Blue 1995, Angliss et al. 1996, Blachut et al.

1997, Keating et al. 1997b), and such emolisms usually occur in patients with multiple trauma.

Reaming and nailing procedures cause liberation of bone marrow fat into the lungs with subsequent impairment in lung function (Pell et al. 1993), referred to as fat embolism syndrome (FES). This complication may be fatal, but it is rare after IM nailing of tibial shaft fractures, the incidence varying from 0% to 3% of patients (Batten et al. 1978, Anglen and Blue 1995, Angliss et al. 1996, Harrington et al. 1996, Blachut et al. 1997, Keating et al. 1997b). Christie (1996) used transesophageal echocardiography (TEE) to investigate the effects of femoral and tibial nailings and showed that 92% of their patients could have at least asymptomatic embolic phenomena after nailing. All of the clinical problems were confined to the femur procedure. In addition, Aoki et al. (1998) showed that not all patients with large emboli diagnosed by TEE develop FES.

6.5.8   Thermal necrosis

Thermal necrosis of the tibial diaphysis after reaming is an unusual, but serious, complication. Its true incidence is unknown (Bucholz et al. 2006). Laboratory data suggest that irreversible damage to bone occurs at sustained temperatures greater than 50°C (Karunakar et al. 2004). Thermal damage to tissue appears to be related to the maximum temperature to which the tissue is exposed and to the length of time the tissue is subjected to the elevated temperature. Temperatures above 50°C for 1 minute have been suggested to result in thermal necrosis (Karanakar et al. 2004). The bigger the reamer or the smaller the diameter of the medullary canal, the greater the work required to cut the bone, and, therefore, the higher the generated temperature (Garcia et al. 2004). The use of a tourniquet reduces the blood flow of the tibia and therefore the cooling effect to the bone and may be a risk for thermal necrosis. A review of the literature revealed that only a few cases have been reported (Leunig et al. 1996, Karunakar et al. 2004). The patients had pre-existing medullary canal problems or a very narrow medullary canal (diameter < 8mm) (Giannoudis et al. 2002). Reaming to 1.5 mm above the required diameter of the nail appeared to

be a safe clinical practice (Karunakar et al. 2004). Typical medullary reaming did not exceed the limits that would produce bone necrosis (Garcia et al. 2004).

6.5.9 Vascular damage

The most feared vascular complication of tibial nailing is drill damage to the popliteal artery in the area of arterial trifurcation (Bucholz et al. 2006). Shetty et al. (2003) found that, with the knee flexed (90 degrees), the popliteal artery was closer to the posterior tibial surface, at 1 to 2 cm below the joint line, in 39% of their cases. In most cases, the artery disappears from the posterior surface of the tibia during flexion (Orrico et al. 2007). In only a few cases has a traumatic lesion of the popliteal artery occurred during the last 15 years (Orrico et al. 2007). Damage to the medial inferior genicular artery, the posterior tibial artery, and the peroneal arteries has also been reported (Bucholz et al. 2006). Severe vascular complications of IM nailing are rare and should be avoidable if correct nailing techniques are used (Bucholz et al. 2006).

6.6 Anterior knee pain after IM nailing of tibial shaft fractures

An earlier analysis of the technique carried out in a hospital in Edinburgh suggested that the commonest problem associated with tibial nailing is anterior knee pain, with a recorded incidence of 40.8% (Court-Brown et al. 1990). Pain usually begins or is diagnosed several months after the nailing procedure (Keating et al.1997b, Devitt et al. 1998). The aetiology of this complication is still unknown, and some studies show that anterior knee pain is commoner after IM nailing of tibial shaft fractures than after other treatment choices (Karladani et al. 2000, Bråten et al. 2005). In the anterior part of the knee, many structures, alone or in combination, can be a source of anterior knee pain (Biedert and Sanchis-Alfonso 2002).

6.6.1 Epidemiology

The incidence of anterior knee pain after IM nailing of tibial shaft fractures varies from 10% to 86% in the literature, the mean incidence being 47% (Alho et al. 1990, Court-Brown et al. 1990, Koval et al. 1991, Orfaly et al, 1995, Haddad et al. 1996, Keating et al. 1997b, Court-Brown and Brydone 1997, Karachalios et al. 2000, Karladani et al. 2000, Skoog et al. 2001, Dogra et al. 2002, Katsoulis et al. 2006, Young and Topliss 2007, Chalidis et al.2009). The incidence of anterior knee pain seems to decrease after 60 years of age (Court-Brown et al. 1997, Keating et al. 1997b), and this decline may be related to lower physical activity levels in this group. Anterior knee pain is worse during kneeling and squatting, but some patients experience pain even at rest (Court-Brown et al. 1997). Generally (90% of cases), anterior knee pain is mild or moderate.

6.6.2 Nailing procedure

6.6.2.1 Incision placement and the nail entry point

The classic technique that was recommended for years involves a longitudinal incision over the patellar ligament at the level of the joint, splitting the tendon longitudinally (i.e., use of the transtendinous approach [TTA]) (Müller et al. 1992, Chapman et al. 2000). Nowadays an optional technique can be used in which the incision is made medially to the patellar ligament and the tendon is retracted about 20 mm laterally (i.e., the paratendinous approach [PTA]) (Figure 8). Considerable global variation occurs in the surgical approach amongst orthopaedics (Bhandari et al. 2002).
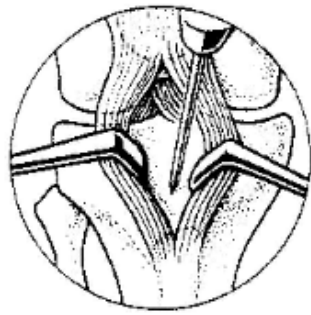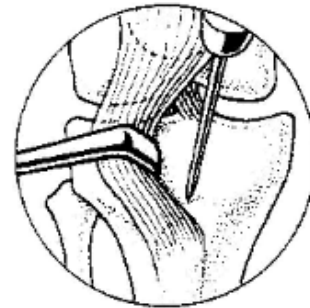
Transtendinous approach (TTA)   Paratendinous approach (PTA)

Figure 8. Two different approach techniques (Müller et al. 1992). Reprinted with the permission of Springer-Verlag.

Orfaly et al. (1995) found that, when a PTA had been used, 51% of their patients suffered anterior knee pain. On the other hand, when IM nail insertion took place through the patellar tendon (TTA), 78% developed subsequent anterior knee pain. Keating et al. (1997b) showed that insertion of the nail through the patella tendon was associated with a higher incidence of the anterior knee pain than with the use of PTA (77% and 50%, respectively). In addition, TTA was found to have a significant risk for anterior knee pain amongst 200 patients who had been treated with IM nailing, 70% versus 19% between approaches (Yu et al. 1999). Djahangiri et al. (2006) also noted that there is significantly more anterior knee pain with TTA than with PTA. Koval et al. (1991) reported 10 cases (22%) of what they termed patellar tendonitis and noted that a patellar tendon splitting approach had been used for 7 of these 10 patients. Opposite findings were reported by Court-Brown et al. (1997), who reported that 45% of their patients had anterior knee pain after TTA, whereas 54% suffered from such pain after medial PTA—there was no significant difference between the techniques.

Karladani and Styf (2001a) described a new approach in which the skin incision is located on either the medial or lateral side of the patella and nailing is performed percutaneously. In their technique, the skin incision is removed from the area involved in kneeling, it reduces the risk of trauma to the infrapatellar nerve, and it minimizes the contact pressure in the patello-femoral joint.

Samuelson et al. (2002) investigated the proper insertion point for a tibial IM nail in the coronal plane using 61 embalmed cadaveric lower legs. They recommended using a medial PTA or TTA for nail insertion and that lateral PTA should be avoided. Burç et al. (2009) reported that only 2.8% of their patients had anterior knee pain after the use of medial PTA for the nail insertion.

Weil and Gardner (2009) found a low incidence of anterior knee pain (18%) in their retrospective study. They used a lateral approach and atraumatic elevation of the infrapatellar fat pad. Therefore, the injury to certain anatomical structures (infrapatellar fat pad and the infrapatellar branch of the saphenous nerve) could be minimized.

6.6.2.2 *Intra-articular damage and the anatomical safe zone*

The subchondral bone has a rich nerve supply, and elevated subchondral bone pressure has been shown to produce pain (Biedert and Sanchis-Alfonso 2002). The ideal bony starting point for tibial nailing has been the subject of much debate. As early as 1962, Alms (1962) recommended lateral entry on the extrasynovial anterosuperior surface. Chapman (2000) recommended an entry site just above the tibial tubercle, reached via TPA. In an anatomical study, Tornetta et al. (1999) described the anatomical safe zone for nail placement as a portal averaging 22.9 mm, but as narrow as 12.6 mm and located 9.1 ± (SD 5 mm) lateral to the midline of the plateau, between the medial meniscus and the lateral articular surface (Figure 9). In addition, Weninger et al. (2009) identified the safe zone as a triangular zone in the posteromedial aspect of Hoffa's fat pad and anterior to the tibial insertion of the anterior cruciate ligament (ACL), posterior to the transverse ligament, and lateral to the anterior part of the medial meniscus. The mean dimension of this safe zone was 19.4 mm³.

Lateral   **Medial**

Sweet Spot
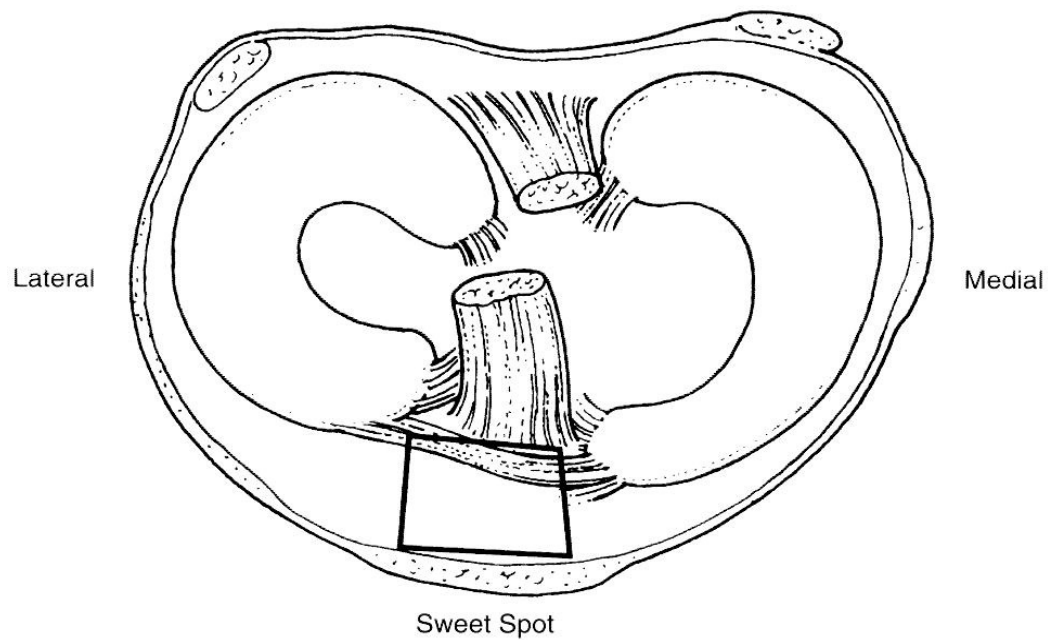
Figure 9. The safe zone, located 9.1 mm lateral to the centre of the plateau and 3 mm lateral to the centre of the tibial tubercle (Tornetta et al. 1999). Reprinted with the permission of Wolters Kluwer Health.

The radiographic correlate of this area is essential if damage to the intra-articular structures is to be prevented during portal placement and nail insertion. With standard anteroposterior and lateral radiograph views, intra-operatively, the ideal tibial portal is located immediately medial to the lateral tibial spine on the anteroposterior view and immediately anterior to the articular margin on the lateral view (Figure 10) (McConnell et al. 2001).
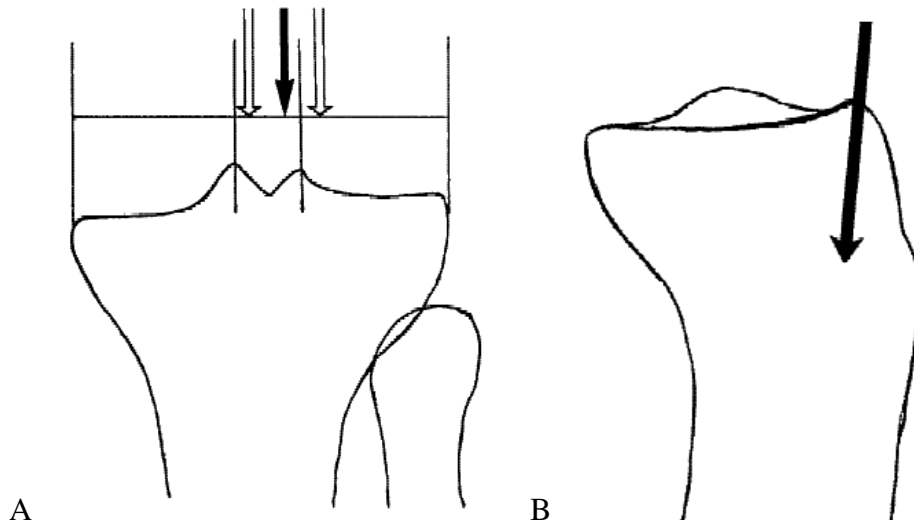
Figure 10. Anteroposterior view of the tibia (A): The black arrow represents the average position of the centre of the safe zone. The white arrows indicate the most extreme positions of the centre of the safe zone (McConnell et al. 2001). Reprinted with the permission of Wolters Kluwer Health. Lateral view of the tibia (B): The black arrow represents the starting portal adjacent to the anterior articular margin (McConnell et al. 2001). Reprinted with the permission of Wolters Kluwer Health.

Using eight cadaver knees, Devitt et al. (1998) showed that the insertion of an IM nail into the tibia significantly increases contact pressures at the patellofemoral joint. They used two different approaches, medial PTA and TTA. A significant increase in contact pressures was found at the lateral facets when medial PTA was used (p = 0.01) for the proximal tibia and at the medial facet when TTA was used for the proximal tibia (p = 0.001). When TTA was used, contact pressure increases were recorded for both facets; this finding suggests that chondral injury is more likely when TTA is used. They also found arthroscopic evidence of chondromalacia in a small number of patients with anterior knee pain after tibial nailing (Devitt et al. 1998). Weninger et al. (2009) compared the following three surgical approaches: the medial parapatellar approach, the lateral parapatellar approach, and the transtendinous approach. Their results showed damage to the intra-articular anatomical structures with the

lateral parapatellar and transtendinous approaches but not with the medial parapatellar approach.

Interindividual variation exists in the anatomical relationship between the patellar tendon and the lateral tibial spine. Althausen et al. (2002) stated that individual variations in the patellar tendon should be considered when the proper entry site is chosen for tibial nailing, and the routine use of a single approach for all tibial nails may no longer be justified. Furthermore, a preoperative fluoroscopic measurement before incision can guide the surgeon as to whether a medial paratendinous, transtendinous, or lateral paratendinous approach provides the best and most direct access to the entry site. According to their study, the safest entry point for the tibial nail seems to be just medial to the tibial spine at the anterior margin of the articular surface. Samuelson et al. (2002) studied cadaver tibiae after retrograde nailing of the bones. They measured the exit hole of the nail in relation to the tibial tubercle using the distance in the coronal plane along the transcondylar axis of the proximal tibia (the transcondylar axis being defined as the line between the most medial and most lateral aspects of the tibial plateaus) (Figure11). Except for one tibia, the IM nail exit point was always located medial to the centre of the tibial tubercle, the average being 8 mm.
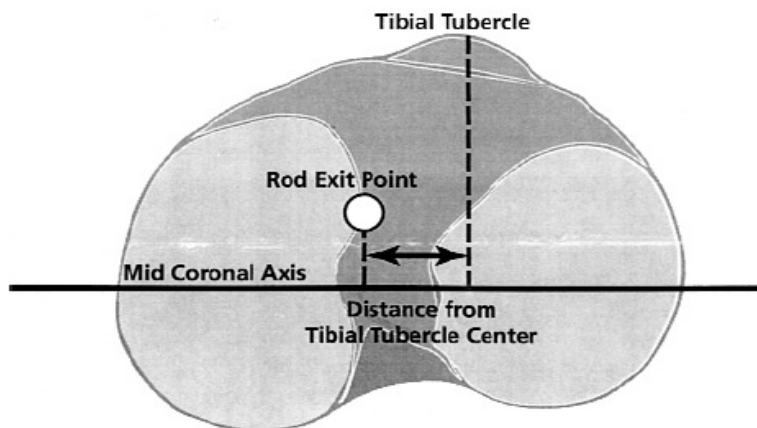
Figure 11. Diagram of proximal tibia showing the measurement technique for the rod exit point (Samuelson et al.2002). Reprinted with the permission of Wolters Kluwer Health.

Hernigou and Cohen (2000) studied 12 pairs of cadaver knees after IM nailing of the tibia. The intra-articular structures particularly at risk of damage during tibial nailing proved to be the medial meniscus, the lateral tibial plateau, and the transverse ligament. Their results showed that, in some bones, the safe zone was smaller than the size of standard reamers and the proximal part of some nails. In addition, they retrospectively analyzed the radiographs of 30 patients who had undergone tibial nailing and recorded unrecognized articular penetration and damage during surgery for four patients. These patients had pain in the knee, and there was a possibility that this pain was linked to unrecognized articular damage.

The risk of unrecognized articular penetration is higher when the tibia is shorter, and the length of the tibia is related to the size of the patient (Mensch and Amstutz 1975, Yoshika et al. 1989). Therefore the PTA is dangerous for patients with a small build (Hernigou and Cohen 2000). Järvelä et al. (2000) showed that the occurrence of patellofemoral and medial tibiofemoral osteoarthritis did not have significant differences between the subgroups of anterior knee pain after the reconstruction of the ACL, whereas lateral tibiofemoral osteoarthritis did ($p = 0.021$). Joensen et al. (2001) found a significant positive association between the presence of articular lesions of the patella and the presence of anterior knee pain; however, the presence of articular cartilage lesions was not associated with the duration of symptoms or the intensity of the anterior knee pain.

There are no nerve fibres in the hyaline cartilage (Biedert and Sanchis-Alfonso 2002), and Dye et al. (1998) did not feel any pain during the arthroscopic palpation of his extensive lesion of the patellar cartilage without intra-articular anaesthesia. However, the destruction of articular cartilage leads to local tissue response with episodes of inflammation and synovitis (Biedert and Sanchis-Alfonso 2002).

6.6.2.3 Nail protrusion

One obvious cause of anterior knee pain is marked nail prominence proximally. The nail will cause pain and even patella impingement (Court-Brown 1991), and most surgeons now advance the nail at least to the level of the tibia during insertion and many actually bury the nail within the bone. Court-Brown et al. (1997) subjectively felt that there was no obvious association between anterior knee pain and a few millimeters of nail prominence. None of the studies found an association between anterior knee pain and nail prominence in relation to the anterior cortex or tibial plateau. In a study by Keating et al. (1997b), nail protrusion made no difference as regards anterior knee pain, even with nail protrusion in excess of 5 mm, when compared with the rest of the series. The findings of Üzümcügil et al. (2009) suggest that the distances from the nail to the tibial plateau and anterior tibial cortex do not have any role in the development of postoperative anterior knee pain.

6.6.2.4 Deformity after nailing

Malunion rates have been reported to be 0% to 12% after IMLN treatment of tibial shaft fractures (Bone and Johnson 1986, Court-Brown et al. 1990, Alho et al. 1990, Koval et al. 1991, Coles and Gross 2000). Kyrö (1997) investigated the malunion of tibial shaft fractures after IM nailing and found that five (42%) patients had knee pain in the malunion group and eight (25%) patients experienced knee pain in the sound union group. Each patient with a varus or valgus angulation of at least 10 degrees or a shortening of at least 15 mm or both had a worse subjective outcome than the average of the whole malunion group. Patients with combined component internal rotation were more than five times as likely to experience anterior knee pain after total knee arthroplasty than those with combined component external rotation (Barrack et al. 2001). Patients for whom conservative management for anterior knee pain failed were compared with 14 volunteers with no symptoms, and external rotation was increased significantly in the patients with symptoms (7 degrees) in

the comparison with the volunteers with no symptoms (1 degree) (Eckhoff et al. 1997).

6.6.2.5 IM reaming

Court-Brown et al. (1996) performed a prospective, randomized study on 50 patients with Tsherne C1 tibial diaphyseal fractures and compared treatment with reamed and unreamed IM nails. They found that there was no difference in the incidence of anterior knee pain between the techniques used. In addition, Keating et al. (1997b) showed no difference in anterior knee pain between the methods used for treating open fractures of the tibial shafts. There is no mention of the entry point of IM in these studies.

In the study of Larsen et al. (2004), 10 patients in the reamed group and 9 in the unreamed group complained of anterior knee pain. The used visual analogue scale (VAS) showed a mean value of 1.64 and 1.70, respectively, for the two groups. The maximum VAS scale score was 5.9 and 6.7, respectively. The difference was not statistically significant. The authors performed nailing through a midpatellar skin incision using TTA on the proximal tibia, and the entry point was chosen in the midline between the fat pad of Hoffa and the tibial tuberosity.

6.6.2.6 Thigh muscle function

A deficit in thigh muscle strength after a tibial fracture has been reported in several articles (Holder-Powell Rutherford 1999, Gaston et al. 2000, Karladani et al. 2000, Karladani et al. 2001). Karladani et al. (2001b) found significant differences between the isometric torque values of injured and uninjured legs in the casted group only, and there were no significant differences regarding isokinetic muscle strength between the two groups. Seven patients in the nailed group complained of anterior knee pain during the isokinetic strength tests, but there was no mention of a relationship to anterior knee pain or thigh muscle strength. The presence of an open fracture and the Tscherne grade of closed fractures correlated with the knee extension and flexion muscle power and

the patients' ages. Age mainly determines muscle recovery after a fracture of the tibial diaphysis (Gaston et al. 2000).

Nyland et al. (2001) recorded an average deficit of 25% and 17% for the extensor and flexor torque, respectively, in the operated limb more than 1 year [18 (SD 6) months] after the IM nailing of isolated tibial fractures. Järvelä et al. (2000) studied anterior knee pain after ACL reconstruction surgery and used a logistic regression analysis to show that the deficit in the knee extension torque was the only factor that had a significant association with anterior knee pain.

6.6.2.7   The IPBSN

Injury to the infrapatellar branch of the saphenous nerve (IPBSN) can lead to anaesthesia, formation of a neuroma, and reflex sympathetic dystrophy (Mochida and Kikcki 1995, Tifford et al. 2000). The saphenous nerve arises as a division of the femoral nerve and leaves the adductor canal between the tendons of gracilis and semitendinous muscles. It then divides into the main saphenous branch, which continues down to the ankle, and infrapatellar branch (Tennent et al. 1998). The IPBSN arises from the fascia lata, level with the inferior pole of the patella, and then traverses from the medial to the lateral, inferior to the patella. It provides cutaneous sensation from the lower patella to the upper anterior portion of the leg, and injury to the IPBSN results in discomfort only when the affected person is in a kneeling position or when pressure is applied directly (Mochida and Kikucki 1995). The IPBSN has one to four branches, when crossing the patellar ligament (Kartus et al. 1999). In only 1 knee out of 60 did one of the branches of the IPBSN not pass through the area between the apex of the patella and the tibial tubercle (Kartus et al. 1999). There is a safe area that avoids the IPBSN; it is within an approximate 30-mm area from the medial margin of the patella at the level of midpatella, and within an approximate 10-mm area from the medial margin of the patellar tendon at the level of the distal pole of the patella (Mochida and Kikucki 1995) (Figure 12).
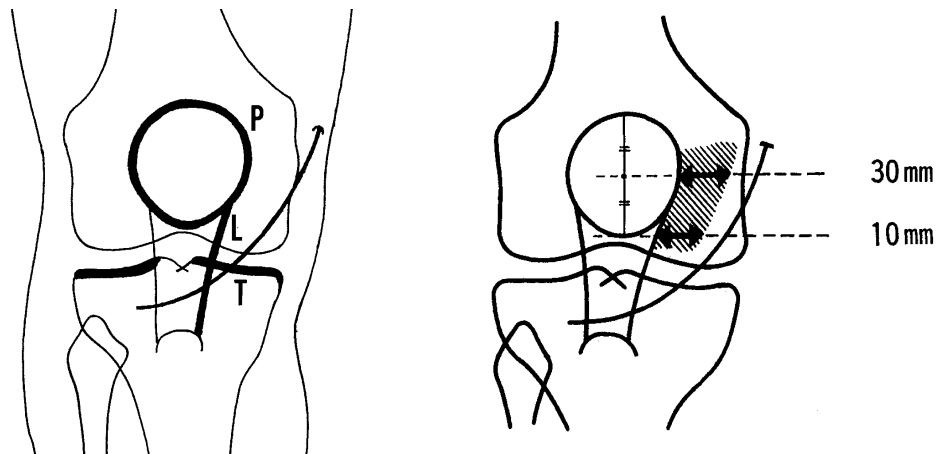
Figure 12. Landmarks for identifying nerve position (P = edge of the patella; L = edge of the patellar ligament; T = proximal edge of the tibia) (figure on the left) and safe areas for blind puncture during arthroscopic surgery (figure on the right) (Mochida and Kikucki 1995). Both figures were reprinted with the permission of Springer.

In addition, Boon et al. (2004) investigated the IPBSN and found a safe area of approximately 1.5 cm for both knees on the plane of the tibial tuberosity. In the harvesting tendons of semitendinosus and gracilis muscles, they recommend an oblique incision be made between 3.7 cm and 5.5 cm from the tibial tubercle (right knee) and between 3.6 and 4.9 cm from the tibial tubercle (left knee). The degrees of incision should be 51.6 or 52.5 degrees, respectively. Retrospective comparisons have been made between the vertical and horizontal incisions used for patellar ligament harvesting in ACL reconstruction surgery (Portland et al. 2005). No differences were found between the groups with respect to the incidence of knee pain at rest or in activity or as regards evidence of damage to the IPBSN. Weil and Gardner (2009) found a low incidence (18%) of anterior knee pain using the parapatellar approach, and therefore they could probably minimize the injury to the IPBSN.

The incidence of sensory changes after tibial nailing decreased as the length of the follow-up increased (Mistry and O'Meeghan 2005), and the area of hypoaesthesia also decreased over time (Johnson et al. 2000).

6.6.2.8   Infrapatellar fat pad

The infrapatellar fat pad lies intra-articularly but extrasynovially to the knee joint and fills the total anterior knee compartment in every position of the joint (Smillie 1963). Impingement of the infrapatellar fat pad with a total knee arthroplasty prosthesis and other knee pathologies and operations has been described (Kramers-De Quervain et al. 2005). The diagnosis can be confirmed intra-operatively by the presence of areas of necrosis and fibrosis of the fat pad (Kramers-De Quervain et al. 2005). Impingement of the infrapatella fat pad has not been described after IM nailing, but a lesion of the fat pad could be related to continuous irritation caused by the protrusion of the nail or after peroperative trauma (Katsoulis et al. 2006). In the cadaver study by Bohnsack et al. (2004), a total resection of the infrapatellar fat pad resulted in a significant decrease in the tibial external rotation to the femur between 63 degrees of flexion and full knee extension, combined with a significant medial translation of the patella. In addition, the retropatellar contact pressure was significantly reduced. The authors concluded that the infrapatellar fat pad has a biomechanical function and may play a role in anterior knee pain.

Bohnsack et al. (2005b) also found a significant increase in infrapatellar tissue pressure at a knee flexion angle of less than 20 degrees and greater than 100 degrees at all of the extension moments tested. In a study using magnetic resonance imaging (MRI) (Shabshin et al. 2006), it was shown that oedema of the suprapatellar fat pad may be a cause of anterior knee pain. Resection of the fat pad led to a complete resolution of the symptoms in one patient in a retrospective evaluation of MRI. Roth et al. (2004) showed that the finding of an effect of the quadriceps fat pad mass on the suprapatellar recess was significantly associated with anterior knee pain in a physical examination. Weil and Gardner (2009) used atraumatic elevation of the fat pad instead of perforating it, and their study showed a low incidence of anterior knee pain (18%) in comparison with the incidence of most series, which reported an average incidence of 50%.

The fat pad is highly vascular, its blood supply originating from the synovial membrane (Magi et al. 1991), and its nerve supply is primarily derived from the posterior articular nerve, a branch of the posterior tibial nerve (Kennedy et al. 1982). Bohnsack et al. (2005a) resected the infrapatellar fat pad of 21

patients and determined and specified the nerves. Neurotransmitter substance-P (SP) nerves were significantly more frequently associated with blood vessels inside the fat pad (43%, $p < 0.05$) than in the synovial tissue (28%). They concluded that the occurrence and distribution of SP nerves inside the infrapatellar fat suggest a nociceptive function and a neurohistological role in the anterior knee pain syndrome. The injection of 0.20 to 0.25 ml of 5% hypertonic saline into the medial infrapatellar fat pad was found to produce moderate to severe pain in the anterior knee region of persons with no history of knee pain (Bennel et al. 2004). The pain was most commonly felt in the region of the fat pad medial to the patella.

Infrapatellar fat pad oedema, produced by a chronic mechanical impingement in knee flexion and extension and tissue hyperpressure, lends support to the idea of a neurohistological pathology for anterior knee pain (Bohnsack et al.2006).

6.6.2.9   Radiological findings

There are few studies in which ultrasound has been used to monitor fracture healing after the IM nailing of a tibial fracture (Berton et al. 1995, Berton et al. 1998 a and b). However, only one previous ultrasound study after IM nailing of a tibial shaft fracture and chronic anterior knee pain has been published. Sala et al. (1998) investigated chronic anterior knee pain retrospectively after IM nailing. They made an ultrasound examination an average of 10.9 months after the surgery and used patellar transtendinous access in each case. In their study, the IM nails were still in place. They recorded nail–tendon impingement frequently but found no statistical significance. The patellar tendon was thickened when compared with the contralateral one. The tendinous morphostructure did not reveal any correlation with chronic anterior knee pain. Another study found no effect of low-intensity ultrasound on the healing time of IM-fixed tibial fractures (Emami et al. 1999a, Emami et al.1999b).

MRI for patients with persistent pain after the removal of the nail has shown patellar tendonitis, fibrosis, and chondropathy, as well as irregular fibrosis of the fat pad (Sala et al. 1998). Also adhesions from the nail inserted towards

the patellar tendon had been showed after the removal of the nails (Gustafsson et al. 2008). Järvelä et al. (2004) made an ultrasonographic and power Doppler evaluation of the patellar tendon after harvesting its central third for reconstruction of the ACL. There were no statistically significant differences in the ultrasound changes between the patients with or without anterior knee pain.

Heterotopic ossification (HO) of the patellar tendon has seldom been reported after IM nailing of the tibia (Kelley and Insall 1987). In a retrospective study, Gosselin et al. (1993) found HO radiographically in 2 of 31 (6.1%) patients after IM nailing of the tibia. They also noted that HO remains undiagnosed especially when PTA is used for a patient with a head injury. One of their two patients complained of pain and disability.

6.6.2.10   Trauma and fracture type

In a study by Keating et al. (1997b), the rate of anterior knee pain was slightly higher for patients with open fractures (30 of 45 or 66%) than for those with closed fractures (38 of 65 or 58%), but the difference was not significant. Court-Brown et al. (1997) found no difference in anterior knee pain in relation to fracture morphology (AO classification, Tsherne classification, open or closed fracture).

There is a high incidence of ipsilateral knee ligament injuries as regards open tibial shaft fractures (Thiagarajan et al. 1997); the incidence has been reported to be between 11% and 33% (Muckle 1981, Templeman and Marder 1989, Matic et al. 1992). The possibility of disruption of the knee ligaments should be considered for all patients with fractures of both the femoral and tibial shaft (Szalay et al. 1990, van Raay et al. 1991). There were no data available in these studies with respect to the prevalence of anterior knee pain.

6.6.2.11   Removal of IMLN

The objection to the routine removal of an IM nail is based on the fact that stress shielding is negligible with IM nails (Bråten et al. 1992, Brumback et al. 1992). Many patients name anterior knee pain as the reason for the removal.

In a study by Keating et al. (1997b), 49 (46%) patients went through nail removal at a mean duration of 16 months after nailing procedure; pain was completely relieved in 22 cases (45%). However, 17 patients (35%) experienced only partial relief, and for the remaining 10 (20%) there was no improvement. Sala et al. (1998) found no resolution of anterior knee pain after nail removal in cases in which an MRI study showed patellar tendinitis. In addition, Babis et al. (2007) showed that 12 of 15 patients with anterior knee pain experienced a complete cessation of pain after the nail removal. The patients also managed mild anterior knee pain effectively with the use of oral non-steroidal anti-inflammatory drugs.

In retrospective review of tibial shaft fractures, there were 16 nail removals due to anterior knee pain. In 9 out of the 16 cases the pain improved after the tibial nail was removed, but 4 patients, previously asymptomatic, developed anterior knee pain after the removal (Boerger et al. 1999). Lin (2006) also found that the pain was not relieved for every patient after the removal of an IM nail. In addition, anterior knee pain may worsen after nail removal (Court-Brown et al. 1997). Thus no patient should be guaranteed complete pain relief after the removal of an IM nail (Busam et al. 2006). The outcome after nail removal to alleviate pain is generally poor, and the removal of a nail should not be undertaken unless there is a convincing indication (Karladani et al.2007, Chalidis et al. 2009).

7. AIMS OF THE STUDY

The aims of the present study were:

I   To determine whether there is an association between anterior knee pain and thigh muscle weakness in patients treated with an intramedullary locking nail (IMLN) for a tibial shaft fracture.

II   To determine whether there is an association between sonographic changes in the patellar tendon and the occurrence of anterior knee pain in patients treated with the use of an IMLN for a tibial shaft fracture.

III   To establish whether patients treated with the use of an IMLN for a tibial shaft fracture and having postoperative anterior knee pain also had associated thigh muscle weakness and decreased functional knee scores in a long-term follow-up and to determine the presence of anterior knee pain over the same long-term period.

IV   To determine whether there is a difference in the prevalence of anterior knee pain after two different surgical approaches an average of 8 years after the IMLN procedure. The functional capacity and performance of the knees was also assessed.

8. PATIENTS AND METHODS

8.1   Patients and their inclusion criteria

Fifty consecutive patients [23 men and 27 women, mean age of 42 (SD 5) years] with an isolated tibial shaft fracture were treated with a reamed intramedullary (IM) nail with two interlocking bolts at both ends of the nail (Grosse-Kempf nail, Howmedica) at the Tampere University Hospital, Finland, between July 1996 and January 1998 and enrolled in this prospective study.

The inclusion criteria included the age of 15 years or more, absence of any major comorbid illnesses, and absence of any fracture line extending up to the knee joint or down to the ankle joint. No patient had previous injuries or symptoms related to either extremity. All of the patients were informed of the study procedure, purposes, and known risks, and all of them gave their written informed consent.

8.2   Treatment protocol

IM nailing was performed within 24 hours for 42 patients and between 1 and 12 days for 6 patients after a tibial shaft fracture. Closed IM nailing was performed with the patient lying supine, with the knee on the affected side flexed to at least 90 degrees. Slight traction was maintained using an os calcis pin. No tourniquet was used during the operation.

The incision for the transtendinous approach (Figure 8) was made longitudinally through the midline of the patellar tendon for a distance of 3 to 5 cm. After the insertion of the nail, the incision was closed with interrupted sutures. In the paratendinous approach (PTA) (Figure 8), a medial longitudinal

incision was made, care being taken not to violate the patellar tendon or its sheath. In all of the cases, standard proximal and distal locking screws were used. All of the nails were countersunk below the cortical bone of the proximal tibia. All of the patients routinely received an intravenous cephalosporin antibiotic (1.5 g, Kefurion™) at the induction of the anaesthesia.

Postoperative immobilization in a cast or brace was not used. The patients were allowed to progress to one-leg weight-bearing 6 weeks (leg weight to operative side) postsurgery and to full weight-bearing 12 weeks postsurgery. All of the patients received instructions (instructions with paper and normal physiotherapy instructions in the department) dealing with thigh muscle rehabilitation in the hospital, but no formal physiotherapy was instituted at any time after the initial surgery.

Nails were routinely removed regardless of the presence or absence of knee pain, after an average of 1.6 (SD 0.2) years after the insertion, using the same entry incision and approach as in the nail insertion. After removal of the nail, neither instructions on thigh muscle rehabilitation nor physiotherapy were given.

8.3   Study groups in the series

In Study **IV**, patients, after their informed consent, were randomized according sealed envelopes into one of two treatment groups: closed IM nailing using the transtendinous approach (TTA) (25 patients) or closed IM nailing using a medial paratendinous approach (PTA) (25 patients). In both groups, one patient was excluded from the study because of deep infection and nail removal, and two patients died from causes not related to the tibial shaft fracture. In addition, four patients could not be traced for the examination [an average of 3.2 (SD 0.4) years after the nail insertion and 1.7 (SD 0.3) years after the nail extraction. Thereafter, two patients died from causes not related to the tibial shaft fracture. Five patients had new trauma or acute heart or lung disease and were excluded from the long-term follow-up. Five patients refused to participate further in the follow-up. In addition, two patients were untraceable for the 8-year follow-up

examination. Thus 28 (67%) patients were available for the 8-year re-examination in Study **IV**. This re-examination was performed an average of 8.1 (SD 0.3) years after the nail insertion and an average of 6.6 (SD 0.3) years after the nail extraction.

In Studies **I** and **II**, the patients were divided postoperatively into two groups, depending on the presence of chronic anterior knee pain: (1) a symptomatic group (patients with chronic anterior knee pain) and (2) an asymptomatic group (patients without chronic anterior knee pain). In Studies **I** and **II,** two patients were excluded in the early phase of treatment because the nail had to be removed due to a deep infection. Two patients died during the follow-up from causes not related to the tibial shaft fracture. Two patients were initially managed with a cast and then treated with nailing when corrective osteotomy was performed (the first one 6 months after the surgery and the second one 18 months after the injury), and they were also excluded from the study. In addition, four patients could not be located or contacted for the follow-up of isokinetic strength testing; thus there were 40 patients (Study **I**), an average of 3.2 (SD 0.4) years after the nail insertion and an average of 1.7 (SD 0.3) years after the nail extraction. In addition, for various reasons, four patients never attended the ultrasound examination, an average of 2.5 (SD 0.5) years after the nail insertion and 1.0 (SD 0.3) years after the nail extraction. Thus the number of patients available for ultrasound examination (Study **II**) was 36.

In Study **III**, the patients were divided into the following three groups depending on the evaluation of anterior knee pain during the follow-up period: patients who were painless initially and still painless after the long-term follow-up [never any pain (NP)]; patients whose anterior knee pain had disappeared during the follow-up [pain, no pain (PNP)], and patients who had anterior knee pain both initially and at the time of the follow-up [always pain (AP)]. There were 40 patients in the first isokinetic muscle strength check-up (Study **I**). Two patients subsequently died from causes not related to the tibial shaft fracture. Five patients sustained a new trauma or acute heart or lung disease and were excluded from the study. Three patients refused further follow-up. Lastly, two patients could not be found for the 8-year follow-up examination. Thus there

were 28 patients (in Study **III**) available for isokinetic strength testing and pain evaluation after 8 years [average 8.1 (SD 0.3) years after the nailing].

8.4   Evaluation of isokinetic muscle strength

The first isokinetic quadriceps and hamstring strength testing (Study **I**) was carried out using the Cybex system (Cybex 6000, Division of Lumex, Inc., New York, USA, 11779). The long-term check-up (Studies **III** and **IV**) was conducted using the Dyna-Com system (Dyna-Com 650, Oy Diter-Elektroniikka Ab, Turku, Finland, 11304). Both tests were carried out by the same physician, who was not a part of the surgical team.

Before the test, the patients did a warm-up exercise on a bicycle ergometer for 5 minutes. Then they were fixed to the isokinetic device with straps around the chest, pelvis, thigh, and malleoli. Before the testing, the patients were instructed to perform a sufficient number of submaximal and maximal repetitions of knee extension and flexion at both test velocities (60 and 180 degrees per second) in order to become familiar with the machine.

Figure 13. Isokinetic testing machine and patient position in the machine.

The actual test included knee joint extension and flexion with both legs at two different angular velocities. The range of movement (ROM) was 90 degrees (0 degrees to 90 degrees). The test included five maximal repetitions at both speeds. There was a 30-second rest period between the two test speeds. Each patient was verbally encouraged to do his or her best. The repetition during which the maximal peak torque was produced was recorded.

8.5   Ultrasonographic and radiographic evaluation

The ultrasonographic and power Doppler evaluation of the patellar tendons (Study **II**) was done by one experienced senior radiologist from the Department of Radiology. The radiologist was blinded to the clinical results. All of the ultrasound investigations were performed using an Acuson 512 Ultrasound

system and a power Doppler technique (Acuson Sequoia, Mountain View, California, USA) with a 7.5-MHz real-time linear array transducer (8L5 38-mm linear Multihertz, Acuson, Mountain View, California, USA).

The patients were in a sitting position with the knee joint at 30 degrees of flexion. The measured parameters were calcification of the patellar tendon, granulation tissue at the nail entry point, and hypoechoic lesions of the patellar tendon. The power Doppler technique was used to measure the blood flow of the patellar tendon and the entry point. In addition, the thickness of the distal and proximal parts of the patellar tendon in the operated limb and non-operated limb were determined.

In Study **IV**, the distance from the plateau surface of the tibia to the proximal tip of the nail and the extent of nail protrusion (nail prominence in relation to the bone cortex in millimeters) was determined from the postoperative lateral plain radiograph.

8.6   Clinical evaluation (subjective and objective)

In all of the studies (**I** to **IV**), the patients used a 100-mm visual analogue scale (VAS) to grade their anterior knee pain during rest, walking, running, squatting, kneeling, stair climbing, and stair descension, as well as after long-term sitting, 0 denoting no pain and 100 denoting the worst pain that the patient could imagine (Aitken 1969). The patients also assessed the impairment caused by their anterior knee pain with use of a 100-mm scale, on which 0 meant no impairment, <33 meant mild impairment, 33 to 66 meant moderate impairment, and >66 meant severe impairment.

In addition, in all of the studies (**I** to **IV**), all of the patients completed the standardized scoring scales described by Lysholm and Gillquist (1982) (Appendix 3) and by Tegner et al. (1988) (Appendix 4), as well as the Iowa knee score (Merchant et al. 1989) (Appendix 5).

The functional evaluation (Appendix 6) (Study **IV**) was performed with the use of a modification of the method developed by Kannus et al. (1992). The evaluator used a 0- to 3-point scale to rate the patients' ability to perform one-leg

jumping and duck-walking (3 points signified the ability to perform without problems and no pain, and 0 points represented the inability to perform and intense pain), their ability to perform a 25-repetition full-squat test (0 signified the inability to perform any squat without pain, 1 point represented the ability to perform 1 to 10 squats without pain, 2 points signified 11 to 20 squats, and 3 points represented more than 20 squats), and their ability to kneel (0 points meant that it was impossible to kneel, 1 point was given if it was possible to kneel for less than 10 seconds without pain, 2 points represented kneeling for less than 20 seconds without pain, and 3 points signified that there was no time limitation). The scores acquired from these tests were summed and averaged for the final between-group comparisons.

The impairment scale and the functional testing scale (Study **IV**) were developed specifically for the purpose of this study. For validation, Spearman's correlation coefficients between these tests and those of Lysholm and Gillquist (1982) and the Iowa knee score (Merchant et al. 1989) were assessed.

One physician performed a blinded clinical evaluation of all the patients in all of the studies (**I** to **IV**).

8.7 Statistical analysis

To describe the data, the mean [and standard deviation (SD)] and the 95% confidence interval (95% CI) of the differences between the groups were reported for the continuous variables in all of the studies (**I** to **IV**). In addition, both percentages and risk ratios were reported for the categorized variables in Study **IV**.

The differences between the categorized variables were tested using the Fisher's exact test in Studies **I**, **II**, and **IV**, and in Study **III** the differences between the categorized variables were tested using the chi-square test. In the statistical analyses, the differences between the two groups were tested with the use of the Mann-Whitney U-test for continuous variables (Studies **I**, **II**, and **VI**) because the distributions were skewed. In Study **III**, due to the skewness of the

data distribution, the differences between the groups were tested using the Kruskal-Wallis test for continuous variables.

The preliminary power calculations of Studies **I** and **III** suggested that, with use of less than a 5% probability of a type-I error ($p < 0.05$) and a power of 80% (type-II error, 0.20), a sample size of 18 patients (9 patients/group) was necessary to detect a 15% difference in muscle strength between the two study groups. In these preliminary power calculations, this 15% was considered a clinically relevant difference, since the strength and function of thigh muscles seem to be up to 85% of normal 1 year after the fracture of the diaphysis of the tibia (Haddad et al. 1996), and the thigh muscle deficits have been reported to be 17% to 25% after IM nailing of isolated tibial fractures (Nyland et al. 2001). In addition, the mean of the thigh muscle strength of the operated limb was compared with that of the non-operated limb to determine the deficit, reported as the percentage difference between the two in Studies **I** and **III**.

The statistical analysis was carried out with use of the program SPSS for Windows (version 10.0 in Study **I**, version 11.0 in Study **II**, and version 12.0 in Studies **III** and **IV**; SPSS Inc., Chicago, Illinois, USA). Univariate logistic regression analyses were carried out with use of version 14.0. Throughout the studies, a p-value of < 0.05 was considered significant.

9. RESULTS

9.1 Measurement of thigh muscle strength and anterior knee pain after IM nailing of tibial shaft fractures (Study I)

The study groups were comparable with respect to age, body mass index (BMI), nail protrusion, nail-plateau distance, operation time, and Tegner's knee scores (before the operation). There were statistically significantly more women than men in the symptomatic group (Fisher's exact test, p = 0.007) (Table 1).

In a comparison of the subjective outcome of the patients with anterior knee pain with that of patients without such pain, there were statistically significantly intergroup differences in the Iowa knee score (after the operation) [94 (SD 9) versus 99 (SD 1), Mann-Whitney test, p = 0.003], the Lysholm knee score (after the operation) [88 (SD 2) versus 98 (SD 2), Mann-Whitney test, p = 0.014), and the Tegner knee score (after the operation) [3.4 (SD 1.3) versus 4.3 (SD 1.3), Mann-Whitney test, p = 0.053].

Table 1. Basic characteristics of the patients with and without anterior knee pain (AKP and NoAKP, respectively) after the IM nailing of a tibial shaft fracture.

	AKP n = 28	NoAKP n = 12	p- value†
Age (years)	42 (SD 13)	45(SD 12)	0.515*
BMI (kg/m²)	25.6 (SD 5.2	26.1 (SD 3.6)	0.658*
Sex			0.008†
Female	15 (94%)	1 (6%)	
Male	14 (54%)	12 (46%)	
Protrusion (mm)	5.3 (SD 3.9)	4.0 (SD 4.0)	0.415*
Plateau distance (mm)	12.5 (SD 9.6)	10.3 (SD 9.0)	0.495*
Operation time (min)	87 (SD 40)	70 (SD 15)	0.110*
Tegner B‡	3.9 (SD 1.6)	4.1 (SD 1.3)	0.577*

* According to the Mann-Whitney test.

† According to Fisher's exact test.

‡ Tegner's knee score before the surgery.

In our study, there was no difference in thigh muscle atrophy between the symptomatic and asymptomatic patients (p-value = 0.570, Mann-Whitney test).

Table 2. Thigh muscle atrophy (operated leg versus non-operated leg) amongst symptomatic and asymptomatic patients an average of 3.2 (SD 0.4) years after the IM nailing.

Thigh muscle atrophy	Symptomatic patients n = 29	Asymptomatic patients n = 13
None	4	11
1 to 2 cm	8	17
Over 2 cm	1	1

With reference to the hamstring muscles, the mean peak torque deficit of the injured limb (as compared with the mean peak torque of the uninjured limb) was 2 (SD 11)% for the painless group and 11 (SD 17)% for the pain group at a speed of 60°/s (p = 0.09, 95% confidence interval (95% CI) for the group difference = –18% to 0%]. At a speed of 180°/s, the corresponding deficits were –3 (SD 13)% and 10 (SD 21)% [p = 0.03, 95% CI for the group difference = –24% to –2%]. With reference to the quadriceps muscles, the mean peak torque deficit of the injured limb was 14 (SD 15)% for the painless group and 15 (SD 15)% for the pain group at a speed of 60°/s [p = 0.71, 95% CI for the group difference = –11% to 10%]). At a speed of 180°/s, the corresponding deficits were 9 (SD 11% and 14 (SD 17% (p = 0.46, [95% CI for the group difference = –14% to 5%]. The absolute power values (Nm) for muscle strength are shown in Figure 14.
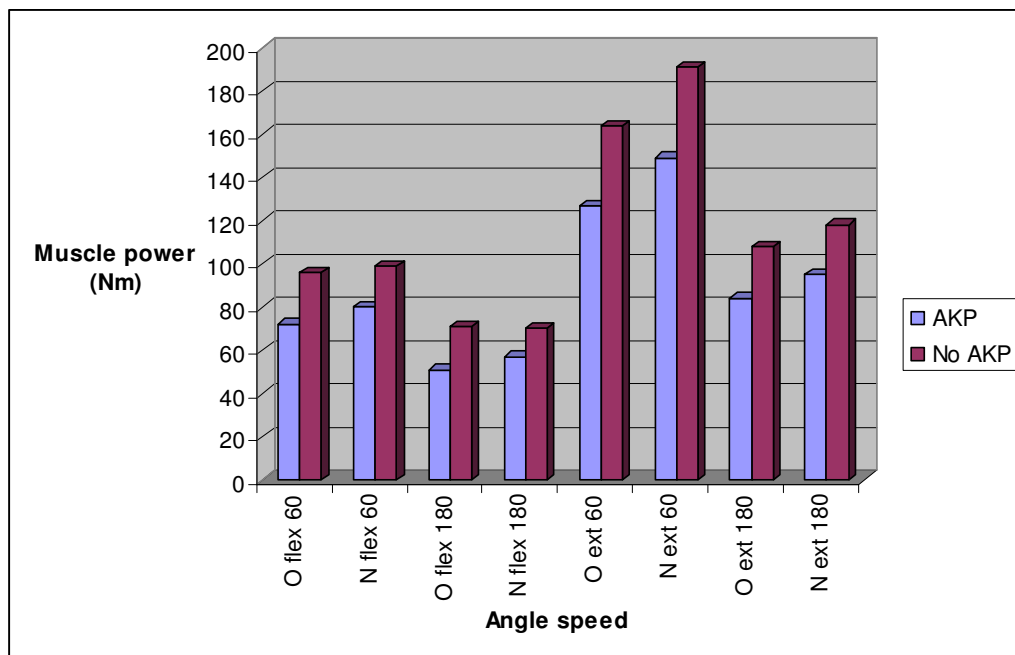
Figure 14. Thigh muscle strength in the non-operated (N) and operated (O) limbs an average of 3.2 (SD 0.4) years after the IM nailing.

9.2 Ultrasonographic evaluation and anterior knee pain after IM nailing of tibial shaft fractures (Study II)

Of the 36 patients, none had a surgical complication, such as patellar tendon rupture, compartment syndrome (CS), or broken hardware. The study groups were comparable with respect to age, BMI, nail protrusion, nail-plateau distance, and nail insertion and removal. There were only 2 painless women, and the remaining 12 had anterior knee pain, whereas, amongst the men, 10 were painless and 12 had anterior knee pain ($p = 0.07$, Fisher's exact test).

There were no statistically significantly differences between the study groups as regards blood circulation at the patellar tendon or nail entry point, calcification of the patellar tendon, granulation tissue at the entry point, or the occurrence of hypoechoic lesions of the patellar tendon (Table 3).

Table 3. Ultrasound measurements of patients with and without anterior knee pain (AKP and No AKP, respectively) an average of 2.5 (SD 0.5) years after the IM nailing.

Measurement	NoAKP n = 12	AKP n = 24	p-value
Calcification			
Yes	7 (58%)	11 (46%)	0.725†
No	5 (42%)	13 (54%)	
Hypoechoic lesion			
Yes	7 (58%)	15 (63%)	1.000†
No	5 (42%)	9 (37%)	
Granulation at the ep*			
Yes	2 (17%)	7 (29%)	0.685†
No	10 (83%)	17 (71%)	
Circulation in the patellar tendon			
Yes	3 (25%)	2 (8%)	0.307†
No	9 (75%)	22 (92%)	
Circulation at the ep* of the tendon			
Yes	2 (17%)	4 (17%)	1.000†
No	10 (83%)	20 (83%)	

* Entry-point of the nail.

† Fisher's exact test.

With reference to the difference in the thickness of the distal part of the patellar tendon in the operated versus non-operated limb, the mean difference was 1.4 (SD) 1.1 mm in the chronic pain group and 2.6 (SD 2.5) mm in the painless group (p = 0.135). The mean difference at the proximal part of the patellar tendon was 1.4 (SD 1.3) mm in the chronic pain group and 2.3 (SD 2.3) mm in the painless group (p = 0.251), respectively (Table 4).

Table 4. Difference in the patellar tendon thickness between the operated and non-operated limbs an average of 2.5 (SD 0.5) years after the IM nailing.

Thickness difference region	NoAKP n = 12	AKP n = 24	p-value*	95% CI
Distal part of the patella (mm)	2.6 (SD 2.5)	1.4 (SD 1.1)	0.135	–0.4 to 2.8
Proximal part of the patella (mm)	2.3 (SD 2.3)	1.4 (SD 1.3)	0.251	–0.7 to 2.4

  * Mann-Whitney test.

With an alpha level of less than 5% (p < 0.05) and a difference between the means of 1.2 mm, the final number of patients per group (12 without pain and 24 with pain) gave a minimum 85% statistical power for the study.

There were only 2 women in the painless group (16%) and 10 (84%) others had anterior knee pain. Amongst the men, there were 10 (45%) without and 12 (55%) with anterior knee pain. The difference was obvious, but not quite statistically significant. The thickness of the proximal and distal parts of the patellar tendon showed no difference between the men and women (Table 5).

Table 5. Thickness difference of the patellar tendon according to sex over an average period of 2.5 (SD 0.5) years after the IM nailing.

Thickness difference region	Male n = 22	Female n = 14	P value*	95% CI
Distal part of the patella (mm)	2.0 (SD 2.0)	1.8 (SD 2.0)	0.475	-0.7 to 1.7
Proximal part of the patella (mm)	1.5 (SD 1.3)	1.5 (SD 1.2)	0.490	-0.8 to 1.4

* Mann-Whitney test.

The difference in the thickness of the distal part of the patellar tendon with PTA versus TTA, the mean difference was 1.4 (SD 1.2) mm for the chronic pain group and 2.2 (SD 2.0) mm for the painless group (p = 0.135, 95% CI for the group difference = –0.4 to 2.0). The mean difference for the proximal part of the patellar tendon was 1.2 (SD 1.1) mm for the chronic pain group and 2.0 (SD 2.1) mm for the painless group (p = 0.251, 95% CI for the group difference = –0.4 to 2.0]). The differences were not statistically significant with respect to the patellar tendon thickness, although the patellar tendon was somewhat thicker with the TTA. This occurrence did not, however, explain the between-group difference in the occurrence of chronic anterior knee pain (Table 4).

9.3 Eight-year follow-up of the measurement of thigh muscle strength and anterior knee pain (Study III)

Of the original material of 40 patients, 35 reported anterior knee pain before the nail removal, on the average 1.5 years after the nail insertion. Nineteen (54%) had a complete or marked resolution of pain after the nail extraction.

Of the remaining 28 patients, 7 (25%) were painless and 21 (75%) reported chronic anterior knee pain in the first follow-up. The long-term follow-up test was performed an average of 8 years after the nail insertion. Twenty (71%) patients were painless, and only eight (29%) complained of chronic anterior knee pain at the final check-up. Anterior knee pain had thus disappeared for 13 patients during the second follow-up period. Amongst the eight patients with pain, the pain was worse in kneeling and squatting and after long-term sitting (Figure 15).
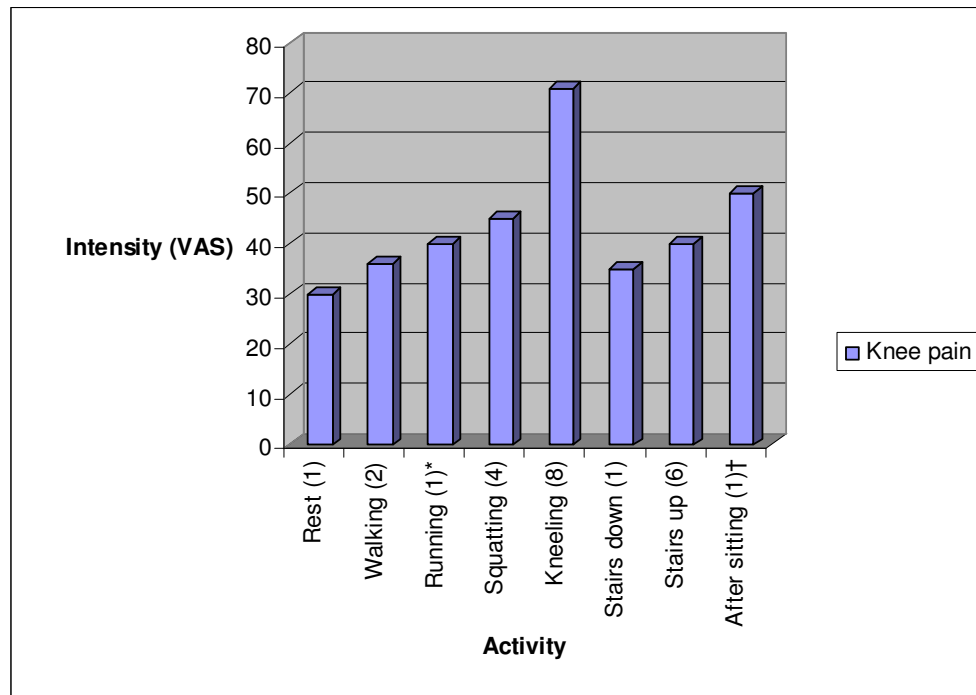
Figure 15. Intensity of anterior knee pain in the pain group (AKP, n = 8) an average of 8.1 (SD 0.3) years after the IM nailing.

* One patient had not started running activity.

† After long-term sitting.

The 28 patients were divided into the following three groups: 7 who were painless initially and still painless at the follow-up (NP), 13 whose anterior knee pain disappeared during the follow-up (PNP), and the remaining eight had anterior knee pain both initially and at follow-up (AP). The three study groups were comparable with respect to age, body mass index, nail protrusion, operation time, nail insertion site, hospital time and range of movement in the knee joint (Table 6).

Table 6. Basic characteristics of the patients who never had anterior knee pain (NP), patients for whom anterior knee pain had vanished during follow-up (PNP), and patients with continuous anterior knee pain (AP) an average of 8.1 (SD 0.3) years after the IM nailing.

	NP n = 7	PNP n = 13	AP n = 8	p- value
BMI (kg/m²)	26.5 (SD 3.3)	25.5 (SD 2.9)	25.4 (SD 8.3)	0.725*
Age (years)	44 (SD 15)	48 (SD 9)	40 (SD 18)	0.464*
Sex				0.018†
Female	0 (0%)	8 (62%)	5 (63%)	
Male	7 (100%)	5 (38%)	3 (37%)	
Nail insertion				0.896†
Transtendinous	4 (57%)	6 (46%)	4 (50%)	
Paratendinous	3 (43%)	7 (54%)	4 (50%)	
Smoking				0.924†
No	5 (71%)	9 (69%)	5 (63%)	
Yes	2 (29%)	4 (31%)	3 (37%)	
Plateau‡ (mm)	15.3 (SD 8.0)	7.2 (SD 5.5)	12.4 (SD 8.1)	0.060*
Protrusion§ (mm)	2.7 (SD 3.3)	5.0 (SD 4.2)	6.4 (SD 4.3)	0.220*
Operation time (min)	70 (SD 19)	84 (SD 20)	96 (SD 66)	0.419*
Hospital time (d)	7.6 (SD 3.3)	5.2 (SD 1.7)	7.6 (SD 3.4)	0.162*
ROM‖(°), first control	139 (SD 9)	140 (SD 7)	138 (SD 11)	0.620*
ROM‖(°), long-term control	150 (SD 0)	150 (SD 0)	148 (SD 5)	0.075*

* Kruskal-Wallis's test.

† χ²-test

‡ Nail plateau distance, the distance (mm) from the plateau surface of the tibia to the proximal tip of the nail.

§ Nail protrusion, nail prominence (mm) in relation to the bone cortex.

‖ Range of movement in the knee joint (0–150 degrees).

There were clear differences between the groups with respect to the nail-plateau distance (the distance from the plateau surface of the tibia to the

proximal tip of the nail), although these differences were not statistically significant (p = 0.060) (Table 6). In the first check-up, the Iowa knee scores were as follows: 99.0 (SD 0.8) for the NP group and 98.1 (SD 1.8) for the PNP group, and 88.3 (SD 11.4) for the AP group (Kruskal-Wallis test; χ^2 = 15.8, p = 0.000). At the time of the long-term check-up, the Iowa scores were 100 (SD 0.0), 100 (SD 0.0) and 95.0 (SD 3.4) (Kruskal-Wallis test; χ^2 = 22.0, p = 0.000), respectively. The Lysholm knee scores were 97.9 (SD 1.8), 96.9 (SD 3.4) and 76.4 (SD 16.1), respectively, in the first check-up (Kruskal-Wallis test; χ^2 = 16.6, p = 0.000), and, at the time of the long-term check-up, the scores were 98.9 (SD 1.1), 99.7 (SD 0.8), and 84.9 (SD 14.6), respectively (Kruskal-Wallis test; χ^2 = 15.4, p = 0.000). The Tegner knee scores are shown in Table 7.

Table 7. Tegner's knee scores for the patients who never had anterior knee pain (NP), the patients for whom anterior knee pain had vanished during the follow-up (PNP), and the patients with continual anterior knee pain (AP).

	NP n = 7	PNP n = 13	AP n = 8	p-value*
Tegner's knee score†	4.9 (SD 0.7)	3.7 (SD 1.3)	4.8 (SD 2.1)	χ^2 = 4.2, p = 0.120
Tegner's knee score ‡	4.9 (SD 1.1)	3.7 (SD 1.3)	3.3 (SD 1.3)	χ^2 = 7.3, p = 0.026
Tegner's knee score §	5.0 (SD 1.1)	3.7 (SD 1.0)	4.5 (SD 1.7)	χ^2 = 4.7, p = 0.093

* Kruskal-Wallis test.

† Patients' Tegner knee score at the baseline (before the trauma and surgery).

‡ Scores at the first follow-up an average of 3.2 (SD 0.4) years after the IM nailing.

§ Scores at the long-term follow-up an average of 8.1 (SD 0.3) years after the IM nailing.

No group differences emerged with regard to the mode of injury or type of fracture; however the level of the fracture seemed to be more proximal in the AP group (Table 8).

Table 8. Type of fracture in the patients who never had anterior knee pain (NP), the patients for whom anterior knee pain had vanished during the follow-up (PNP), and the patients with continual anterior knee pain (AP) an average of 8.1 (SD 0.3) years after the IM nailing.

	NP n = 7	PNP n = 13	AP n = 8	p- value
Mode of Injury				0.821*
Low energy	6 (86%)	11 (85%)	6 (75%)	
High energy	1 (14%)	2 (15%)	2 (25%)	
AO Classification				0.826*
A1	3 (44%)	9 (68%)	5 (61%)	
A2	0 (0%)	1 (8%)	1 (13%)	
A3	1 (14%)	1 (8%)	1 (13%)	
B1	1 (14%)	1 (8%)	0 (0%)	
B2	1 (14%)	1 (8%)	1 (13%)	
C2	1 (14%)	0 (0%)	0 (0%)	
Fibular fracture				0.263*
No	0 (0%)	2 (15%)	2 (25%)	
High	4 (57%)	5 (38%)	0 (0%)	
Middle	2 (29%)	2 (15%)	2 (25%)	
Low	1 (14%)	4 (32%)	4 (50%)	
Fracture location				0.154*
Middle diaphysis	1 (14%)	2 (15%)	4 (50%)	
Distal diaphysis	6 (86%)	11 (85%)	4 (50%)	

* χ^2-test.

In the measurement of the isokinetic thigh muscle strength, the study groups differed regarding the extension torque deficit. The patients who still had

anterior knee pain at the follow-up clearly showed an extension deficit in the operated leg in comparison with the extension of the non-operated leg (Table 8). The thigh muscle strength of the operated limb was better as regards both flexion and extension in the group in which anterior knee pain had vanished during the follow-up (Table 9).

Table 9. Difference† (%) in thigh muscle strength between the operated and non-operated lower limb amongst the patients who never had anterior knee pain (NP), those for whom anterior knee pain had vanished during follow-up time (PNP), and those with continual anterior knee pain (AP) an average of 8.1 (SD 0.3) years after the IM nailing.

	NP n = 7	PNP n = 13	AP n = 8	p-value*
Flexion 60° (%)	–2.2 (SD 12.0)	1.6 (SD 15.3)	10.3 (SD 30.3)	$\chi^2 = 1.0$, p = 0.593
Extension 60° (%)	–2.8 (SD 8.8)	5.9 (SD 14.7)	–13.0 (SD 15.5)	$\chi^2 = 7.9$, p = 0.019
Flexion 180° (%)	–2.9 (SD 22.5)	7.0 (SD 18.9)	4.4 (SD 16.2)	$\chi^2 = 1.70$, p = 0.429
Extension 180° (%)	–9.4 (SD) 13.4)	4.9 (SD 16.3)	–1.9 (SD 8.8)	$\chi^2 = 4.8$, p = 0.092

 * Kruskal-Wallis test.

 † Difference = [(operated limb – non-operated limb) / non-operated limb x 100%). A minus value indicates that the operated limb was weaker than the non-operated limb.

As regards the strength of the knee extension, the symptomatic group (anterior knee pain group) differed from the asymptomatic group, but the differences were not clinically or statistically significant. As for the knee flexion strength (at the speed of 60°/s), the symptomatic group differed from the asymptomatic group, although the intergroup difference of 9% was not statistically significant (p = 0.09). A significant intergroup difference was found for knee flexion at 180°/s, and, with this speed of movement, the strength difference was 13% (p = 0.03). With the use of an alpha level of less than 5% (p

< 0.05) and the 13% muscle strength difference between the groups considered clinically relevant, the final number of patients per group (12 without pain and 28 with pain) gave a minimum 80% statistical power for the study.

9.4 Eight-year follow-up comparing two different approach techniques in the IMLN surgery of tibial shaft fractures (Study IV)

The study groups were comparable with respect to sex, age, BMI, nail protrusion, nail-plateau distance, operation and hospital time, smoking, fracture location, and mode of injury.

At the time of the 8-year follow-up, 4 (29%) of the 14 patients treated with the TTA and 4 (29%) of the 14 patients treated with the PTA reported anterior knee pain during one or more of the activities that they assessed using the visual analogue scale (p = 1.000, relative risk = 1.00, 95% CI = 0.6 to 1.6. Anterior knee pain had vanished from six (43%) patients in the TTA group and seven (50%) patients in the PTA group between the two re-examinations.

Four of the 14 patients treated with the TTA reported that they experienced pain at the patellar tendon, whereas 1 patient experienced pain also at the medial border of the patellar tendon. None of these patients had tenderness on the lateral side of the patellar tendon. One patient in the TTA group had palpation tenderness in the pain region. One of the fourteen patients treated with the PTA reported pain at the patellar tendon, and three had pain at the medial and lateral borders of the tendon. Three patients in the PTA group had palpation tenderness in the pain region.

With the numbers available, no significant difference was found between the study groups with respect to the prevalence and intensity of anterior knee pain during rest, walking, running, squatting, kneeling, stair-climbing or stair descension, or after long-term sitting (Figure 16).
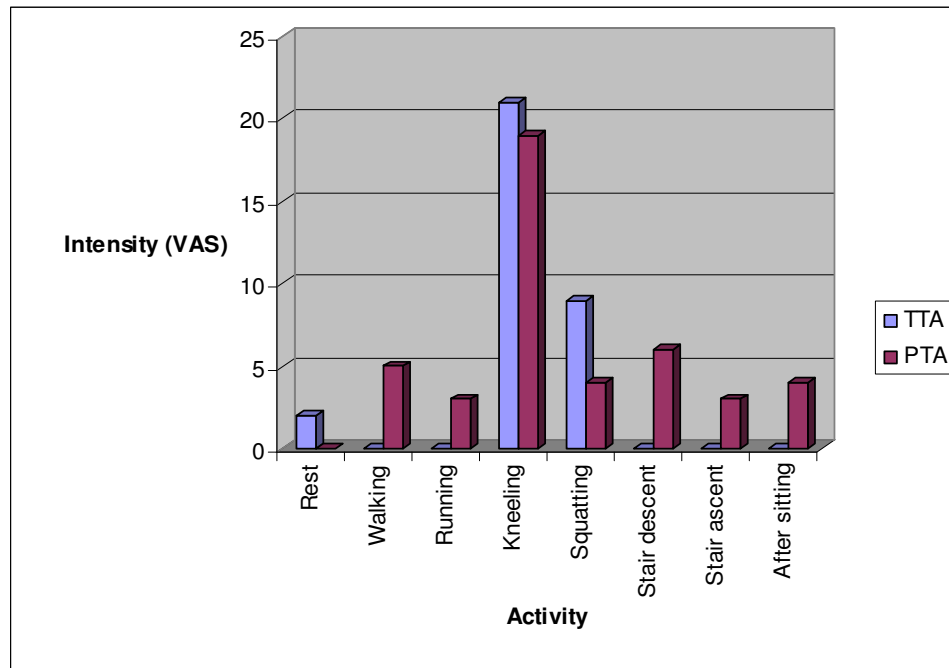
Figure 16. Comparison of the intensity (mean value of the VAS pain scores) of anterior knee pain during different activities between the two treatment groups an average of 8.1 (SD 0.3) years after the IM nailing.

The mean total score for the functional tests at the time of the first re-examination was 10.2 (SD 3.4) points for the patients treated with the TTA and 9.6 (SD 3.0) points for those treated with the PTA (p = 0.272). The respective functional scores at the time of the second re-examination was 10.8 (SD 2.6) points for the patients treated with the TTA and 11.1 (SD 1.3) points for those treated with the PTA (p = 0.648). The difference between the two re-examinations is shown in Table 10.

Table 10. Functional test scores at the first [3.2 (SD 0.4) years after the IM nailing] and second [8.1 (SD 0.3) years after the IM nailing] follow-up examination and the difference between the examinations.

	TTA n = 14	PTA n = 14	p-value*	95% CI
Examination 1	10.2 (SD 3.4)	9.6 (SD 3.0)	0.272	−1.8 to 3.1
Examination 2	10.8 (SD 2.6)	11.1 (SD 1.3)	0.648	−1.9 to 1.3
Difference between the two examinations	0.6 (SD 1.0)	1.5 (SD 2.2)	0.295	−2.3 to 0.4

* Mann-Whitney test.

Compared with the score before the injury, the mean Tegner score at the time of the first re-examination decreased 0.71 (SD 1.27) points for the patients treated with the TTA and 0.14 (SD 0.77) points for those treated with the PTA (p = 0.250). At the time of the second re-examination, the mean Tegner score had increased back to the preoperative level (Table 11). Respectively, the mean Lysholm activity score had increased to the level of 97.5 (SD 4.2) points for the patients treated with the TTA and 93.0 (SD 13.5) points for those treated with the PTA (p = 0.564) (Table 10). The Iowa knee scores were 98.8 (SD 2.4) and 98.4 (SD 3.3) points, respectively (p = 0.694) (Table 11)

Table 11. Functional knee scores at the first and second re-examinations 3 and 8 years after the nailing procedure.

	TTA n = 14	PTA n = 14	p-value*	95% CI
Tegner's knee score†	4.36 (SD1.34)	4.21 (SD 1.67)	0.653	0.15 (–1.0 to 1.3)
Tegner's knee score ‡	3.64 (SD 1.22)	4.07 (SD 1.44)	0.538	–0.43 (–1.5 to 0.6)
Tegner's knee score §	4.21 (SD 1.25)	4.29 (SD 1.49)	0.887	–0.08 (–1.1 to 1.0)
Iowa knee score ‡	96.7 (SD 3.3)	94.3 (SD 10.3)	0.924	2.4 (–3.5 to 8.3)
Iowa knee score §	98.8 (SD 2.4)	98.4 (SD 3.3)	0.694	0.4 (–1.8 to 2.7)
Lysholm's knee score ‡	93.6 (SD 8.6)	88.9 (SD 16.0)	0.317	4.7 (–5.3 to 14.6)
Lysholm's knee score §	97.5 (SD 4.2)	93.0 (SD 13.5)	0.564	4.5 (–3.2 to 12.2)

* Mann-Whitney U-test.

† Preinjury Tegner's knee score.

‡ Scorings at the first re-examination an average of 3.2 (SD 0.4) years after the IM nailing.

§ Scorings at the second re-examination an average of 8.1 (SD 0.3) years after the IM nailing.

An extension torque deficit was found for the thigh muscles after the tibial nailing, but it was not associated with the type of entry point that had been used.

9.5 Univariate logistic regression analyses of whole data explaining anterior knee pain after the IM nailing of tibial shaft fractures

The IM nail was removed from 35 patients an average of 1.5 years after the nailing. After the nail extraction, 23 patients had a marked or complete resolution of pain. Only 12 patients had no change in anterior knee pain or worsening after the nail removal (Table 12). Thirteen of fourteen patients in the TTA group reported that they experienced pain at the patellar tendon, whereas the remaining patient experienced pain at the medial border of the patellar tendon. Seven of fifteen patients treated with PTA reported pain at the patellar tendon, seven had pain at the medial border of the tendon, and one had pain at the lateral border of the tendon. Younger and physically active patients seemed to benefit more from the nail removal than the patients who were not so physically active (Table 12), but the differences were not statistically significant. There were 19 patients included in the univariate logistic regression analyses (at the long-term follow-up) who attended the ultrasonographic measurements at the time. There was more calcification of the patellar tendon in the pain group, but the regression analyses did not provide any explanation for the anterior knee pain (Table 13).

Univariate regression analyses of the data were also performed after the long-term follow-up investigations; the regression concerned anterior knee pain and compared patients who still had anterior knee pain after a long time (AP) and those whose anterior knee pain had vanished during the follow-up (PNP) (Tables 14 and 15). The pain group stayed longer in hospital, probably due to the pain involved in starting the rehabilitation process (5 days versus 7 days between the pain and no pain groups, respectively). They also had more pain at the first isokinetic control (3 years after the nailing procedure), and there was a statistically significant difference with respect to squatting and kneeling. There was also a statistically significant difference in the functional test at the time of the first isokinetic control (6.5 versus 12.0 between the pain and no pain groups, respectively). Muscle strength was lower in the pain group during extension and

flexion at the time of first isokinetic test, and also during the extension in the follow-up examination after 8 years (Table 15).

Table 12. Characteristics of the pain groups (complete or marked relief from anterior knee pain versus no effect or worsening of the anterior knee pain) after nail removal and results of the univariate logistic regression analyses explaining anterior knee pain after IM nailing of tibial shaft fracture.

	Complete or marked relief (n = 23)		No or worsening effect (n = 12)		OR	95% CI	p-value
Sex	N	%	N	%			0.39
Male	15	71.4	6	28.2	1	Ref	
Female	8	57.1	6	42.9	0.53	0.13–2.21	
Nail insertion	N	%	N	%			0.90
Transtendinous approach	12	67.7	6	33.3	1	Ref	
Paratendinous approach	11	64.7	6	35.3	0.92	0.23–3.70	
Age (years) median, min–max	42.0	15–57	50.0	26–64	1.05	0.98–1.11	0.17
Protrusion (mm) median, min–max	6.0	-2–12	3.5	0–11	0.92	0.77–1.11	0.40
Plateau distance (mm) median, min – max	10.0	0–38	12.5	2–27	1.00	0.92–1.08	0.97
Tegner before median, min–max	4.0	2–8	3.5	2–5	0.64	0.37 –1.10	0.11
BMI (kg/m²) median, min–max	24.7	17.9–31.2	26.8	19.2–43.4	1.13	0.96–1.34	0.15

Table 13. Characteristics of the pain (anterior knee pain in the long-term follow-up, AP) and no pain (anterior knee pain had vanished over the 8-year follow-up, PNP) groups and the results of the univariate logistic regression analyses explaining anterior knee pain after the IM nailing of tibial shaft fractures.

	AP group n = 6		PNP group n = 13		OR	95% CI	p-value
Calcification							0.15
Yes	5	46%	6	54%	0.17	0.02–1.91	
No	1	13%	7	88%	1	Ref	
Hypoechoic lesion							1.00
Yes	6	46%	7	54%	1.00	0–	
No	0	0%	6	100%	1	Ref	
Granulation at the entry point							0.83
Yes	2	29%	5	71%	1.25	0.16–9.54	
No	4	33%	8	67%	1	Ref	
Circulation							0.94
Yes	1	33%	2	67%	0.91	0.07–12.52	
No	5	31%	11	69%	1	Ref	
Circulation at the entry point							0.38
Yes	2	50%	2	50%	0.36	0.04–3.52	
No	4	27%	11	73%	1	Ref	
Thickness difference at the proximal part (mm)	1.7	0–4.4	1.4	-0.2–3.9	1.28	0.62–2.61	0.50
Thickness difference at the distal part (mm)	1.9	0–3.8	1.5	0.1–4.5	1.18	0.53–2.60	0.70

Table 14. Characteristics of the pain (anterior knee pain at the long-term follow-up, AP) and no pain (anterior knee pain had vanished over the 8-year follow-up, PNP) groups and the results of the univariate logistic regression analyses explaining anterior knee pain after the IM nailing of tibial shaft fractures.

	AP group		PNP group		OR	95% CI	p-value
Sex	N	%	N	%			0.97
Male	3	37.5	5	62.5	1	Ref	
Female	5	38.5	8	61.5	0.96	0.16–5.9	
Age (years) median, min–max	45	15–64	50	30–60	0.95	0.89–1.02	0.18
Nail insertion	N	%	N	%			0.86
Transtendinous approach	4	40	6	60	1	Ref	
Paratendinous approach	4	36.4	7	63.6	1.17	0.20–6.80	
Nail protrusion (mm) median, min – max	7	0–11	5	-2–12	1.08	0.87–1.36	0.48
Plateau distance (mm) median, min–max	11.5	3–28	5.0	0–15	1.13	0.97–1.33	0.12
Operation time (min)	70	46–239	80	51–115	1.01	0.99–1.03	0.53
Hospital time (d)	7	4–12	5	3–8	1.47	0.97–2.22	0.07
Smoking	N	%	N	%			0.75
Yes	3	42.9	4	57.1	0.74	0.12–4.73	
No	5	35.7	9	64.3	1	Ref	
Fracture location	N	%	N	%			0.10
Middle diaphysis	4	33.3	2	66.7	1	Ref	
Lower diaphysis	4	26.7	11	83.3	5.50	0.71–42.6	
Trauma energy	N	%	N	%			0.59
Low	6	35.3	11	64.7	1	Ref	
High	2	50	2	50	0.55	0.06–4.91	

Table 15. Characteristics of the pain (anterior knee pain in the long-term follow up, AP) and no pain (anterior knee pain had vanished during the 8-year follow-up, PNP) groups and the results of the univariate logistic regression analyses explaining anterior knee pain after the IM nailing of the tibial shaft fractures.

	AP group		PNP group		OR	95% CI	p-value
Tegner before fracture median, min–max	5.0	2–8	3.0	2–6	1.54	0.84–2.80	0.16
Pain intensity (VAS) median, min–max	43.0	20–80	10.0	8–40	1.13	1.01–1.27	0.03
ROM (degrees) median, min–max	132.5	125–150	140.0	130–150	0.96	0.86–1.07	0.45
Iowa knee score median, min–max	91.5	62–97	99.0	95–100	0.42	0.19–0.92	0.03
Lysholm median, min–max	81.0	42–92	97.0	88–100	0.58	0.35–0.96	0.03
BMI (kg/m²) median, min–max	24.0	17.9–43.4	25.2	20.3–31.2	1.00	0.84–1.18	0.97
Functional tests median, min–max	6.5	1–11	12.0	8–12	0.47	0.24–0.91	0.03
Pain intensity (VAS) during different activities, median, min–max							
Running	25.8	0–57	4.4	0–57	1.05	1.00–1.11	0.07
Squatting	30.6	0–60	9.2	0–50	1.05	1.00–1.10	0.05
Kneeling	79.3	55–100	49.0	8–99	1.05	1.00–1.10	0.04
After sitting	4.0	0–20	0.2	0–2	1.34	0.76–2.37	0.32

** At the time of the first isokinetic muscle testing, approximately 3.2 (SD 0.4) years after the nailing procedure.

Table 16. Characteristics of the pain (anterior knee pain in the long-term follow-up, AP) and no pain (anterior knee pain had vanished during the 8-year follow-up, PNP) groups and the results of the univariate logistic regression analyses explaining anterior knee pain after the IM nailing of the tibial shaft fractures.

	AP group		PNP group		OR	95% CI	p-value
Ext 60 degrees* median, min–max	25.5	9–41	12.0	-7–42	1.07	0.99–1.15	0.08
Ext 180 degrees* median, min–max	15.5	5–73	11.0	0–44	1.04	0.98–1.11	0.22
Ext 240 degrees* median, min–max	20.0	-21–75	16.0	-22–49	1.02	0.98–1.07	0.30
Flex 60 degrees* median, min–max	21.0	-11–61	9.0	-9–28	1.07	0.99–1.15	0.08
Flex 180 degrees* median, min–max	17	-7–84	4	-16–29	1.05	0.99–1.11	0.14
Flex 240 degrees* median, min–max	31.0	-14–80	6	-66–43	1.05	1.00–1.10	0.06
Ext 60 degrees† median, min–max	-12.3	-41.8 –6.5	8.8	-18.3–30.7	0.91	0.84–0.99	0.03
Ext 180 degrees† median, min–max	-1.9	-16.4–12.9	6.8	-25.9–35.3	0.96	0.90–1.03	0.29
Flex 60 degrees† median, min–max	12.9	-32.8–56.3	3.2	-25.9–25.5	1.02	0.98–1.06	0.37
Flex 180 degrees† median, min–max	6.7	-30.8–22.5	6.1	-26.5–42.5	0.99	0.94–1.04	0.74

* At the time of the first isokinetic muscle testing, approximately 3.2 (SD 0.4) years after the nailing procedure.

† At the time of the long-term follow-up, approximately 8.1 (SD 0.3) years after the nailing procedure

10. DISCUSSION

10.1 Patients and methods

Amongst the 5 million Finnish population, approximately 1200–1400 tibial shaft fractures occurred within 1 year during the recent decade (Figure 2). In Finland these fractures are distributed amongst all Finnish hospitals, and therefore the fractures treated in each hospital are clearly reduced. During July 1996 through January 1998, the Tampere University Hospital treated 50 isolated tibial shaft fractures. As discussed earlier, there were eventually 42 patients who were included in the study. One limitation of this study series is the relatively small number of patients, particularly in the long-term follow-up. On the other hand, the long follow-up of over 8 years is a strength of the study, as was the randomized, prospective nature of the study design.

We did not categorize the patients involved in the study due to their co-morbidities and medications, such as diabetes or corticosteroids. In addition, there was no information available concerning the social lives of the patients.

The distribution of the patients' ages in the study was similar to that of other patients with tibial fractures in the Finnish population. Middle-age persons between 45 and 55 years form the group usually experiencing tibial shaft fractures (Figures 3 and 17).
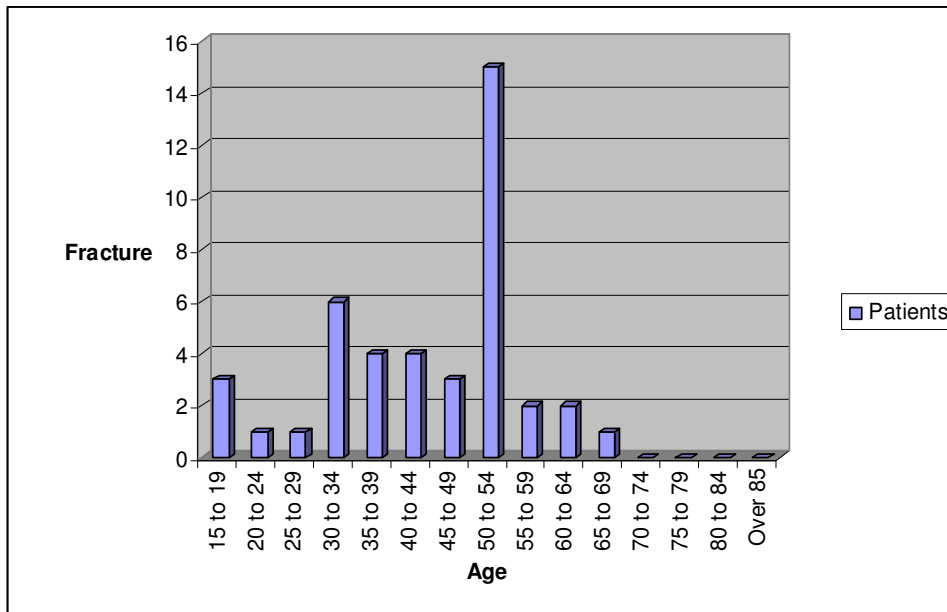
Figure 17. Distribution of patients sustaining tibial shaft fractures in different age groups in the study series.

During the last decade, 60% of the tibial shaft fractures involved men, and 40% occurred amongst women. In the study population, there were 26 men (62%) and 16 women (38%).

The different scores (Lysholm, Tegner, Iowa knee score) used in the subjective evaluation are standardized methods widely employed to evaluate the functional capacity of the extremities after knee injuries. The additional functional tests were also reliable, as shown by the high Spearman's correlation coefficients determined between them and the other tests.

In the late 1960s, the concept of isokinetic exercise developed by James Perrine proved to be a revolution in exercise training and rehabilitation. The term isokinetics refers to the use of a fixed speed with a variable resistance that totally accommodates the individual throughout the range of movement (ROM). Therefore, the velocity is constant at a preselected dynamic rate at which the resistance varies to exactly match the force applied at every point in the ROM. In the study the Cybex system was used in the first isokinetic evaluation, and the long-term evaluation was conducted using the Dyna-Com system. A different isokinetic machine had to be used in the second evaluation because the isokinetic test machine was changed between 2000 and 2006 in the Department of Physiotherapy of the Tampere University Hospital. Therefore, a comparison of

the absolute power (Nm) values between evaluations was not possible. However, in this study, both tests were carried out by the same physician, who was not a part of the surgical team.

The isokinetic values obtained at 60 and 180 °/s are highly reproducible if adequate calibration, gravity correction, and patient positioning are recorded and standardized (Pincivero et al. 1997). The test variable used, the peak torque, has been regarded to be the most properly studied testing parameter of isokinetic strength (Kannus 1994).

10.2 Ultrasonographic and radiographic evaluation

In the present study, there was increased blood circulation in the patellar tendon in the patients without anterior knee pain when compared with those with such pain, but the difference was not significant. In a comparison of the paratendinous approach (PTA) and the transtendinous approach (TTA), there was no difference in the blood circulation of the patellar tendon although, in the TTA group, the patellar tendon was clearly thicker than that in the PTA group, probably due to scar tissue in the tendon. The tendon thickness between the PTA versus the TTA did not explain the prevalence of anterior knee pain amongst the patients in this study. In addition, there were no differences between the other parameters used in the study.

Only one previous ultrasound study has been carried out after IM nailing of tibial shaft fractures and chronic anterior knee pain. In this retrospective study of Sala et al. (1998), the IM nails were still in place. In the material of the present study, only two patients (17%) in the painless group and three patients (13%) in the pain group had a nail still in place. Sala et al. (1998) reported that the index patellar tendon was thickened when compared with the contralateral tendon, but there was no relationship between the tendon morphology and structure, as well as chronic anterior knee pain. Tuncyurek et al. (2009) studied anterior knee pain (patients with a morphological knee anomaly that may have caused anterior knee pain were excluded from the study) and the morphometry of the patellar tendon with magnetic resonance imaging (MRI). Patellar tendon

length, thickness, and surface area do not seem to be significant parameters to help explain the aetiology of anterior knee pain (Tuncyurek et al. 2009).

In the present study, ultrasonographic evaluation was used to determine the changes in the patellar tendon. MRI is more sensitive with respect to changes in the knee region, but overdiagnoses may be a problem. In addition, the intramedullary nails should be removed before MRI can be performed. Moreover, MRI is less available and more expensive than ultrasonography. The degenerative changes of the injured knee were not measured in the present study nor was the possibility of articular or meniscical damage in the knee clarified.

There were only 2 women in the painless group (16%) and 10 (84%) others had anterior knee pain. Amongst the men, there were 10 (45%) without and 12 (55%) with anterior knee pain. The difference was obvious, but not quite statistically significant.

The impingement of the infrapatellar fat pad has been thought to be related to knee pathology. Such an association has not been described after IM nailing, but a lesion of the fat pad could be related to continuous irritation caused by the protrusion of the nail or after peroperative trauma (Katsoulis et al. 2006).

The distance from the plateau surface of the tibia to the proximal tip of the nail and the extent of nail protrusion (nail prominence in relation to the bone cortex in millimeters) was determined from the postoperative radiograph of the lateral plain, and it was mentioned in every study. There were no differences between the relationship of the distance from the tibial head and nail protrusion to anterior knee pain.

In the present study, the mechanical axis of the lower extremities (valgus or varus) or the rotation of the tibia was not determined. Moreover, the recurvatum or antecurvatum of the tibia was not measured. These factors may influence the function of the knee and not determining or measuring them is one weakness of the study.

Previous data have not indicated any influence of a nail protrusion of a few millimeters on anterior knee pain (Keating et al. 1997b). However, if there is marked proximal nail prominence, the nail will cause pain and even patella impingement, which has been demonstrated previously (Court-Brown 1991). Tibia nails can also migrate towards the tibial plateau and become symptomatic,

even if they are locked proximally and distally, probably because of osteoporosis (Skoog et al. 2001). In the present study, no relationship was found between the nail plateau distance and anterior knee pain. The univariate logistic regression analyses seemed to indicate more calcification in the patellar tendon in those patients who still suffered from anterior knee pain at the time of long-term follow-up (Table 12).

10.3 Two different treatment techniques

In the series of this study, the use of PTA did not reduce the incidence of anterior knee pain when compared with the effect of TTA. In addition, there were no differences in the ultrasound findings or the pathology of the patellar tendons. The prevalence of anterior knee pain was similar after 3 years of IM nailing, and it also remained similar 8 years after the nailing procedure. Anterior knee pain had vanished in some patients, but there was no relationship to the approach used in the nailing procedure. The subjective and objective measurements were similar between the treatment groups during the entire 8 years of the follow-up.

Katsoulis et al. (2006) attempted to correlate the incidence of anterior knee pain with the type of approach used. They reviewed 10 studies and found a total of 761 tibial shaft fractures, 211 of which had been treated with PTA and 550 had undergone TTA. There was no statistical difference between the approaches used with respect to pain. It has been mentioned that injury of the infrapatellar branch of the saphenous nerve is associated with anterior knee pain (Figure 18).
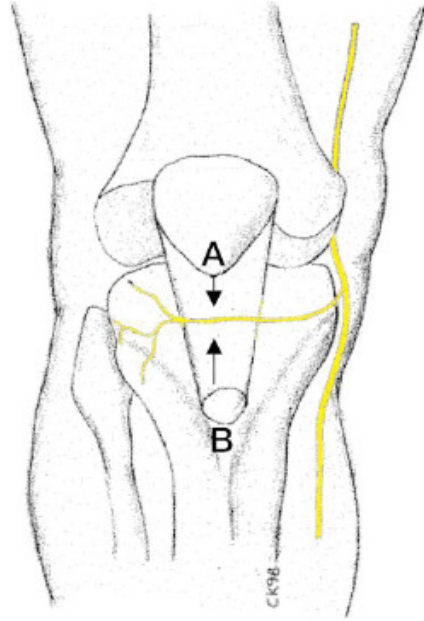
Figure 18. The anatomy of the infrapatellar nerve branch crossed the region of the patellar ligament. The mean distance from the tibial tubercle (B) was 27 (SD 27) mm, and that from the apex of the patella (A) was 30 (SD 27) mm (Kartus et al. 1999). Reprinted with the permission of Elsevier.

After arthroscopy of the knee or after harvesting of the patellar tendon or hamstrings in the reconstruction of the ACL, IPBSN (infrapatellar branch of the saphenous nerve) damage, hypoaesthesia, dysaesthesia, and anterior knee pain have been reported (Kartus et al. 1997, Boon et al. 2004, Portland et al. 2005). During the IM nailing procedure using TTA or medial PTA, the risk of iatrogenic damage of the infrapatellar nerve is obvious, but, for many patients, the incidence of anterior knee pain declins after the IM nail has been removed (Court-Brown et al. 1997, Keating et al. 1997b). This phenomenon was also seen in the present study. Only the medial parapatellar approach was used rather than both parapatellar approaches (lateral and medial), as well as a vertical skin incision. Some authors have used short horizontal skin incision to avoid the iatrogenic damage to the infrapatellar branches of the saphenous nerve.

In the present series, after 3 years of IM nailing, there were 29 patients who had anterior knee pain. The pain was in the area of the patellar tendon in 20 patients and in the parapatellar region in 9 patients. After 8 years, only 9 patients

had anterior knee pain. In 5 cases the pain was in the region of the patellar tendon, and in 4 cases it was in the parapatellar region. In addition, there were no differences between the treatment choices in the univariate regression analyses (Table 14).

10.4   Thigh muscle strength

In the series of the present study, the first isokinetic testing was carried out 3 years after the IM nailing. There was a significant difference in strength between the two study groups (symptomatic and asymptomatic) in knee flexion (hamstring muscles), but this was not the case with knee extension (quadriceps <<muscle). In the 8-year follow-up, there was a significant difference in strength between the study groups (NP, PNP and AP groups) in knee extension at a speed of 60°/s (quadriceps muscle), whereas this was not the case for knee flexion (hamstring muscle). The patients who never had anterior knee pain had almost balanced muscle strength during the follow-up period, the operated limb being 2–9% weaker than the non-operated one. The patients whose anterior knee pain had disappeared during the follow-up had more strength in knee extension and flexion in the operated limb than in the non-operated limb, perhaps due to painless rehabilitation. In addition, the pain group (AP) had better flexion strength in the operated than the non-operated limb, but extension strength was clearly better in the non-operated limb.

In the univariate regression analyses, muscle function at extension and flexion differed between the groups (AP and PNP) in the first control and at extension at the time of the long-term follow-up (Table 16). The muscle function recovered to the normal level amongst the patients whose anterior knee pain vanished between the clinical follow-ups.

A deficit of thigh muscle has been reported in several articles after tibial shaft fractures. There are no data available that show a correlation between thigh muscle strength and anterior knee pain. Kobayashi et al. (2004) showed that 24 months after ACL reconstruction, the muscle strength of the quadriceps had recovered to approximately 90% of the level of the uninvolved side in an

isokinetic muscle test (speed at 60 and 180°/s). There was also delayed recovery of muscle strength amongst patients with anterior knee pain.

Callaghan and Oldham (2004) showed that patients with the patellofemoral pain syndrome had a 3% difference in the cross-sectional area of the quadriceps of their injured and uninjured limbs. This value did not differ from that of a control group with respect to the dominant and non-dominant limbs. There was, however, a significant difference between the patients with the patellofemoral pain syndrome and the control groups as regards the percentage differences in the isokinetic peak torque of lower limb extension. This finding indicates that the existence of muscular dysfunction in the affected leg was not related to muscle size. The patellar pain after ACL reconstruction was associated with atrophy of the quadriceps (O'Brien et al. 1991). In our series, there was no difference in thigh muscle atrophy between the symptomatic and asymptomatic patients (p-value = 0.570, Mann-Whitney test).

In our series the effect of a deficit in muscle strength (first the hamstring and then the quadriceps) amongst the symptomatic patients may have been related to an earlier recovery of hamstring muscle strength than of quadriceps muscle strength after the operation (Kobayashi et al. 2004). Some authors have noted a strong correlation between pain in the knees of the injured and uninjured limbs. The aut<hors suggested that a preoperative assessment could predict which patients would be more likely to develop severe post-tibial anterior knee pain (Cartwright-Terry et al. 2007). In addition, it has been suggested that patients with chronic anterior knee pain may experience bilateral symptoms as a result of weakness or activation failure in the bilateral quadriceps (Hart et al.2010).

Eckhoff et al. (1997) studied anterior knee pain and showed that external rotation of the tibia relative to the femur increased significantly in patients with symptoms. There is clinical relevance with respect to these observations in that the usual therapy regimen (strengthening exercises for the short arc quadriceps) may strengthen the internal rotators (semi-membranosus, gracilis, semi-tendinosus, and sartorius). Some patients may thus benefit from specific rehabilitation of the knee and thigh muscles after surgery for a tibial shaft fracture. A home-based, self-managed programme of simple knee strengthening

exercises over a 2-year period can significantly reduce knee pain and improve knee function in overweight and obese people with knee pain (Jenkinson et al. 2009). Anterior knee pain has also been reported to be a frequent problem in the long-term follow-up of tibial fracture patients treated using plaster casts (Greenwood et al. 1997).

On the other hand, it should be kept in mind that, in all patients, the strength of both the quadriceps and hamstring muscles decreases, and muscle atrophy rapidly becomes evident after the injury, especially during the first 1 to 2 weeks (Appel 1990). If early rehabilitation has been completely forgotten and ignored, it may prove extremely difficult to restore the strength and power of the muscles to normal (Holder-Powell and Rutherford 1999).

10.5 Influence of gender on anterior knee pain

An interesting additional finding in the current series was that there was more anterior knee pain amongst the women than the men. Women have also been shown to have a significantly greater degree of pain after ACL reconstruction (Asano et al. 2002, Kobayashi et al. 2004). Osteoarthritis rates for females exceed those of males at all ages (Verbrugge 1995). This phenomenon may indicate that female cartilage is more vulnerable, and cartilage damage would cause pain (Asano et al. 2002). The total expression of neurotransmitter substance-P (SP) in the synovial tissue of the females was significantly greater than that of the males, and within the female population, the total number of SP immunoreactive fibres was found to correlate significantly with pain intensity (Zhang et al. 2006).

Obvious anthropometric and anatomical differences between the men and women may explain the female overrepresentation with respect to anterior knee pain. The greater pelvic width and the broader pelvis (the quadriceps or Q angle) (Figure 19) move the hip joints further laterally relative to the midline of the body and therefore produce an increased valgus angle from the hip to the knee and then to the ground.
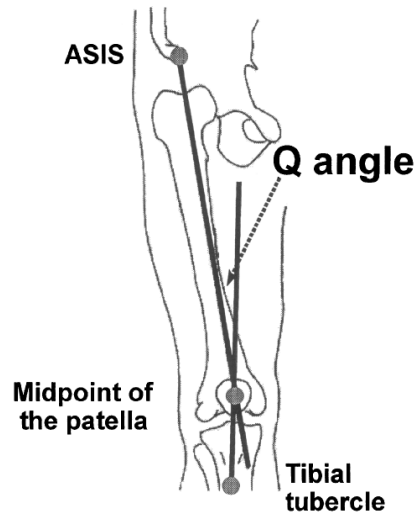
Figure 19. Quadriceps angle (Q angle) formed by the intersection of a line from the anterior superior iliac spine (ASIS) to the midpoint of the patella, with a line from the midpoint of the patella to the midpoint of the tibial tubercle (Livingston and Mandigo 1999). Reprinted with the permission of Elsevier.

In addition, females have a higher prevalence of increased femoral anteversion, which in turn affects the biomechanics of the patellofemoral joint (Fulkerson and Arendt 2000). A Q angle of less than 10° provides the most efficient line of pull for the quadriceps (Brezzo et al. 1996), and people with Q angles greater than 10 degrees may be at a mechanical disadvantage in terms of the generating capacity of the quadriceps force (Herrington and Nester 2004). Q angles in excess of 15 degrees for men and 20 degrees for women are thought to predispose a person to knee pathologies (Livingston and Mandigo 1999). An increase in the Q angle can also lead to lateral patellar dislocation or increased lateral patellofemoral contact pressures (Mizuno et al. 2001).

Çubuk et al. (2000) investigated indicators of malalignment for women with anterior knee pain. They reported that there is a general lateralisation of the tibial tubercle in patients with patellofemoral pain. The same result has been reported previously (Muneta et al. 1994). Keser et al. (2008) measured the lateral trochlear inclination (LTI) in axial MRI scans. The condition was termed trochlear dysplasia when the LTI was below 11 degrees. There was a statistically

significant difference between the groups (anterior knee pain versus control) in the mean LTI values (17.32° versus 21.5°). More trochlear dysplasia occurred in the anterior knee pain group, but there were no difference between the groups regarding sex.

Effects of oestrogen hormone on connective tissue synthesis have been recorded for women, and postural and sociological factors, such as wearing high heels and sitting with legs adducted, can influence the incidence and severity of anterior knee pain amongst women (Fulkerson and Arendt 2000). Equinus gait increased the knee flexion angle during the midstance phase in the gait cycle and unlocked the knee joint (You et al. 2009). This increase causes inadequate control of the knee joint and may influence both knee work during gait and knee sensation.

In addition, the risk of unrecognized articular penetration is higher when the tibia is shorter (Hernigou and Cohen 2000). Since the length of the tibia is related to the size of the patient (Mensch and Amstutz 1975, Yoshioka et al. 1989), the medial and lateral approaches can be dangerous for patients with a small build. The IM nails are usually proximally thicker than they are distally, and therefore there may be a risk of iatrogenic damage during the nailing procedure.

In the univariate regression analyses of the current study, there were no differences between the sexes regarding the relief of anterior knee pain between the first isokinetic control and the long-term follow-up control (Table 14).

10.6 General discussion

Smoking is associated with impaired wound healing and delayed bony union. Smoking has also been shown to be the single most important risk factor for the development of complications after elective arthroplasty of the hip or knee (Moller et al. 2003). People who smoke have a compromised functional outcome after primary ACL reconstruction (Karim et al. 2006). In the current series, there was no correlation between anterior knee pain and smoking after the

IM nailing of tibial shaft fractures. There were also no differences between the groups in the univariate regression analyses (Table 14).

It has been reported that the incidence of anterior knee pain is commoner amongst younger patients than older ones. This difference may be due to a more sedentary lifestyle amongst elderly patients (Keating et al. 1997b). There is a clear relationship between social deprivation and tibial fractures, and the deprivation was also found to be associated with male sex and younger age (Court-Brown and Brydone 2007). Court-Brown and Brydone (2007) also believed that the main reason that the effects of deprivation decrease with age is related to the different modes of injury at different ages. In the current data, patients whose anterior knee pain decreased between the two controls were older than those still experiencing anterior knee pain, and they were also not so active (Table 14).

At the beginning of the study, the intensity of anterior knee pain and the impairment during daily activities were mild for 20 patients and moderate for 7. Only 2 patients complained of severe impairments. All of the patients were at work normally after the surgery; only two of the always pain group did not go to work before 12 months after the accident and operation. Eight years after the fracture and IM nailing procedure, the Tegner knee score had returned to the preoperative level also in the pain group (8 patients). This finding may indicate that anterior knee pain is rarely severe and that patients resume their preinjury activity levels. Lefaivre et al. (2008) also showed that, 14 years after IM nailing, patients' activities were comparable to population norms.

According to the current data, patients who stay longer in the hospital and have more pain when starting rehabilitation may benefit from aggressive strengthening of the thigh muscle after the IM nailing of a tibial shaft fracture. Physical activity seems to worsen anterior knee pain however. Future studies could assess the benefits of physiotherapy with respect to the development of anterior knee pain after IM nailing of tibial shaft fractures. There is more anterior knee pain amongst women than amongst men, and this difference also requires further study.

Tibial nail removal is not a routine procedure nowadays in Finland. The current data showed that patients whose activity level is high (Tegner knee

score) may benefit from nail removal after the tibial shaft fracture has healed. Younger patients may also benefit more from IM removal than their older counterparts. Thus nail removal could concentrate on the young, active population.

Anterior knee pain after IM nailing of a tibial shaft fracture is likely to have a multifactorial origin, and there is no consensus about its aetiology and pathogenesis. Anterior knee pain is common after this procedure, but fear of postoperative chronic anterior knee pain should not hinder the use of IM nails in the treatment of tibial shaft fractures, because, in the long term, anterior knee pain disappears from many patients.

11. SUMMARY AND CONCLUSIONS

The primary findings and conclusions of the present series of studies are summarized as follows:

I Although anterior knee pain is the commonest postoperative complication following a nailing procedure used for a tibial shaft fracture, it is rarely severe, and many patients can return to their previous work and preinjury level of activity. The study showed that anterior knee pain after IM nailing of tibial shaft fractures may be related to a deficiency in the strength of the knee flexors. The incidence of anterior knee pain is higher amongst women than amongst men.

II Ultrasound and power Doppler measurements showed no changes in the morphology of the patellar tendon, which could explain the anterior knee pain after IM nailing of tibial shaft fractures.

III Anterior knee pain, when present after IM nailing of tibial shaft fractures, disappears in the great majority of patients 3 to 8 years after surgery. Weakness of the quadriceps muscle, but not the hamstring, and lower functional knee scores are associated with anterior knee pain 8 years after the nailing. Some patients (women and patients with intensive AKP and those with a long period in the hospital) may benefit from specific rehabilitation of the knee and thigh muscles (especially knee extensors) after surgery for a tibial shaft fracture.

IV   Compared with a transtendinous approach, a medial paratendinous approach for nail insertion does not reduce the prevalence of chronic anterior knee pain or functional impairment 8 years after IM nailing of a tibial shaft fracture. In the long term, anterior knee pain seems to disappear from many patients, and the activity of the patients usually returns to the preoperative level.

12. ACKNOWLEDGEMENTS

This study was carried out at the Medical School of the University of Tampere, the Department of Surgery in the Orthopaedic and Traumatology Unit of the Tampere University Hospital, and The National Graduate School of Clinical Investigation during 2000 and 2007.

I wish to express my sincere thanks to Professor Markku Järvinen for providing me with the facilities needed to perform the studies. I also wish thank him for helping me when I had problems. And special thanks are extended for helping me with my achilles tendon problems during my athletic career. In addition, I want to thank him for recommending me to the National Graduate School of Clinical Investigation.

I am grateful to my supervisor, Jarmo Toivanen, MD, Ph.D, for helping me finish my study. You have always been friendly toward me and always had time to help me when I needed guidance. Without your previous work reported within this dissertation, your help, and your faith in my work, I could not have finished this study.

I owe my thanks to Docent Pekka Kannus, MD, for helping me with the language of the articles and with statistical issues of the study. You have been a very great aide to me and have made me think more critically about my own work.

I wish to thank Docent Timo Paakkala, MD, for making the ultrasonographic and power Doppler measurements included in this study. I also wish to thank the Department of Radiology for the opportunity to do these measurements.

I would also thank Heini Huhtala for helping me with my final statistical problems with the univariate regression analyses of the data.

I also want to thank my friends for the possibility to exchange experiences and opinions about the scientific work, and also thank them for sharing the "non-scientific" parts of my life.

My warmest gratitude goes to my parents, Jorma and Leena Väistö, for supporting me throughout my life unselfishly and also encouraging me in choosing an academic profession. Without your support (also financial), my education would not have been possible.

From the bottom of my heart, I express my thanks to my wife and best friend Hannele, who has supported me always with endless love and sympathy. You have been my loving helper, and you have sacrificed your own time and education to help me and care for our children. I hope that we shall be together for ever after.

Also I wish to thank my little sunshines Emilia and Oskari. Since you came into my life, there has been no "dark" days. Everyday is a new day to learn and play, and, with you, there is no need to think about work or the need to write. I look forward to seeing you grow, and I hope that I can offer both of you as much support as my parents offered me. I hope yours lives will be memorable.

Permission from the copyright owners of the original articles to reproduce the publications is acknowledged.

Tampere, May 2010

Olli Väistö

13. REFERENCES

Aitken RC (1969): Measurements of feelings using visual analogue scales. Proc R Soc Med 62: 989–993.

Alberts KA, Loohagen G, and Einarsdottir H (1999): Open tibial fractures: faster union after unreamed nailing than external fixation. Injury 30: 519–523.

Alho A, Ekeland A, Stromsøe K, Folleras G, and Thoresen BO (1990): Locked intramedullary nailing for displaced tibial shaft fractures. J Bone Joint Surg 72-B: 805–809.

Alho A, Benterud JG, Hogevold HE, Ekeland A, and Strømsøe K (1992): Comparison of functional bracing and locked intramedullary nailing in the treatment of displaced tibial shaft fractures. Clin Orthop 277: 243–250.

Alms M (1962): Medullary nailing for fracture of the shaft of the tibia. J Bone Joint Surg 44-B: 328–339.

Althausen PL, Neiman R, Finkemeier CG, and Olson SA (2002): Incision placement for intramedullary tibial nailing: An anatomic study. J Orthop Trauma 10: 687–690.

Altman RD, Latta LL, Keer R, Renfee K, Hornicek FJ, and Banovac K (1995): Effect of non-steroidal anti-inflammatory drugs on fracture healing: a laboratory study in rats. J Orthop Trauma 9: 392–400.

Anglen JO and Blue JM (1995): A comparison of unreamed and reamed nailing of the tibia. J Trauma 39: 351–355.

Angliss RD, Tran TA, Edwards ER, and Doig SG (1996): Unreamed nailing of tibial shaft fractures in multiply injured patients. Injury 27: 255–260.

Aoki N, Soma K, Shindo M, Kurosawa T, and Ohwada T (1998): Evaluation of potential fat emboli during placement of intramedullary nails after orthopaedic fractures. Chest 113: 178–181.

Appel HJ (1990): Muscular atrophy following immobilisation. Int J Sports Med 10: 42–58.

Asano H, Muneta T, and Shinomiya (2002): Evaluation of clinical factors affecting knee pain after anterior cruciate ligament reconstruction. J Knee Surg 15: 23–28.

Babis GC, Benetos IS, Karachalios T, and Soucacos PN (2007): Eight years' clinical experience with the Orthofix® tibial nailing system in the treatment of tibial shaft fractures. Injury 38: 227–234.

Barrack RL, Schrader T, Bertot AJ, Wolfe MW, and Myers L (2001): Component rotation and anterior knee pain after total knee arthroplasty. Clin Orthop 392: 46–55.

Batten RL, Donaldson LJ, and Aldridge MJ (1978): Experience with the AO method in the treatment of 142 cases of fresh fracture of the tibial shaft treated in the UK. Injury 10: 108–114.

Bekmezci T, Baca E, Kocabaş R, Kaynak H, and Tonbul M (2005): Early results of treatment with expandable intramedullary nails in tibia shaft fractures. Acta Orthop Traumatol Turc 39: 421–424.

Ben-Galim P, Rosenblatt Y, Parnes N, Dekel S, and Steinberg EL (2007): Intramedullary fixation of tibial shaft fractures using an expandable nail. Clin Orthop 455: 234–240.

Bennell K, Hodges P, Mellor R, Bexander C, and Souvlis T (2004): The nature of anterior knee pain following injection of hypertonic saline into the infrapatellar fat pad. J Orthop Res 22: 116–121.

Berton RM, Watson JT, Goldschmidt P, and van Holsbeeck M (1995): Ultrasound for the early diagnosis of fracture healing after interlocking nailing of the tibia without reaming. Clin Orthop 310: 137–144.

Berton RM, Kim EC, van Holsbeeck M, Schaffler MB, Subramanian S, Bouffard JA, and Craig JG (1998a): Ultrasound for the early diagnosis of tibial fracture healing after static interlocked nailing without reaming: Histologic correlation using a canine model. J Orthop Trauma 12: 200–205.

Berton RM, Subramanian S, van Holsbeeck M, Watson JT, Cramer KE, Karges DE, Craig JG, and Bouffard JA (1998b): Ultrasound for the early diagnosis of tibial healing after static interlocked nailing without reaming: clinical results. J Orthop Trauma 12: 206–213.

Bhandari M, Guyatt GH, Swiontkowski MF, and Schemitsch EH (2000a): Treatment of open fractures of the shaft of the tibia. A systematic overview and meta-analysis. J Bone Joint Surg 82-B: 62–68.

Bhandari M, Guyatt GH, Tong D, Adili A, and Shaughnessy SG (2000b): Reamed versus non-reamed intramedullary nailing of lower extremity long bone fractures; a systematic overview and meta-analysis. J Orthop Trauma 14: 2–9.

Bhandari M, Guyatt GH, Tornetta P III, Swiontkowski MF, Hanson B, Sprague S, Syed A, and Schemitsch EH (2002): Current practice in the

intramedullary nailing of tibial shaft fractures: an international survey. J Trauma 53:725–732.

Bhandari M, Tornetta P, Sprague S, Najibi S, Petrisor B, Griffith L, and Guyatt GH (2003): Predictors of reoperation following operative management of fractures of the tibial shaft. J Orthop Trauma 17: 353–361.

Bhandari M, Guyatt G, Tornetta III P, Schemitsch EH, Swiontkowski M, and Sanders D (2008): Randomized trial of reamed and undreamed intramedullary nailing of tibial shaft fractures. By the study to prospectively evaluate intramedullary nails in patients with tibial fractures (SPRINT) investigators. J Bone Surg 78A: 2567–2578.

Biedert RM and Sanchis-Alfonso V (2002): Sources of anterior knee pain. Clin Sports Med 21: 335–347.

Blachut PA, O'Brien PJ, Meek RN, and Broekhuyse HM (1997): Interlocking intramedullary nailing with and without reaming for the treatment of closed fractures of the tibial shaft. A prospective, randomized study. J Bone Joint Surg 79-A: 640–646.

Blum J, Karagül Göksen, Sternstein W, and Rommens PM (2005): Bending and torsional stiffness in cadaveric humeri fixed with a self-locking expandable or interlocking nail system: a mechanical study. J Orthop Trauma 19: 535–542.

Boerger TO, Patel G, and Murphy JP (1999): Is routine intramedullary nail removal justified? J Bone Joint Surg 81-B:suppl: 297.

Bohnsack M, Wilharm A, Hurschler C, Ruhmann O, Stukenborg-Colsman C, and Wirth CJ (2004): Biomechanical and kinematic influences of a total infrapatellar fat pad resection on the knee. Am J Sports Med 32: 1873–1880.

Bohnsack M, Meier F, Walter GF, Hurschler C, Schmolke S, Wirth CJ, and Ruhmann O (2005a): Distribution of substance-P nerves inside the infrapatellar fat pad and the adjacent synovial tissue: a neurohistological approach to anterior knee pain syndrome. Arc Orthop Trauma Surg 125: 592–597.

Bohnsack M, Hurschler C, Demirtas T, Rühmann O, Stukenborg-Colsman C, and Wirth C-J (2005b): Infrapatellar fat pad pressure and volume changes of the anterior compartment during knee motion: possible clinical consequences to the anterior knee pain. Knee Surg Sports Traumatol Arthrosc 13: 135-141.

Bohnsack M, Klages P, Hurschler C, Halcour A, Wilharm A, Ostermeier S, Rühmann O, and Wirth C-J (2006): Influence of an infrapatellar fat pad edema on patellofemoral biomechanics and knee kinematics: a possible relation to the anterior knee pain syndrome. Arch Orthop Trauma Surg Oct13 [Epub ahead of print]

Bone LB, and Johnson KD (1986): Treatment of tibial fractures by reaming and intramedullary nailing. J Bone Joint Surg 68-A: 877–887.

Bone LB, Sucato D, Stegemann PM, and Rohrbacher BJ (1997): Displaced isolated fractures of the tibial shaft treated with either a cast or intramedullary nailing. An outcome analysis of matched pairs of patients. J Bone Joint Surg 79-A: 1336–1341.

Bong MR, Kummer FJ, Koval KJ, and Egol KA (2007): Intramedullary nailing of the lower extremity: biomechanics and biology. J Am Acad Orthop Surg 15: 97–106.

Boon JM, Van Wyk J, and Jordaan D (2004): A safe area and angle for harvesting autogenous tendons for anterior cruciate ligament reconstruction. Surg Radiol Anat 26: 167–171.

Boucher M, Leone J, Pierrynowski M, and Bhandari M (2002): Three–dimensional assessment of tibial malunion after intramedullary nailing: A preliminary study. J Orthop Trauma 16: 473–483.

Bourne RB and Rorabeck CH (1989): Compartment syndromes of the lower leg. Clin Orthop 240: 97–104.

Brezzo R, Fort I, and Hall K (1996): Q-angle: the relationship with selected dynamic performance variables in women. Clin Kinesiol 50: 66–70.

Brown NAT, Bryan NA, and Stevens PM (2007): Torsional stability of intramedullary compression nails: tibial osteotomy model. Clin Biomech 22: 449–456.

Brumback RJ, Ellison TS, Poka A, Bathon GH, and Burgess AR (1992): Intramedullary nailing of femoral shaft fractures. Part III: Long-term effects of static interlocking fixation. J Bone Joint Surg 74-A: 605–611.

Bråten M, Nordby A, Terjesen T, and Rossvoll I (1992): Bone loss after locked intramedullary nailing. Computed tomography of the femur and tibia in 10 cases. Acta Oryhop Scand 63: 310–314.

Bråten M, Helland P, Grøntvedt T, Aamodt A, Benum P, and Mølster A (2004): External fixation versus locked intramedullary nailing in tibial shaft fractures: a prospective, randomised study of 78 patients. Arch Orthop Trauma Surg 125: 21–26.

Bråten M, Helland P, Grøntvedt T, Aamodt A, Benum P, and Mølster A (2005): External fixation versus locked intramedullary nailing in tibial shaft fractures: a prospective, randomised study of 78 patients. Arch Orthop Trauma Surg 1: 21–26.

Bucholz RW, Heckman JD, Court-Brown CM, Koval KJ, Tornetta III P, and Wirth MA (2006): Rockwood and Green's Fractures in adults. 6th ed Lippincott Williams & Wilkins, Philadelphia.

Burç H, Dursun M, Orhun H, Gürkan, V and Bayhan I (2009): Treatment of adult tibial diaphysis fractures with reamed and locked intramedullary nailing. Acta Orthop Traumatol Turc 43:7–13.

Busam ML, Esther RJ, and Obremskey WT (2006): Hardware removal: indications and expectations. J Am Acad Orthop Surg 14: 113–120.

Busse JW, Bhandari M, Sprague S, Johnson-Masotti AP, and Gafni A (2005): An economic analysis of management strategies for closed and open grade I tibial shaft fractures. Acta Orthop Scand 76: 705–712.

Böstman OM (1986): Spiral fractures of the shaft of the tibia: Initial displacement and stability of reduction. J Bone Joint Surg 68-B: 462–466.

Callaghan MJ and Oldham JA (2004): Quadriceps atrophy: to what extent does it exist in patellofemoral pain syndrome? Br J Sports Med 38: 295–299.

Canale TS, Daugherty K, and Jones L (2003): Campbell's operative orthopaedics. 10th ed. Mosby, Philadelphia (Pa).

Cartwright-Terry M, Snow M, and Nalwad H (2007): The severity and prediction of anterior knee pain post tibial nail insertion. J Orthop Trauma 21:381–385.

Castillo R, Bose M, MacKenzie E, and Patterson B (2005): The impact of smoking on fracture healing and risk of complications in limbthreatening open tibial fractures. J Orthop Trauma 19: 151–157.

Chalidis BE, Petsatodis GE, Sachinis NC, Dimitriou CG, and Christodoulou AG (2009): Reamed interlocking intramedullary nailing for the treatment of tibial diaphyseal fractures and aseptic non-unions. Can we expect an optimum result? Strat Traum Limb Recon 4:89–94.

Chapman MW, Szabo RM, Marder RA, Vince KG, Mann RA, Lane JM, McLAin RF and Rab G (2000): Chapman's Orthopaedic Surgery. Lippincott-Williams & Wilkins, Philadelphia (Pa).

Charnley J (1963): The closed treatment of common fractures. 3rd ed. Churchill Livingstone, Edinburgh, London, New York.

Christie J (1996): The coagulative effects of fat embolisation during intramedullary manipulative procedures. Tech Orthop 11: 14–17.

Cole JD and Latta L (1992): Fatigue failure of interlocking tibial nail implants. J Orthop Trauma 6: 507–508.

Coles CP and Gross M (2000): Closed tibial shaft fractures: management and treatment complications. A review of the prospective literature. Can J Surg 43: 256–262.

Court-Brown CM, Christie J, and McQueen MM (1990): Closed intramedullary tibial nailing. Its use in closed and type I open fractures. J Bone Joint Surg 72-B: 605–611.

Court-Brown CM (1991): An atlas of closed nailing of the tibia and femur. Martin Dunitz, London.

Court-Brown CM and McBirnie J (1995): The epidemiology of tibial fractures. J Bone Joint Surg 77-B: 417–421.

Court-Brown CM, Will E, Christie J, and McQueen MM (1996): Reamed or unreamed nailing for closed tibial fractures: A prospective study in Tscherne C1 fractures. J Bone Joint Surg 78-B: 580–583.

Court-Brown CM, Gustilo T, and Shaw AD (1997): Knee pain after intramedullary tibial nailing: Its incidence, etiology, and outcome. J Orthop Trauma 11: 103–105.

Court-Brown CM (2004): Reamed intramedullary tibial nailing: An overview and analysis of 1106 cases. J Orthop Trauma 18: 96–101.

Court-Brown CM and Brydone A (2007): Social deprivation and adult tibial diaphyseal fractures. Injury [Epub ahead of print].

Crist BD and Wolinsky PR (2009): Reaming does not add significant time to intramedullary nailing of diaphyseal fractures of the tibia and femur. J Trauma 67:727–734.

Çubuk SM, Sindel M, Karaali K, Arslan AG, Akyildiz F, and Özkan O (2000): Tibial tubercle position and patellar height as indicators of malalignment in women with anterior knee pain. Clin Anat 13: 199–203.

De Bastiani G, Aldegheri R, and Brivio LR (1984): The treatment of fractures with a dynamic axial fixator. J Bone Joint Surg 66-B:538–545.

de Santos de la Fuente FJ, Lopez AR, Tena CC, Ramos SJC, and Fernandez MJM (1998): Intramedullary nailing and functional bracinc of tibial shaft fractures: 167 cases followed for minimum 2 years. Acta Orthop Scand 69: 493–497.

Devitt TA, Coughlan KA, Ward T, McCormack D, Mulcahy D, Felle P, and McElwain JP (1998): Patellofemoral contact forces and pressures during intramedullary tibial nailing. Int Orthop 22: 92–96.

Dewey H, Jones IV, and Schmeling G (1999): Tibial fracture during removal of a tibial intramedullary nail. J Orthop Trauma 13: 271–273.

Dickson K, Katzman S, Delgado E, and Contreras D (1994): Delayed unions and non-unions of open tibial shaft fractures. Correlation with arteriography results. Clin Orthop 302: 189–193.

Djahangiri A, Garofalo R, Chevalley F, Leyvraz P-F, Wettstein M, Borens O, Schizas C, and Mouhsine E (2006): Closed and open Grade I and II tibial shaft fractures treated by reamed intramedullary nailing. Med Princ Pract 15: 293–298.

Dogra AS, Ruiz AL, and Marsh DR (2002): Late outcome of isolated tibial fractures treated by intramedullary nailing: the correlation between disease-specific and generic outcome measures. J Orthop Trauma 16: 245–249.

Drosos GI, Stavropoulos NI, and Kazakos KI (2006): Peroneal nerve damage by oblique proximal locking screw in tibial fracture nailing: a new emerging complication? Arch Orthop Trauma Surg 24 (Epub ahead of print)

Dye SF, Vaupel GL, and Dye CC (1998): Conscious neurosensory mapping of the internal structures of the human knee without intraarticular anaesthesia. Am J Sports Med 26: 773–777.

Eckhoff DG, Brown AW, Kilcoyne RF, and Stamm ER (1997): Knee version associated with anterior knee pain. Clin Orthop 339: 152–155.

Edwards P (1965): Fracture of the shaft of the tibia: 492 consecutive cases in adults. Importance of soft tissue injury. Acta Orthop Scand Suppl 76:1–82

Ekeland A, Thoresen BO, Alho A, Strömsöe K, Follerås G, and Haukeboe A (1988): Interlocking intramedullary nailing in the treatment of tibial fractures. Clin Orthop 231: 205–215.

Emami A, Petrén-Mallmin M, and Larsson S (1999a): No effect of low-intensity ultrasound on healing of intramedullary fixed tibial fractures. J Orthop Trauma 13: 252–257.

Emami A, Larsson A, Petrén-Mallmin M, and Larsson S (1999b): Serum bone markers after intramedullary fixed tibial fractures. Clin Orthop 368: 220–229.

Epps CH Jr (1994): Complications in orthopaedic surgery. 3rd ed. J.B. Lippincott Company, Philadelphia (Pa).

Fairbank AC, Thomas D, Cunningham B, Curtis M, and Jinnah RH (1995): Stability of reamed and unreamed intramedullary tibial nails: a biomechanical study. Injury 26: 483–485.

Finkemeier CG, Schmidt AH, Kyle RF, Templeman DC, and Varecka TF (2000): A prospective, randomized study of intramedullary nails inserted with and without reaming for the treatment of open and clodes fractures of the tibial shaft. J Orthop Trauma 14: 187–193.

Forster MC, Bruce AS, and Aster AS (2005): Should the tibia be reamed when nailing? Injury 36: 439–444.

Fortis AP, Dimas A, and Lamprakis AA (2008): Expandable nailing system for tibial shaft fractures. Injury 39: 940–946.

Frankel VH and Johnson EE (1968): The biomechanics of refracture of bone. Clin Orthop 60: 221–225.

Fulkerson JP and Arendt EA (2000): Anterior knee pain in females. Clin Orthop 23: 69–73.

Garcia OGR, Mombiela FL, De la Fuente CJ, Aranguez MG, Escribano DV, and Martin JV (2004): The influence of the size and condition of the reamers on bone temperature during intramedullary reaming. J Bone Joint Surg 86-A: 994-999.

Garcia-Lopez A, Marco F, and Lopez-duran L (1998): Unreamed intramedullary locking nailing for open tibial fractures. Int Orthop 22: 97–101.

Gaston P, Will E, McQueen MM, Elton RA, and Court-Brown CM (2000): Analysis of muscle function in the lower limb after fracture of the diaphysis of the tibia in adults. J Bone Joint Surg 82-B: 326–331.

Georgiadis GM (1995): Tibial shaft fractures complicated by compartment syndrome: Treatment with immediate fasciotomy and locked unreamed nailing. J Trauma 38: 448–452.

Giannoudis PV, Snowden S, Matthews SJ, Smye SW, and Smith RM (2002): Temperature rise during reamed tibial nailing. Clin Orthop 395: 255–261.

Gosselin RA, Belzer JP, and Contreras DM (1993): Heterotopic ossification of the patellar tendon following intramedullary nailing of the tibia: report on two cases. J Trauma 34: 161–163.

Greenwood DC, Muir KR, Doherty M, Milner SA, Stevens M, and Davis TR (1997): Conservatively managed tibial shaft fractures in Nittingham, UK: are pain, osteoarthritis, and disability long-term complications? J Epidemiol Community Health 51: 701–704.

Grütter R, Cordey J, Bühler M, Johner R, and Regazzoni P (2000): The epidemiology of diaphyseal fractures of the tibia. Injury 31:S; C64–67.

Gullihorn L, Karpman R, and Lippiello L (2005): Differential effects of nocotine and smoke condensate on bone cell metabolic activity. J Orthop Trauma 19: 17–22.

Gustafsson J, Toksvig-Larsen S, and Jonsson K (2008): MRI of the knee after locked undreamed intramedullary nailing of tibia. Chir Organi Mov 91: 45-50.

Gustilo RB and Anderson JT (1976): Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones. Retrospective and prospective analyses. J Bone Joint Surg 58-A: 453–458.

Gustilo RB, Mendoza RM, and Williams DN (1984): Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma 8: 742–746.

Haddad FS, Desai K, Sarkar JS, and Dorrell JH (1996): The AO unreamed nail: friend or foe. Injury 27: 261–263.

Haines JF, Williams EA, Hargadon EJ and Davies DR (1984): Is conservative treatment of displaced tibial shaft fractures justified? J Bone Joint Surg 66-B:84–88

Harrington P, Sharif I, Smyth H, Fenelon GC, Mulcahy D, and Pegum M (1996): Unreamed nailing of tibial fractures—a prospective study of the routine use of the unreamed tibial nail. Ir J Med Sci 165: 282–285.

Harris I, and Lyons M (2005): Reoperation rate in diaphyseal tibia fractures. ANZ J Surg 75: 1041–1044.

Hart JM, Pietrosimone B, Hertel Jay, and Ingersoll CD (2010): Quadriceps activation following knee injuries: A sustematic review. J Athletic Train 45:87–97.

Hasenboehler E, Smith WR, Laudicina L, Philips GC, Stahel P, and Morgan SJ (2006): Fatique behavior of Ilizarov frame versus tibial interlocking nail in a comminuted tibial fracture model: a biomechanical study. J Orthop Surg 11: 16.

Heim D, Schlegel U, and Perren SM (1993): Intramedullary pressure in reamed and unreamed nailing of the femur and tibia—an in vitro study in intact, human bones. Injury 24 Suppl 3: S56–S63.

Helfet DL, Jupiter JB, and Gasser S (1992): Indirect reduction and tension-band plating of tibial non-union with deformity. J Bone Joint Surg 74-B: 1286–1297.

Hems TE and Jones BG (2005): Peroneal damage associated with the proximal locking screws of the AIM tibial nail. Injury 36: 651–654.

Henley MB, Chapman JR, Agel J, Swiontkowski MF, Benirschke SK, and Mayo KA (1995): Comparison of unreamed tibial nails and external fixators in the treatment of grade II and III open tibial shaft fractures. Orthop Trans 19: 438–439.

Henley MB, Chapman JR, Agel J, Harvey EJ, Whorton AM, and Swiontkowski MF (1998): Treatment of type II, IIIA, and IIIB open fractures of the tibial shaft: a prospective comparison of unreamed interlocking intramedullary nails and half-pin external fixatores. J Orthop Trauma 12: 1–7.

Hernigou P and Cohen D (2000): Proximal entry for ontramedullary nailing of the tibia. The risk of unrecognised articular damage. J Bone Joint Surg 82-B: 33–41.

Herrington L and Nester C (2004): Q-angle undervalued? The relationship between Q-angle and medio-lateral position of the patella. Clin Biomech 19: 1070–1073.

Hey Groves EW (1922): On modern methods treating fractures including the Jacksonian prize essay on bone grafting. Edited by Bristol: Wright J 1922. 2nd ed. William Wood and Company, New York (NY).

Hicks CA, Noble P, and Tullos H (1995): The anatomy of the tibial intramedullary canal. Clin Orthop 321:111–116.

Holbrook JL, Swiontkowski MF, and Sanders R (1989): Treatment of open fractures of the tibial shaft: Ebder nailing versus external fixation. J Bone Joint Surg 71-A: 1231–1238.

Holder-Powell HM and Rutherford OM (1999): Unilateral lower limb injury: Its long-term effects on quadriceps, hamstring, and plantarflexor muscle strength. Arch Phys Med Rehabil 80: 717–720.

Hooper GJ, Keddell RG, and Penny ID (1991): Conservative management or closed nailing for tibial shaft fractures. J Bone and Joint Surg 73-B: 83–85.

Hupel TM, Aksenov SA, and Schemitsch EH (1998): Muscle perfusion after intramedullary nailing of the canine tibia. J Trauma 45: 256–262.

Hupel TM, Weinberg JA, Aksenov SA, and Schemitsch EH (2001): Effect of unreamed, limited reamed, and standard reamed intramedullary nailing on cortical bone porosity and new bone formation. J Orthop Trauma 15: 18–27.

Im GI, and Lee KB (2003): Difficulties in removing ACE tibial intramedullary nail. Int Orthop 27: 355–358.

Jekinson CM, Doherty M, Avery AJ, Read A, Taylor MA, Sach TH, Silcocks P, and Muir KR (2009) : Effects of dietary intervention and quadriceps strengthening exercises on pain and function in overweight people with knee pain: randomised controlled trial. BMJ 18;339:b3170

Jenny J-Y, Jenny G, and Kempf I (1994): Infection after reamed intramedullary nailing of lower limb fractures. Acta Orthop Scand 65: 94–96.

Jensen JS, Hansen FW, Johansen J (1977): Tibial shaft fractures: A comparison of conservative treatment and internal fixation with conventional plates or AO compression plates. Acta Orthop Scand 48: 204–212.

Joensen AM, Hahn T, Gelineck J, Overvad K, and Ingemann-Hansen T (2001): Articular cartilage lesions and anterior knee pain. Scand J Med Sci Sports 11: 115–119.

Johnson DF, Love DT, Love BR, and Lester DK (2000): Dermal hypoesthesia after total knee arthoplasty. Am J Orthopedics 29: 863–866.

Järvelä T, Kannus P, and Järvinen M (2000): Anterior knee pain 7 years after an anterior cruciate ligemant reconstruction with a bone-patellar tendon-bone autograft. Scand J Med Sci Sports 10: 221–227.

Järvelä T, Paakkala T, Kannus P, Toivanen J, and Järvinen M (2004): Ultrasonographic and power evaluation of the patellar tendon ten years after harvesting its central third for reconstruction of the anterior cruciate ligament: comparison of patients without or with anterior knee pain. Am J Sports Med 32: 39–46.

Kaftandziev I, Pejkova S, and Saveski J (2006): Operative treatment of III grade open fractures of the tibial diaphysis. (Prilozi) Contributions, Sec. Biol. Med. Sci., MASA, XXVII: 121–131.

Kakar S, Firoozabadi R, McKean J, and Tornetta III P (2007a): Diastolic blood pressure in patinets with tibia fractures under anaesthesia: Implications for the diagnosis of compartment syndrome. J Orthop Trauma 21: 99–103.

Kakar S and Tornetta III P (2007b): Open fractures of the tibia treated by immediate intramedullary tibial insertion without reaming: a prospective study. J Orthop Trauma 21: 153–157.

Kannus P, Natri A, Niittymäki S, and Järvinen M (1992): Effect of intraarticular glycosaminoglycan polysulfate treatment on patellofemoral pain syndrome. A prospective, randomized double-blind trial comparing glycosaminoglycan polysulfate with placebo and quadriceps muscle exercises. Arthritis Rheum 35: 1053–61.

Kannus P (1994): Isokinetic evaluation of muscular performance: Implications for muscle testing and rehabilitation. Int J Sports Med 15: S11–S18.

Karachalios Th, Babis G, Tsarouchas J, Sapkas G and Pantazopoulos (2000): The clinical performance of a small diameter tibial nailing system with a mechanical distal aiming device. Injury 31:451–459.

Karim A, Pandit H, Murray J, Wandless F, and Thomas NP (2006): Smoking and reconstruction of the anterior cruciate ligament. J Bone Joint Surg 88-B: 1027–1031.

Karladani HA, Granhed H, Edshage B, Jerre R, and Styf J (2000): Displaced tibial shaft fractures. A prospective randomized study of closed intramedullary nailing versus cast treatment in 53 patients. Acta Orthop Scand 2: 160–167.

Karladani HA and Styf J (2001a): Percutaneous intramedullary nailing of tibial shaft fractures: a new approach for prevention of anterior knee pain. Injury 32: 736–739.

Karladani HA, Svantesson U, Granhed H, and Styf J (2001b): Postural control and torque of the knee joint after healed tibial shaft fracture. Injury 32: 57–60.

Karladani AH, Ericksson PÅ, Granhed H, Karlsson L, and Nyberg P (2007): Tibial intramedullary nails—should they be removed? Acta Orthopaedica 78:668–671.

Kartus J, Magnusson L, Stener S, Brandsson S, Eriksson BI, and Karlsson J (1997): Complications following arthroscopic anterior cruciate ligament reconstruction. A 2–5 year follow-up of 604 patients with special emphasis on anterior knee pain. Knee Surg Sports Traumatol Arthrosc 7: 2–8.

Kartus J, Ejerhed L, Eriksson BI, and Karlsson J (1999): The localization of the infrapatellar nerves in the anterior knee region with special emphasis on central third patellar tendon harvest: a dissection study on cadaver and amputated specimens. Arthroscopy 15: 577–586.

Karunakar MA, Frankenburg EP, Le TT, and Hall J (2004): The termal effects of intramedullary reaming. J Orthop Trauma 18: 674-679.

Katsoulis E, Court-Brown C, and Giannoudis PV (2006): Incidence and aetiology of anterior knee pain after intramedullary nailing of the femur and tibia. J Bone Joint Surg 88-B: 576–580.

Keating JF, O'Brien PJ, Blachut PA, Meek RN, and Broekhuyse HM (1997a): Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft. J Bone Joint Surg 79-A: 334–341.

Keating JF, Orfaly R, and O'Brien PJ (1997b): Knee pain after tibial nailing. J Orthop Trauma 11: 10–13.

Kellam JF (1985): Early results of the Sunnybrook experience with locked intramedullary nailing. Orthopedics 8: 1387–1388.

Kelley M and Insall J (1987): Post-patellectomy extensive ossification of patellar tendon: a case report. Clin Orthop 215: 148.

Kennedy JC, Alexander IJ, and Hayes KC (1982): Nerve supply of the human knee and its functional importance. Am J Sports Med 10: 239–335.

Keser S, Savranlar A, Bayar A, Ege A, and Turhan E (2008): Is there a relationship between anterior knee pain and femoral trochlear dysplasia? Assessment of lateral trochlear inclination by magnetic resonance imaging. Knee Surg Sports Traumatol Arthrosc 16: 911–915.

Klein M, Rahn BA, Frigg R, Kessler S, and Perren SM (1989): Die Blutzirkulation nach marknagelung ohne aufbohren. Proceedings, Berhard Küntsher Kreis, Vienna.

Klein MP, Rhan BA, Frigg R, Kessler S, and Perren SM (1990): Reaming versus non-reaming in medullary nailing: interference with cortical circulation of the canine tibia. Arch Orthoph Trauma Surg 109: 314–316.

Klemm K and Börner M (1986): Interlocking nailing of conplex fractures of the femur and tibia. Clin Orthop 212: 89–100.

Kneifel T and Buckley RT (1996): A comparison of one versus two distal locking screws in tibial fractures treated with unreamed tibial nails: a prospective randomized clinical trial. Injury 27: 271–273.

Kobayashi A, Higuchi H, and Terauchi M (2004): Muscle performance after anterior cruciate ligament reconstruction. Int Orthop 28: 48–51.

Koval KJ, Clapper MF, Brumback RJ, Ellison Jr PS, Poka A, Bathon H, and Burgess AR (1991): Coplications of reamed intramedullary nailing of the tibia. J Orthop Trauma 5: 184–189.

Kramers-de Quervain IA, Engel-Bicik IE, Miehlke W, Drobny T, and Munzinger U (2005): Fat-pad impingement after total knee artroplasty with LCS A/P-Glide system. Knee Surg Sports Traumatol Arthrose 13:174–178.

Kutty S, Laing AJ, Prasad CVR, and McCabe JP (2005): The effect of traction on compartment pressures during intramedullary nailing of tibial-shaft fractures. a prospective randomized trial. Int Orthop 29: 186–190.

Küntscher G (1940): Ein neues Frakturheilverfahren. Klin Wochenschr 19: 335.

Kyrö A, Usenius JP, Aarnio M, Kunnamo I, and Avikainen V (1993): Are smokers a risk group for delayed healing of tibial shaft fractures? Ann Chir Gynaecol 82: 254–262.

Kyrö A (1997): Malunion after intramedullary nailing of tibial shaft fractures. Ann Chir Gynaecol 86: 56–64.

Lang GJ, Cohen BE, Bosse MJ, and Kellam JF (1995): Proximal third tibial shaft fractures: should they be nailed? Clin Orthop 315: 64–74.

Larsen LB, Madsen JE, Høiness PR, and Øvre S (2004): Should insertion of intramedullary nails for tibial fractures be with or without reaming? J Orthop Trauma 18: 144–149.

Lee Y-S, Lo T-Y, and Huang H-L (2008): Intramedullary fixation of tibial shaft fractures: a comparison of the unlocked and interlocked nail. In Orthop 32:69–74.

Lefaivre KA, Guy P, Chan H, and Blachut PA (2008): Long-term follow-up of tibial shaft fractures treated with intramedullary nailing. J Orthop Trauma 8: 525–529.

Leunig M, and Hertel R (1996): Thermal necrosis after tibial reaming for intramedullary nailing on fracture healing. A report of three cases- J Bone Joint Surg 78-B: 584-587.

Lin J (2006): Effectiveness of completely round nails with both-ends-threated locking screwes for tibial shaft fractures. J Trauma 61: 893–899.

Lindholm RV (1980): Küntscher bone nailing – forecast and actuality. Ann Chir Gynaecol 69: 85–91.

Lindström T, Gullichsen E, Aho A, Helenius H, and Niinkoski J (1998): Tissue perfusion after intramedullary nailing of tibial shaft fracture. Ann Chir Gyn 87: 317–320.

Livingston LA and Mandigo JL (1999): Bilateral Q angle asymmetry and anterior knee pain syndrome. Clin Biomech 14: 7–13.

Lottes JO (1952): Intramedullary fixation for fractures of the shaft of the tibia. South Med J 45: 407–414.

Lottes JO (1974): Medullary nailing of the tibia with the trflange nail. Clin Orthop 105: 253–266.

Lysholm J and Gillquist J (1982): Evaluation of knee ligament surgery results with special emphasis on the use of a scoring scale. Am J Sports Med. 10: 150–154.

Magi M, Branca A, Bucca A, and Langerame V (1991): Hoffa disease. Ital J Orthopaed Traumatol 17: 211–216.

Martens M, van Audekercke R, De Meester P, and Mulier JC (1981): The geometrical properties of human femur and tibia and their importance for the

mechanical behaviour of these bone structures. Arch Orthop Trauma Surg 98: 113–120.

Matic A, Kasic M, and Hudolin I (1992): Knee-ligament injuries associated with leg fractures: a prospective study. Unfallchirurg 95: 469–470.

Matson FA, Winquist RA, and Krugmire RB (1980): Diagnosis and management of compartment syndromes. J Bone Joint Surg 62-A: 286–291.

McConnell, Tornetta III P, Tilzey J, and Casey D (2001): Tibial portal placement: the radiographic correlate of the anatomic safe zone. J Orthop Trauma 3:207–209.

McQueen MM, Christie J, and Court-Brown CM (1990): Compartment pressures after intramedullary nailing of the tibia. J Bone Joint Surg 72-B: 395–397.

Mechrefe AP, Koh EY, Trafton PG, and DiGiovanni CW (2006a): Tibial nonunion. Foot Ankle Clin N Am 11: 1–18.

Mechrefe AP, Koh EY, Trafton PG, and DiGiovanni CW (2006b): Tibial malunion. Foot Ankle Clin N Am 11: 19–33.

Mensch JS and Amstutz HC (1975): Knee morphology as a guide to knee replacement. Clin Orthop 112: 231–241.

Merchant TC and Dietz FR (1989): Long-term follow-up after fractures of the tibial and fibular shafts. J Bone Joint Surg Am 71: 599–606.

Milner SA, Davis TRC, Muir KR, Greenwood DC, and Doherty M (2002): Long-term outcome after tibial shaft fracture: is malunion important? J Bone Joint Surg 84-A: 971–980.

Mistry D and O'Meeghan C (2005): Fate of the infrapatellar branch of the saphenous nerve post total knee arthroplasty. ANZ J Surg 75: 822–824.

Mizuno Y, Kumagai M, Mattessich SM, Elias JJ, Ramrattan N, Cosgarea AJ, and Chao EYS (2001): Q-angle influences tibiofemoral and patellofemoral kinematics. J Orthop Research 19: 834–840.

Mochida H and Kikucki S (199%: Injury to infrapatellar branch of saphenous nerve in arthoscopic knee surgery. Clin Orthop 18: 88–94.

Moller AM, Pedersen T, Villebro N, and Munksgaard A (2003): Effect of smoking on early complications after elective orthopaedic surgery. J Bone Joint Surg 85-B: 178–181.

Moore K (1992): Clinically oriented anatomy. 3rd ed. Williams & Wilkins, Baltimore (MD).

Mubarak SJ, Hargens AR, and Owen CA (1976): The wick cathered technique for measurement of intramuscular pressure: a new research and clinical tool. J Bone Joint Surg 58-A: 1016–1021.

Mubarak SJ, Owen CA, Hargens AR, Garetto LP, and Akeson WH (1978): Acute compartment syndromes: diagnosis and treatment with the aid of the wick cathered. J Bone Joint Surg 60-A: 1091–1095.

Muckle DS (1981): The unstable knee: a sequel to tibial fractures. In: Proceedings of the British Orthopaedic Association. J Bone Joint Surg 63-B: 628.

Muneta T, Yamamoto H, Ishibashi T, Asahina S, and Furuya K (1994): Computerized tomographic analysis of tibial tubercle position in the painful female patellofemoral joint. Am J Sports Med 22: 67–71.

Müller ME, Nazarian S, Koch P, and Schatzker J (1990): The comprehensive classification of fractures of long bones. 1st ed. Springer-Verlag, Berlin, Heidelberg, New York, Tokio.

Müller ME, Allgöwer M, Schneider R, and Willenegger H (1992): Manual of internal fixation. Techniques recommended by the AO-ASIF group. Abridged AO-manual, Limited 3rd ed. Springer-Verlag, Berlin, Heidelberg, New York.

Nassif JM, Gorczyca JT, Cole JK, Pugh KJ, and Pienkowski D (2000): Effect of acute reamed versus unreamed intramedullary nailing on compartment pressure when treating closed tibial shaft fractures: a randomized prospective study. J Orthop Trauma 14: 554–558.

Nelson GE, Kelly PJ, Peterson LFA, and Janes JM (1960): Blood supply of the human tibia. J Bone Joint Surg 42-A: 625–636.

Netter FH (1987): Musculoskeletal system. Part I: Anatomy, physiology, and metabolic disorders. The Ciba Collection of Medical Illustrations. Vol 8. Ciba-Geigy Corporation, Summit, NJ.

Newey ML, Ricketts D, and Roberts L (1993): The AO classification of long bone fractures: an early study of its use in clinical practice. Injury 24: 309–312.

Nicoll EA (1964): Fractures of the tibial shaft: a survey of 705 cases. J Bone Joint Surg 46-B: 373–387.

Nyland J, Bealle DP, Kaufer H, and Johnson DL (2001): Long-term quadriceps femoris functional defecits following intramedullary nailing of isolated tibial fractures. Int Orthop 24: 342–346.

O'Brien SJ, Warren RF, Pavlov H, Panariello R, and Wickiewicz (1991): Reconstruction of the chronically insufficient anterior cruciate ligament with the central third of the patellar ligament. J Bone Joint Surg 73-A: 278–286.

Okike K and Bhattacharyya T (2006): Current concepts review. Trends in the management of open fractures. A critical analysis. J Bone Joint Surg 88-A: 2739–2748.

Oni OO, Hui A, and Gregg PJ (1988): The healing of closed tibial shaft fractures: the natural history of union with closed treatment. J Bone Joint Surg 70-B: 787–790.

Orfaly R, Keating JF, and O'Brien (1995): Knee pain after tibial nailing: does the entry point matter? J Bone Joint Surg 77-B: 976–977.

Orrico M, Lavini F, and Leo DD (2007): Delay of clinical manifestation and medical malpractice in a serious vascular complication of proximal locked tibial nailing. Am J Forensic Med Pathol 28: 150-154.

Pell ACH, Hughes D, Keating J, Christie J, Busuttil A, and Sutherland GR (1993): Brief report: fulminating fat embolism syndrome caused by paradoxial embolism through a patent foramen ovale. N Engl J Med 329: 926–929.

Petrisor B, Anderson S, and Court-Brown CM (2005): Infection after reamed intramedullary nailing of the tibia. A case series review. J Orthop Trauma 19: 437–441.

Pincivero DM, Lephart SM, and Karunakara RA (1997): Reliability and precision of isokinetic strength and muscular endurance for the quadriceps and hamstrings. Int J Sports Med 18: 113–117.

Portland GH, Martin D, Keene G, and Menz T (2005): Injury to the infrapatellar branch of the saphenous nerve in anterior cruciate ligament

reconstruction: Comparison of horizontal versus vertical harvest site incisions. Arthroscopy 21: 281–285.

Puloski S, Romano C, Buckley R, and Powell J (2004): Rotational malalignment of the tibia following reamed intramedullary nail fixation. J Orthop Trauma 18: 397–402.

Puno RM, Teynor JT, Nagano J, and Gustilo RB (1986): Critical analysis of results of treatment of 201 tibial shaft fractures. Clin Orthop 212: 113–121.

Puno RM, Vaughan JJ, Stetten ML, and Johnson JR (1991): Long-term effects of tibial angular malunion on the knee and ankle joints. J Orthop Trauma 5: 247–254.

Reichert ILH, McCarthy ID, and Hughes SPH (1995): The acute vascular response to intramedullary nailing. J Bone Joint Surg 77-B: 490–493.

Rhinelander FW (1987): The vascular response of bone to internal fixation. In: Browner BD, Edwards CC, eds. The science and practice of intramedullary nailing. Pp 25–29, Lea & Febiger, Philadelphia (Pa).

Robinson CM, O'Donnel EW, and Keating JF (1999): Dropped hallux after intramedullary nailing of tibial fractures. J Bone Joint Surg 81-B: 481–484.

Rorabeck CH and Macnab I (1975): The pathophysiology of the anterior tibial compartment syndrome. Clin Orthop 113: 52–57.

Rorabeck CH, Castle JSP, Hardie R, and Logan J (1981): Compartmental pressure measurements: an experimental investigation using the slit cathered. J Trauma 21: 446–449.

Rorabeck CH (1984): The treatment of compartment syndromes of the leg. J Bone Joint Surg 66-B: 93–97.

Rosenthal RE, MacPhail JA, and Oritz JE (1977): Non-union in open tibial fractures. J Bone Joint Surg 59-A: 244–248.

Roth C, Jacobson J, Jamadar D, Caoili E, Morag Y, and Housner J (2004): Quadriceps fat pad signal intensity and enlargement on MRI: Prevalence and associated findings. AJR 182: 1383–1387.

Sala F, Binda M, and Lovisetti G (1998): Anterior gonalgic sydrome after intramedullary nailing: ultrasound and radiologic study. Chir Organi Mov 83: 271–275.

Salam AA, Eyres KS, Cleary J, and el-Sayed HH (1991): The use of a tourniquet when plating tibial fractures. J Bone Joint Surg 73-B: 86–87.

Samuelson MA, McPherson EJ, and Norris L (2002): Anatomic assessment of the proper insertion for a tibial intramedullary nail. J Orthop Trauma 16: 23–25.

Sarangi PP and Karachalios T (1993): Posterior tibial nerve palsy after intramedullary nailing. Int Orthop 17: 125–126.

Sarmiento A, Sobol PA, Sew Hoy AL, Ross SD, Racette WL, and Tarr RR (1984): Prefabricated functional braces for the treatment of fractures of the tibial diaphysis. J Bone Joint Surg 66-A: 1328–1339.

Sarmiento A, Gersten LM, Sobol PA, Shankwiler JA, and Vangsness CT (1989): Tibial shaft fractures treated with functional braces. J Bone Joint Surg 71-B: 602–609.

Sarmiento A, Sharpe FE, Ebramzadeh E, Normand P, and Shankwiler J (1995): Factors influencing the outcome of closed tibial fractures treated with functional bracing. Clin Orthop 315: 8–24.

Sarmiento A and Latta LL (2004): 450 closed fractures of the distal third of the tibia treated with a functional brace. Clin Orthop 428: 261–271.

Sayana MK, Davis BJ, Kapoor B, Rahmatalla A, and Maffulli N (2006): Fracture strain and stability with additional locking screws in intramedullary nailing: a biomechanical study. J Trauma 60: 1053–1057.

Schandelmaier P, Krettek C, Joachim R, and Tscherne H (1995): Outcome of tibial shaft fractures with severe soft tissue injury treated by unreamed nailing versus external fixation. J Trauma 39: 707–711.

Schandelmaier P, Krettek C, Wolter K and Tscherne H (2002): Ability to kneel after tibial nailing: the length of the incision matters. In: 5th European Trauma Congress, Vienna.

Schatzker J and Marvin T (1987): The rationale of operative fracture care. 1st ed. Springer-Verlag, Berlin, Heidelberg.

Schemitsch EH, Kowalski MJ, Swiontkowski MF, and Senft D (1994): Cortical bone blood flow in reamed and unreamed locked intramedullary nailing: a fractured tibia model in sheep. J Orthop Trauma 8: 373–382.

Schemitsch EH, Turchin DC, Kowalski MJ, and Swiontkowski MF (1998): Quantitative assesment of bone injury and repair after reamed and unreamed locked intramedullary nailing. J Trauma 45: 250–255.

Schmitz MA, Finnegan M, Natarajan R, and Champine J (1999): Effect of smoking on tibial shaft fracture healing. Clin Orthop 365: 184–200.

Seebauer CJ, van Scherpenzeel KM, Haas NP, and Bail HJ (2009): Tibia fracture following removal of the ETN® (Expert tibia nail): a case report. Acta Orthop Trauma Surg 129:949–953.

Shabshin N, Schweitzer ME, and Morrison WB (2006): Quadriceps fat pad edema: significance on magnetic resonance images of the knee. Seletal Radiol 35: 269–274.

Shannon FJ, Mullett H, and O'Rourke Kieran (2002): Unreamed intramedullary nail versus external fixation in Grade III open fractures. J Trauma 52: 650–654.

Shetty AA, Tindall AJ, Qureshi F, Divekar M, and Fernando KW (2003): The effect of knee flexion on the popliteal artery and its surgical significance. J Bone Joint Surg 85-B: 218-222.

Singer BR, McLauchlan GJ, Robinson CM, and Christie J (1998): Epidemiology of fractures in 15 000 adults. The influence of age and gender. J Bone Joint Surg 80-B:243–248.

Skoog A, Söderqvist A, Tönkvist H, and Ponzer S (2001): One-year outcome after tibial shaft fractures: Results of a prospective fracture registry. J Orthop Trauma 15: 210– 215.

Smillie IS (1963): Lesions of the infrapatellar fat pad and synovial fringes: Hoffa's disease. Acta Orthop Scand 33: 371–377.

Smith WR, Ziran B, Agudelo JF, Morgan SJ, Lahti Z, Vanderheiden T, and Williams A (2006): Expandable intramedullary nailing for tibial and femoral fractures: A preliminary analysis of perioperative complications. J Orthop Trauma 20: 310–314.

Steinberg EL, Geller DS, Yacoubian SV, Shasha N, Dekel S, and Lorich DG (2006): Intramedullary fixation of tibial shaft fractures using an expandable nail: early results of 54 acute tibial shaft fractures. J Orthop Trauma 20: 303–309.

Swanson TV, Spiegel JD, Sutherland TB, Bray TJ, and Chapman MW (1990): A prospective, comparative study of the Lottes nail versus external fixation in 100 open tibia fractures. Orthop Trans 14: 716–717.

Szalay MJ, Hosking OR, and Annear P (1990): Injury of knee ligament associated with ipsilateral femoral shaft fractures and with ipsilateral femoral and tibial shaft fractures. Injury 21: 398–400.

Takakuwa M, Funakoshi M, Ishizaki K, Aono T, and Hamaguchi H (1997): Fracture on removal of the Ace tibial nail. J Bone Joint Surg 79-B: 444–445.

Tang P, Gates C, Hawes J, Vogt M, and Prayson MJ (2006): Does open reduction increase the chance of infection during intramedullary nailing of closed tibial shaft fractures? J Orthop Trauma 20: 317–322.

Tegner Y, Lysholm J, Odensten M, Gillquist J (1988): Evaluation of cruciate ligament injuries. A review. Acta Orthop Scand 59: 336–41.

Templeman DC and Marder RA (1989): Injuries of the knee associated with fractures of the tibial shaft: detection by examination under anaesthesia: a prospective study. J Bone Joint Surg 71-A: 1392–1395.

Tennent TD, Birch NC, Holmes MJ, Birch R, and Goddard NJ (1998): Knee pain and infrapatellar branch of the saphenous nerve. J R Soc Med 91: 573–575.

Thiagarajan P, Ang KC, Das De S, and Bose K (1997): Ipsilateral knee ligament injuries and open tibial diaphyseal fractures: incidence and nature of knee ligament injuries sustained. Injury 28: 87–90.

Tifford CD, Spero L, Luke T, and Plancher KD (2000): The relationship of the infrapatellar branches of the saphenous nerve to arthroscopy portals and incisions for anterior cruciate ligament surgery. An anatomic study. Am J Sports Med 28: 562–567.

Tischenko GJ and Goodman SB (1990): Compartment syndrome after intramedullary nailing of the tibia. J Bone Joint Surg 72-A: 41–44.

Trafton PG (1988): Closed unstable fractures of the tibia. Clin Orthop 230: 58–67.

Tscherne H and Gotzen L (1984): Fractures with soft tissue injuries. Springer, Berlin, Heidelberg, New York.

Toivanen JAK, Hirvonen M, Auvinen O, Honkonen SE, Järvinen TLN, Koivisto A-M, and Järvinen MJ (2000): Cast treatment and intramedullary locking nailing for simple and spiral wedge tibial shaft fractures – a cost benefit analysis. Ann Chir Gynaecol 89: 138–142.

Toivanen JAK, Honkonen SE, Koivisto A-M, and Järvinen MJ (2001): Treatmnet of low-energy tibial shaft fractures: plaster cast treatment compared with intramedullary nailing. Int Othop 25: 110–113.

Toivanen JAK, Väistö O, Kannus P, Latvala K, Honkonen S, and Järvinen M (2002): Anterior knee pain after intramedullary nailing of fractures of the tibial shaft. A prospective, randomized study comparing two different nail-insertion techniques. J Bone Joint Surg 84-A:580–585.

Tornetta P, Bergman M, Watnik N, Berkowitz G, and Steuer J (1994): Treatment of grade-IIIb open tibial fractures. A prospective randomised comparison of external fixation and non-reamed locked nailing. J Bone Joint Surg 76-B: 13–19.

Tornetta P III and Templeton D (1996): Compartment syndrome associated with tibial fractured. J Bone Joint Surg 78-A: 1438–1444.

Tornetta P III, Riina J, Geller J, and Purban W (1999): Intraarticular anatomic risks of tibial nailing. J Orthop Trauma 13: 247–251.

Tu YK, Lin CH, Su JI, Hsu DT, and Chen RJ (1995): Unreamed interlocking nail versus external fixator for open type III tibia fractures. J Trauma 39: 361–367.

Tuncyurek O, Ozkol M, Ozic U, and Pabuscu Y (2009): The role of patellar tendon morphometry on anterior knee pain. Surg Radiol Anat 2009 Published online.

Uhlin B and Hammer R (1998): Attempted unreamed nailing in tibial fractures: a prospective consecutive series of 55 patients. Acta Orthop Scand 69: 301–305.

Utvåg SE, Grundnes O, and Reikerås O (1998): Effects of degrees of reaming on healing of segmental fractures in rats. J Orthop Trauma 12: 1922–1929.

Üzümcügil O, Doğan A, Yalçinkaya M and Kabukçuoğlu YS (2009): The relationship between anterior knee pain occurring after tibial intramedullary nailing and the localization of the nail in the proximal tibia. Acta Orthop Traumatol Turc 43:386–389.

Van Der Schoot DKE, Den Outer AJ, Bode PJ, Obermann WR, and Vugt AB (1996): Degenerative changes at the knee and ankle related to malunion of tibial fractures. 15 year follow-up of 88 patients. J Bone Joint Surg 78-B: 722–725.

van Raay JJAM, Raaymakers ELFB, and Dupree HW (1991): Knee ligament injuries combined with ipsilateral tibial and femoral diaphyseal fractures: the "floating knee". Arch Orthop Trauma Surg 110: 75–77.

Verbrugge LM (1995): Women, men, and osteoarthritis. Arthritis Care Res 8: 212–220.

Waddell JP and Reardon GP (1983): Complications of tibial shaft fractures. Clin Orthop 178: 173–178.

Watson JT (1994): Current concepts review. Treatment of unstable fractures of the shaft of the tibia. J Bone Joint Surg 76-A: 1575–1584.

Watson-Jones R and Coltart WD (1943): Slow union of fractures: with a study of 804 fractures of the shafts of the tibia and femur. Br J Surg 30: 260–276.

Weil YA and Gardner MJ (2009): Anterior knee pain following the lateral parapatellar approach for tibial nailing. Arch Orthop Trauma Surg 6: 773–777.

Weninger P, Schultz A, Traxler H, Firbas W, and Hertz H (2009): Anatomical assessment of the Hoffa fat pad during insertion of a tibial intramedullary nail—comparison of three surgical approaches. J Trauma 4: 1140–1145.

Williams J, Gibbons M, Trundle H, Murray D, and Worlock P (1995): Complications of nailing in closed tibial fractures. J Orthop Trauma 9: 476–481.

Wiss DA, and Stetson WB (1995): Unstable fractures of the tibia treated with a reamed intramedullary interlocking nail. Clin Orthop 315: 56–63.

Wood GW (2006): Intramedullary nailing of femoral and tibial shaft fractures. Instructional lecture. J Orthop Sci 11: 657–669.

Wozasek GE, Simon P, Redl H, and Schlag G (1994): Intramedullary pressure changes and fat intravasation during intramedullary nailing: an experimental study in sheep. J Trauma 36: 202–207.

Yoshioka Y, Siu DW, Scudamore RA, and Cooke TDV (1989): Tibial anatomy and functional axes. J Orthop Res 7: 132–137.

You JY, Lee HM, Luo HJ, Leu CC, Cheng PG and Wu SK (2009): Gastrocnemius tightness on joint angle and work of lower extremity during gait. Clin Biomech 24:744–750.

Young H, and Topliss C (2007): Complications associated with the use of a titanium tibial nail. Injury 38: 223–226.

Yu SW, Tu YK, Fan KF, and Su JY (1999): Anterior knee pain after intramedullary tibial nailing. Chanqqenq Yi Xue Za Zhi 22: 604–608.

Zhang B, Muneta T, Yagishita K, and Sekiya I (2006): Substance P immunoreactive fibers of synovial tissue in patients with anterior cruciate ligament injury. Knee Surg Sports Traumatol Artrosc 14: 404–410.

14. APPENDICES

Appendix 1.

Grade 0	Injury from indirect forces with negligible soft tissue damage.
Grade I	Closed fracture caused by low-to-moderate energy mechanisms, with superficial abrasions or contusions of soft tissues overlying the fracture.
Grade II	Closed fracture with significant muscle contusion, with possible deep, contaminated skin abrasions associated with moderate-to-sever energy mechanisms and skeletal injury; high risk for compartment syndrome.
Grade III	Extensive crushing of soft tissues, with subcutaneous degloving or avulsion, with arterial disruption or established compartment syndrome.

The Tscherne Classification system for closed fractures of tibial shafts [Tscherne H and Gotzen L (1984): Fractures with soft tissue injuries. Springer, Berlin, Heidelberg, New York].

Appendix 2.

Grade I	Clean skin opening of <1 cm, usually from inside to outside; minimal muscle contusion; simple transverse or short oblique fractures.
Grade II	Laceration of >1 cm, with extensive soft-tissue damage; minimal-to-moderate crushing component, simple transverse or short oblique fractures with minimal comminution.
Grade III	Extensive soft-tissue damage, including muscles, skin, and neurovascular structures; often a high-energy injury with a severe crushing component.
Grade IIIa	Extensive soft-tissue laceration, adequate bone coverage; segmental fractures, gunshot injuries, minimal periosteal stripping.
Grade IIIb	Extensive soft-tissue injuries with periosteal stripping and bone exposure requiring soft-tissue flap closure; usually associated with massive contamination.
Grade IIIc	Vascular injury requiring repair.

Gustilo and Anderson classification for open fractures of the tibial shaft [Gustilo RB and Anderson JT (1976): Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones. Retrospective and prospective analyses. J Bone Joint Surg 58-A: 453–458].

Appendix 3.

Lysholm knee score

1. Limp (5 points)
None	5
Slight or periodical	3
Severe and constant	0

2. Support (5 points)
Full support	5
Stick or crutch	3
Weight bearing impossible	0

3. Stairclimbing (10 points)
No problems	10
Slightly impaired	6
One step at a time	2
Unable	0

4. Squatting (5 points)
No problems	5
Slightly impaired	4
Not past 90 degrees	0

5. Walking, running and jumping (70 points)
A. Instability:
Never giving way	30
Rarely during athletic or other severe exertion	25
Frequently during athletic or other severe exertion (or unable to participate)	20
Occasionally in daily activities	10
Often in daily activities	5
Every step	0

B. Pain:
None	30
Inconstant and slight during severe exertion	25
Marked on giving way	20
Marked during severe exertion	15
Marked on or after walking more than 2 km	10
Marked on or after walking less than 2 km	5
Constant and severe	0

C. Swelling:

None	10
With giving way	7
On severe exertion	5
On ordinary exertion	2
Constant	0

6. Atrophy of thigh (5 points)

None	5
1-2 cm	3
More than 2 cm	0

TOTAL SCORES (max. 100 points)   _____

Lysholm knee score [Lysholm J and Gillquist J (1982): Evaluation of knee ligament surgery results with special emphasis on the use of a scoring scale. Am J Sports Med. 10: 150–4].

Appendix 4.

Level 10	Competitive sports: soccer, football, rugby (national elite)
Level 9	Competitive sports: soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball
Level 8	Competitive sports: racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing
Level 7	Competitive sports: tennis, running, motorcars speedway, handball Recreational sports: soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running
Level 6	Recreational sports: tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week
Level 5	Work: heavy labour (construction, etc.) Competitive sports: cycling, cross-country skiing, Recreational sports: jogging on uneven ground at least twice weekly
Level 4	Work: moderately heavy labour (e.g. truck driving, etc.)
Level 3	Work: light labour (nursing, etc.)
Level 2	Work: light labour Walking on uneven ground possible, but impossible to back pack or hike
Level 1	Work: sedentary (secretarial, etc.)
Level 0	Sick leave or disability pension because of knee problems

Tegner's activity scale [Tegner Y, Lysholm J, Odensten M, and Gillquist J (1988): Evaluation of cruciate ligament injuries. A review. Acta Orthop Scand 59: 336–41].

Appendix 5.

FUNCTION (35 POINTS)

Instructions: Eleven activities of daily living are listed with a value. If the patient can perform the activity easily without restriction, give full value; if the patient cannot (or could not if she/he tried) perform the activity at all, give no points: if the patient can or could perform the activity but with difficulty, give an appropriate number of points between 0 and the full value.

Does most housework or job, which requires moving about (5)
Walks enough to be independent (5)
Dresses unaided (includes tying shoes and putting on socks) (5)
Sits without difficulty at a table or on the toilet, including sitting down and getting up (reduce if additional aid is necessary) (4)
Picks up objects from floor by squatting or kneeling (3)
Bathes without help (3)
Negotiates stairs foot over foot (3)
Negotiates stairs in any manner (2)
Carries objects, such as a suitcase (2)
Gets into automobile or public conveyance unaided and rides comfortably (2)
Drives automobile (1)

FREEDOM FROM PAIN (**maximum, 35 points; circle one only**)

Instructions: Circle the value that is overall the most representative of the patient's pain, using the word descriptors. (Scoring should not be based simply on asking the patient the word descriptors in question form.)

No pain (35)
Mild pain with fatique (30)
Mild pain with weight-bearing (20)
Moderate pain with weight-bearing (15)
Severe pain with weight-bearing, mild or moderate at rest (10)
Severe, continous pain (0)

GAIT (**maximum, 10 points; circle one only**)

No limp, no support (10)
Limp, no support (8)
One cane or crutch (8)
One long brace (8)
One brace with cructh or cane (6)
Two crutches with or without a brace (4)

Cannot walk (0)

ABSENCE OF DEFORMITY OR STABILITY (10 points)

No fixed flexion of more than 10 degrees with weight-bearing (3)
No fixed flexion of more than 20 degrees with weight-bearing (2)
No fixed flexion of more than 30 degrees with weight-bearing (1)
No varus or valgus deformity of more than 10 degrees with weight-bearing (3)
No varus or valgus deformity of more than 20 degrees with weight-bearing (2)
No varus or valgus deformity of more than 30 degrees with weight-bearing (1)
No ligamentous instability (2)
No locking, giving-away, or extension lag of more than 10 degrees (2)

RANGE OF MOTION (10 points)

Instructions: Total amount of flexion or extension, in degrees (normal, 150 degrees); assign 1 point for every 15 degrees.

Maximum total points 100

Iowa knee score [Merchant TC and Dietz FR (1989): Long-term follow-up after fractures of the tibial and fibular shafts. J Bone Joint Surg Am 71: 599–606].

Appendix 6.

Duck walk

    3 = no problem
    2 = slightly difficult
    1 = with severe pain
    0 = cannot perform

One leg jump

    3 = no problem
    2 = slightly difficult
    1 = with severe pain
    0 = cannot perform

Full squat

    3 = able to perform > 20
    2 = able to perform 11–20
    1 = able to perform 1–10
    0 = cannot perform

Kneeling

    3 = No problems, without time limitation
    2 = Possible to kneel for less than 20 seconds
    1 = Possible to kneel for less than 10 seconds
    0 = Impossible to kneel

TOTAL POINTS   _____**/ 12 points**

The functional test used in the study [Kannus P, Natri A, Niittymäki S, and Järvinen M (1992): Effect of intraarticular glycosaminoglycan polysulfate treatment on patellofemoral pain syndrome. A prospective, randomized double-

blind trial comparing glycosaminoglycan polysulfate with placebo and quadriceps muscle exercises. Arthritis Rheum 35: 1053–61].

15. ORIGINAL PUBLICATIONS (I-IV)

Anterior Knee Pain and Thigh Muscle Strength After Intramedullary Nailing of Tibial Shaft Fractures

A Report of 40 Consecutive Cases

Olli Väistö, MD,* Jarmo Toivanen, MD,*† Pekka Kannus, MD,*‡ and Markku Järvinen, MD*†

Objectives: Chronic anterior knee pain is a common complication following intramedullary nailing of a tibial shaft fracture. The source of pain is often not known nor is the reason for a simultaneous decrease in thigh muscle strength. Anterior knee pain has also been reported following an anterior cruciate ligament rupture. No previous investigation has assessed whether weakness of the thigh muscles is associated with anterior knee pain following intramedullary nailing of tibial shaft fractures.

Design: Prospective study.

Setting: University Hospital of Tampere, University of Tampere.

Patients: Fifty consecutive patients with a nailed tibial shaft fracture were initially included in the study. Ten patients did not have isokinetic strength testing for various reasons and were eliminated from the study.

Main Outcome Measurements: Isokinetic muscle strength measurements were done in 40 patients at an average 3.2 ± 0.4 (SD) years after nail insertion (1.7 ± 0.3 years after the nail extraction).

Results: Twelve (30%) patients were painless and 28 (70%) patients had anterior knee pain at follow-up. With reference to the hamstrings muscles, the mean peak torque deficit of the injured limb (as compared with the uninjured limb) was $2 \pm 11\%$ in the painless group and $11 \pm 17\%$ in the pain group at a speed of $60°/s$ ($P = 0.09$, [95% CI for the group difference $= -18\%$ to 0%]). At a speed of $180°/s$, the corresponding deficits were $-3 \pm 13\%$ and $10 \pm 21\%$ ($P = 0.03$, [95% CI for the group difference $= -4\%$ to -2%]). With reference to the quadriceps muscles, the mean peak torque deficit of the injured limb was $14 \pm 15\%$ in the painless group and $15 \pm 15\%$ in the pain group at speed of $60°/s$ ($P = 0.71$, [95% CI for the group difference $= -11\%$ to 10%]). At a speed of $180°/s$, the corresponding deficits were $9 \pm 11\%$ and $14 \pm 17\%$ ($P = 0.46$, [95% CI for the group difference $= -14\%$ to 5%]).

Conclusion: Based on this prospective study, we conclude that anterior knee pain after intramedullary nailing of a tibial shaft fracture, although of multifactorial origin, may be related to deficiency in the flexion strength of the thigh muscles.

Key Words: tibial fracture, intramedullary nailing, anterior knee pain, thigh muscle strength

(*J Orthop Trauma* 2004;18:18–23)

Multiple studies have shown that the outcome of treatment of a tibial shaft fracture using locked intramedullary nailing is superior to that of cast treatment.[1–10] However, the etiology of the most common postoperative problem, chronic anterior knee pain, is still unknown.[10–17] Thigh muscle deficit after tibial fracture has been reported in several articles as well.[6,18–20] Nyland et al recorded an average 25% extensor and 17% flexor torque deficit in the operated limb more than one year (18 ± 6 months) after intramedullary nailing of isolated tibial fractures.[21] However, no previous investigation has assessed whether the weakness of the thigh muscles is associated with chronic anterior knee pain after intramedullary nailing of tibial shaft fractures.

The purpose of this prospective study was, therefore, to find out whether there is an association between chronic anterior knee pain and thigh muscle weakness in patients with a nailed tibial shaft fracture.

MATERIALS AND METHODS

Fifty consecutive patients [23 men and 27 women, mean aged 42 ± 5 (SD) years] with an isolated tibial shaft fracture were treated with a reamed intramedullary nail with two interlocking bolts at both ends of the nail (Grosse-Kempf-nail, Howmedica) at Tampere University Hospital, Finland, be-

tween July 1996 and January 1998 and enrolled in this prospective study. The inclusion criteria included an age of 15 years or more, absence of any major comorbid illnesses, and absence of any fracture line extending up to the knee joint or down to the ankle joint. No patient had previous injuries or symptoms related to either extremity. All subjects were informed of the study procedure, purposes, and known risks, and all gave written informed consent. The study was conducted in conformity with the principles of the Declaration of Helsinki and approved by our Institutional Ethics Committee. Patients were divided postoperatively into two groups during the study depending on chronic anterior knee pain: 1) the symptomatic group (patients having chronic anterior knee pain); and 2) the asymptomatic group (patients without chronic anterior knee pain).

Two patients were excluded from the study in the early phase of treatment because the nail had to be removed due to a deep infection. Two patients died during follow-up from causes not related to the tibial shaft fracture. Two patients were initially managed with a cast and then treated by nailing at the time of corrective osteotomy (the first one 6 months and the second one 18 months after the injury), and they were also excluded from the study. In addition, we were unable to contact four patients for the follow-up examination. Thus, number of patients available for isokinetic strength testings was 40.

Intramedullary nailing was performed within 24 hours in 42 patients and between 1 and 12 days in 6 patients. A tourniquet was not used during the operation. The incision for the transtendinous approach was made longitudinally through the midline of the patellar tendon for a distance of 3 to 5 cm. After insertion of nail, the incision was closed with interrupted sutures. In the paratendinous approach, a medial longitudinal incision was made with care taken not to violate the patellar tendon or its sheath. For all patients, standard proximal and distal locking screws were used. All nails were countersunk below the cortical bone of the proximal tibia. Postoperative immobilization in a cast or brace was not used. Patients were allowed to progress to one-leg weight bearing at 6 weeks postsurgery and to full weight bearing at 12 weeks postsurgery. All patients were given instructions for thigh muscle rehabilitation in the hospital, but no physiotherapy were given after intramedullary nailing. Nails were routinely removed regardless of the presence or absence of knee pain, approximately 1-and-a-half years after the nailing using the same entry incision and approach that was used in nail insertion. After removal of the intramedullary nail, neither instructions for thigh muscle rehabilitation nor physiotherapy were given.

The isokinetic quadriceps and hamstrings strength testing was performed using the Cybex system (Cybex 6000, Division of Lumex, Inc., NY). Before the test, the patients did a warming-up exercise with an ergometer bicycle for 5 minutes. Then the patient was fixed to the isokinetic device with straps around the chest, pelvis, thigh, and malleoli. Before the testing,

the patient was instructed to perform a sufficient number of submaximal and maximal repetitions of knee extension and flexion at both test velocities (60° and 180° per second) to become familiar with the machine.

The actual test included knee joint extension and flexion with both legs with two different angular velocities. Range of movement was 90° (0° to 90°). The test included five maximal repetitions at both speeds. There was a 30-second rest between the 2 test speeds. Each patient was verbally encouraged to do her or his best. The repetition during which the maximal peak torque was produced was recorded.

Along with the isokinetic testing, the patients graded chronic anterior knee pain during rest, walking, running, squatting, kneeling, stair-climbing, stair descent, and after long-term sitting on a 100-mm Visual Analogue Scale (VAS),[22] with 0 denoting no pain and 100 denoting the worst pain that the patient could imagine. All patients also completed standardized knee scoring scales, as described by Lysholm and Gillquist[23] and Tegner et al.[24] The Iowa Knee Score questionnaire[25] was also completed.

STATISTICS

To describe the data, the mean (SD) and the 95% confidence interval (CI) of the differences between the groups are reported for the continuous variables. The mean deficit of the thigh muscle strength in the operated limb was compared with the nonoperated limb and reported as a percentage. The differences between the pain group and painless group were tested using the Mann-Whitney U test for the continuous variables because the distributions were skewed. The reporting also included 95% CI for the differences. The differences between categorized variables were tested using the Fisher exact test. The preliminary power calculations suggested that with use of less than a 5% probability of a type I error ($P < 0.05$) and power of 80% (type II error, 0.20), a sample size of 18 patients (9 patients per group) was necessary to detect 15% muscle strength difference between the 2 study groups. In these preliminary power calculations, this 15% was considered a clinically relevant difference, because the strength and function of thigh muscles seem to be up to 85% of normal 1 year after fracture of diaphysis of tibia,[12] and the thigh muscle deficits have been reported to be 17% to 25% after intramedullary nailing of isolated tibial fractures.[21] The statistical analysis was carried out using the SPSS for Windows program (Version 10.0; SPSS Inc.). Throughout the study, a *P* value of <0.05 was considered statistically significant.

RESULTS

No patient had complications, such as deep or superficial infections, patellar tendon rupture, compartment syndrome, or broken hardware. The isokinetic quadriceps and hamstring strength was performed average 3.2 ± 0.4 years after nail insertion and average 1.7 ± 0.3 years after nail extraction.

Twelve (30%) patients were painless and 28 (70%) patients had chronic anterior knee pain at follow-up. The pain was worse on kneeling and ascent or descent of stairs (Table 1). With reference to the hamstrings muscles, the mean peak torque deficit of the injured limb (as compared with the uninjured limb) was $2 \pm 11\%$ in the painless group and $11 \pm 17\%$ in the pain group at a speed of $60°/s$ ($P = 0.09$, [95% CI for the group difference $= -18\%$ to 0%]). At a speed of $180°/s$, the corresponding deficits were $-3 \pm 13\%$ and $10 \pm 21\%$ ($P = 0.03$, [95% CI for the group difference $= -24\%$ to -2%]). With reference to the quadriceps muscles, the mean peak torque deficit of the injured limb was $14 \pm 15\%$ in the painless group and $15 \pm 15\%$ in the pain group at speed of $60°/s$ ($P = 0.71$, [95% CI for the group difference $= -11\%$ to 10%]). At a speed of $180°/s$, the corresponding deficits were $9 \pm 11\%$ and $14 \pm 17\%$ ($P = 0.46$, [95% CI for the group difference $= -14\%$ to 5%]). The absolute power values (Nm) of muscle strengths are showed in Table 2.

As noted above, at follow-up examination there were 12 patients in the asymptomatic group (30%) and 28 patients in the symptomatic group (70%). Symptoms among the group were minor and no one received surgical treatment or physiotherapy for the problem of anterior knee pain. The study groups were comparable with respect to age, body mass index, nail protrusion, nail-plateau distance, operation time, nail insertion and removal, Tegner et al's knee scores[24] (before operation) and knee joint's range of movement (ROM), but there were statistically significantly more women than men in the symptomatic group (Fisher exact test, $P = 0.007$) (Table 3). Also, there were statistically significantly intergroup differences in the IOWA knee score[25] (after operation) (Mann-Whitney U test $P = 0.003$), Lysholm and Gillquist's knee score[23] (after operation) (Mann-Whitney U test $P = 0.014$), and Tegner et al's knee score[24] (after operation) (Mann-Whitney U test $P = 0.053$) (Table 3).

TABLE 2. Thigh Muscle Strengths in the Nonoperated (Nfoot) and Operated (Ofoot) Limbs

Muscle Power (Nm), Range	Asymptomatic (n = 28)	Symptomatic (n = 12)
NFoot flexion 60°/s	99 ± 25 (37–133)	80 ± 25 (47–134)
OFoot flexion 60°/s	96 ± 26 (41–137)	72 ± 26 (28–123)
NFoot flexion 180°/s	70 ± 22 (24–108)	57 ± 19 (26–103)
OFoot flexion 180°/s	71 ± 22 (28–100)	51 ± 19 (7–94)
NFoot extension 60°/s	191 ± 59 (87–274)	149 ± 50 (89–268)
OFoot extension 60°/s	164 ± 58 (72–289)	127 ± 48 (57–233)
NFoot extension 180°/s	118 ± 40 (49–174)	95 ± 33 (57–167)
OFoot extension 180°/s	108 ± 40 (47–184)	84 ± 34 (18–148)

In knee extension strength, the symptomatic group (anterior knee pain group) differed from the asymptomatic group, but differences were not clinically or statistically significant (Table 4). In knee flexion strength (at the speed of $60°/s$), the symptomatic group differed from the asymptomatic group, although the intergroup difference of 9% was not statistically significant ($P = 0.09$) (Table 4). A significant intergroup dif-

TABLE 3. The Basic Characteristics of Patients With and Without Anterior Knee Pain After Intramedullary Nailing of a Tibial Shaft Fracture

	No Anterior Knee Pain (n = 12)	Anterior Knee Pain (n = 28)	P
BMI (kg/m^2)	26.1 ± 3.6	25.6 ± 5.2	0.658*
Age (yrs)	45 ± 12	42 ± 13	0.515*
Gender			0.008†
Female	1 (6%)	15 (94%)	
Male	12 (46%)	14 (54%)	
Nail insertion			0.500†
Transtendinous	7 (35%)	13 (65%)	
Paratendinous	5 (25%)	15 (75%)	
Lysholm	98 ± 2	88 ± 16	0.014*
Iowaknee	99 ± 1	94 ± 9	0.003*
Tegner et al B‡	4.1 ± 1.3	3.9 ± 1.6	0.577*
Tegner et al A§	4.3 ± 1.3	3.4 ± 1.3	0.053*
Protrus (mm)	4.0 ± 4.0	5.3 ± 3.9	0.415*
Plateau (mm)	10.3 ± 9.0	12.5 ± 9.6	0.495*
ROM (cm)	143 ± 9	139 ± 9	0.267*
Nail removal	10 (77%)	27 (93%)	0.750*
Operating time (mins)	70 ± 15	87 ± 40	0.110*

  *Mann-Whitney test.
  †Fisher exact test.
  ‡Tegner et al's knee scores before surgery.
  §Tegner et al's knee scores after surgery.

TABLE 1. Mean (SD) Intensity of Anterior Knee Pain During Various Activities Among Those Who Reported Pain

Activity	Intensity of Anterior Knee Pain*
Rest	31 (±9), n = 4
Walking	43 (±20), n = 4
Running	47 (±13), n = 4†
Squatting	42 (±18), n = 11
Kneeling	56 (±30), n = 27
Stairs down	60 (±16), n = 5
Stairs up	44 (±9), n = 6
After long-term sitting	23 (±19), n =5

  *Visual Analogue Scale (0, no pain; 100, worst possible pain).
  †7 patients had not started running activity.

TABLE 4. Thigh Muscle Strength Deficits in the Operated Limb as Compared to the Nonoperated Limb (%) According to the Occurrence of Anterior Knee Pain

Movement	Angle Speed	Anterior Knee Pain	Side-to-side Difference (%)	95% CI for the Intergroup Difference	*P**
Flexion	60°/sec	No	2 ± 11	−18 to 0	0.087
		Yes	11 ± 17		
	180°/sec	No	−3 ± 13	−24 to −2	0.025
		Yes	10 ± 21		
Extension	60°/sec	No	14 ± 15	−11 to 10	0.712
		Yes	15 ± 15		
	180°/sec	No	9 ± 11	−14 to 5	0.460
		Yes	14 ± 17		

*Mann-Whitney test.

ference was seen in knee flexion at 180°/s and with this speed of movement the strength difference was 13% (P = 0.03) (Table 4) Using an alpha level of less than 5% (P < 0.05) and considering this 13% muscle strength difference between the groups clinically relevant, the final number of patients per group (12 and 28) gave a minimum 80% statistical power for the study.

DISCUSSION

Our study showed that there was a statistically significant strength difference between the two study groups in knee flexion (hamstring muscles), whereas this was not significant the case with knee extension (quadriceps muscle) (Table 4). Thus, some of the patients may benefit from specific rehabilitation of the knee and thigh muscles (especially knee flexors) after the surgery of a tibial shaft fracture. On the other hand, it should be kept in mind that in all patients, the strength of both the quadriceps and hamstring muscle decreases and the muscle atrophy becomes evident quickly after the injury, especially during the first 1 to 2 weeks.[26] If early rehabilitation of the patient has been completely forgotten and ignored, it may be very difficult to return the strength and power of the muscles back to normal.[19,27]

It is obvious that the source of chronic anterior knee pain after intramedullary nailing of a tibial shaft fracture is multifactorial. Devitt et al demonstrated using eight cadaveric knees that insertion of an intramedullary nail in the tibia significantly increases contact pressures at the patellofemoral joint.[28] They used two different approaches: medial paratendinous and transtendinous approaches. A significant increase in contact pressures was found at the lateral facets using the medial paratendinous approach (P = 0.01) and at the medial facet when using the transpatellar approach (P = 0.001) to the proximal tibia. When the transtendinous approach, the contact pressure increases were recorded on both facets suggesting that chondral injury is more likely with the transtendinous approach.[28]

Hernigou and Cohen[29] investigated 12 pairs of cadaver knees after intramedullary nailing of the tibia. The intraarticular structures particularly at risk for damage during tibial nailing are the medial meniscus, the lateral tibial plateau, and the transverse ligament. Their results showed that in some bones, the safe zone is smaller than the size of standard reamers and the proximal part of some nails. Also, they retrospectively analyzed 30 patients radiologically who had undergone tibial nailing and recorded unrecognized articular penetration and damage during surgery in four patients. These patients had pain in the knee, and there was a possibility that this was linked to unrecognized articular damage.[29] Tornetta et al also studied intra-articular anatomic risks of tibial nailing.[30] They used 40 fresh-frozen cadaveric knees in which nails were placed through medial and lateral parapatellar approaches. There was intra-articular damage in 20% of the specimens and an additional 30% demonstrated the nail to be adjacent to one of the menisci. A lateral paratendinous approach placed the lateral articular surface, and a medial approach the medial meniscus, at the highest risk. They determined a safe zone for portal placement, which was located 9.1 ± 5 mm lateral to the midline of the plateau and 3 mm lateral to the center of tibial tubercle. The width of the safe zone averaged 22.9 mm and was as narrow as 12.6 mm.[30]

McConnell et al[31] also investigated the radiographic correlate of the anatomic safe zone in the intramedullary nailing of tibia in 20 cadaveric knees. They used a 2.0-mm Kirschner wire (K-wire), and it was placed in the center of the anatomic safe zone equidistant from the medial meniscus and the lateral articular surface on the anterosuperior surface of the tibia. The safe zone for tibial nailing as seen on radiographs was just medial to the lateral tibial spine on the anteroposterior (AP) view and immediately adjacent and anterior to the articular surface as visualized on the lateral radiograph. There was some variance on the anteroposterior radiograph but no variance on the lateral radiograph.[31]

Samuelson et al[32] investigated the proper insertion point for a tibial intramedullary nail in the coronal plane using 61 embalmed cadaveric lower legs. They placed a nail in a retrograde fashion through the proximal cortex and the exit hole of the nail was measured in relation to the tibial tubercle. The nail ranged from 1 mm lateral to the tibial tubercle to 21 mm medial to the tibial tubercle with an average of 8 ± 6 mm. Their data supports using a medial or patellar splitting approach for nail insertion and insertion sites lateral to the tibial tubercle should be avoided.[32]

Lembcke et al[33] investigated with the relationship between axial shift and the nail entry point in unreamed nailing of proximal tibia fractures using 22 formaldehyde-fixed tibiae. Their studies show that lateral insertion of the nail usually results in a varus deformity in the fracture as well as a lateral displacement of the distal fragment. The medial insertion has the opposite effect, valgus deformity with medial displacement of the distal fragment.[33]

Kroger et al[34] measured bone mineral density (BMD) using dual x-ray absorptiometry (DXA) at several sites in both fractured and nonfractured limbs in eight patients with femoral shaft fracture and six patients with tibial shaft fracture at the time of the intramedullary nail removal. They conclude that clinically important bone loss up to 21% exist in the distal tibia of the fractured limb. However, BMDs of the fractured side almost reached the baseline level of the nonfractured side (96.9–102.1%) by the final follow-up (>12 months).[34]

In a retrospective study, in which the nail was inserted via a paratendinous incision in 65 fractures and via a tendon-splitting incision in 36 fractures, Keating et al[13] reported that insertion of an intramedullary nail through the patellar tendon resulted in the incidence of knee pain of 50% (33 patients out of 65 fractures), whereas this incidence in the tendon-splitting incision group was 77% (28 patients out of 36 fractures). This difference was significant ($P < 0.01$). They recommended a parapatellar tendon incision for nail insertion. Toivanen et al undertook a prospective randomized study in which they found that chronic anterior knee pain occurred similarly after trans- and paratendinous approach.[16] Karladani and Styf[35] describe an approach in which the skin incision is located on either the medial or lateral side of the patella and the nailing is performed percutaneously. They used this percutaneous technique in 13 patients with an isolated tibial shaft fracture. At the final follow-up of 22 months, all patients were able to kneel on the injured side and no patient had dysfunction of the infrapatellar branch of the saphenous nerve.[35]

The trauma itself and damage to the infrapatellar nerve may also cause anterior knee pain.[36] There is a relationship between injury to the infrapatellar nerve and etiology and natural course of reflex sympathetic dystrophy of the knee.[37] There is a safe area that avoids the infrapatellar nerve; it is within an approximate 30-mm area from the medial margin of the patella at the level of midpatella, and within an approximate 10-mm area from the medial margin of the patellar tendon at the level of the distal pole of the patella.[38] Keating et al reported that the incidence of anterior knee pain is more common among younger than older patients.[13] This may be due to a more sedentary lifestyle of the elderly patients.

Järvelä et al investigated the occurrence and predicting factors of anterior knee pain in patients after an anterior cruciate ligament reconstruction with a bone-patellar tendon-bone autograft.[39] They performed functional, clinical, and radiographic evaluations on 91 patients on average 7 years after the surgery. The most important factor related to the occurrence of anterior knee pain was an extension torque deficit.

An interesting additional finding of our current study was that there were more women than men in the symptomatic group (Table 3). Women have also shown a significantly greater degree of pain after anterior cruciate ligament reconstruction.[40] The reason for this is unknown. Obvious anthropometric and anatomic differences between men and women may explain the female overrepresentation in the symptomatic group. Increased pelvic width and the broader pelvis (Q-angle) move the hip joints further lateral relative to the midline of the body and therefore produce an increased valgus angle from the hip to the knee and then to the ground. In addition, females have a higher prevalence of increased femoral anteversion, which in turn affects the biomechanics of the patellofemoral joint. Also, effects of estrogen hormone on connective tissue synthesis have been recorded with women, and postural and sociologic factors, such as wearing high heels and sitting with legs adducted, can influence the incidence and severity of anterior knee pain in women.[41]

It is also possible that women are more sensitive to feeling pain, or they do more knee-irritating work than men. Overall, there were 1422 tibial shaft fractures in Finland in 1999 (National Research and Development Center for Welfare and Health, Helsinki, Finland). There were 695 males and 471 females of the 1166 patients who were more than 15 years of age. After surgery, women stayed in the hospital an average 16.6 days, whereas men stayed no more than 7.9 days. The reasons for this are unclear but warrant further detailed studies.

Clark et al[42] determined the efficacy of the individual components of physiotherapy with 81 young adults with anterior knee pain. They recorded that proprioceptive muscle stretching and strengthening aspects of physiotherapy had a beneficial effect on anterior knee pain at 3 months sufficient to permit discharge from physiotherapy, these benefits being maintained at 1 year. On the other hand, taping did not influence the outcome.[42]

Bleakney and Maffulli[43] measured quadriceps musculature and atrophy using high-resolution real-time ultrasonography (HRRTU) in 13 skeletally mature male patients with an isolated unilateral diaphyseal fracture of the femur or the tibia. They found clear differences in the quadriceps morphology in

the nailed and unnailed limb following interlocked intramedullary nailing.[43]

Given the above, it is still unclear what is the true causal relationship between the anterior knee pain and the strength deficit in the thigh muscles.

CONCLUSION

Although chronic anterior knee pain is the most common postoperative complication following in nailing procedure of a tibial shaft fracture, it is rarely severe and many patients can return to their previous work and preinjury level of activity. Additionally, the presence of chronic anterior knee pain postoperatively has not hindered the use of intramedullary nails in treatment of tibial shaft fractures.[2,16] The our study has shown that anterior knee pain after intramedullary nailing of a tibial shaft fracture maybe related to deficiencies in the strength of knee flexors. A 13% deficit in knee flexion strength correlated with chronic anterior knee pain.

Further studies regarding surgical techniques of intramedullary nailing, the nails themselves, and knee rehabilitation are warranted to minimize postoperative problems.

REFERENCES

1. Alho A, Ekeland A, Strömsöe K, et al. Locked intramedullary nailing for displaced tibial shaft fractures. *J Bone Joint Surg Br*. 1990;72:805–809.
2. Bone LW, Sucato D, Stegemann PM, et al. Displaced isolated fractures of the tibial shaft treated with either a cast or intramedullary nailing: an outcome analysis of matched pairs of patients. *J Bone Joint Surg Am*. 1997; 79:1336–1341.
3. Court-Brown CM, Christie J, McQueen MM. Closed intramedullary tibial nailing: its use in closed and type I open fractures. *J Bone Joint Surg Br*. 1990;72:605–611.
4. Ekeland A, Thoresen BO, Alho A, et al. Haukeboe: Interlocking intramedullary nailing in the treatment of tibial fractures. *Clin Orthop*. 1988; 231:205–215.
5. Hooper GJ, Keddell RG, Penny ID. Conservative management or closed nailing for tibial shaft fractures. *J Bone Joint Surg Br*. 1991;73:83–85.
6. Karladani HA, Granhed H, Edshage B, et al. Displaced tibial shaft fractures—a prospective randomized study of closed intramedullary nailing versus cast treatment in 53 patients. *Acta Orthop Scand*. 2000;71:160–167.
7. Keating JF, O'Brien PJ, Blachut PA, et al. Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft. *J Bone Joint Surg Br*. 1997;79:334–341.
8. Sarmiento A, Gersten LM, Sobol PA, et al. Tibial shaft fractures treated with functional braces. *J Bone Joint Surg Br*. 1989;71:602–609.
9. Toivanen JAK, Honkonen SE, Koivisto A-M, et al. Treatment of low-energy tibial shaft fractures: plaster cast compared with intramedullary nailing. *Int Orthop*. 2001;25:110–113.
10. Yu SW, Tu YK, Fan KF, et al. Anterior knee pain after intramedullary tibial nailing. *Chang Keng I Hsueh Tsa Chih*. 1999;22:604–608.
11. Court-Brown CM, Gustilo T, Shaw AD. Knee pain after intramedullary tibial nailing: its incidence, etiology and outcome. *J Orthop Trauma*. 1997;11:103–105.
12. Haddad FS, Desai K, Sarkar JS, et al. The AO unreamed nail: friend or foe. *Injury*. 1996;27:261–263.
13. Keating JF, Orfaly R, O'Brien PJ. Knee pain after tibial nailing. *J Orthop Trauma*. 1997;11:10–13.
14. Orfaly R, Keating JF, O'Brien PJ. Knee pain after tibial nailing: does the entry point matter? *J Bone Joint Surg Br*. 1995;77:976–977.
15. Ruiz AL, Kealey W, McCoy GF. Tibial fractures treated by intramedullary nailing in footballers. *J Bone Joint Surg Br*. 1999;81:303.
16. Toivanen JAK, Väistö O, Kannus P, et al. Anterior knee pain after intra-

17. Wiss DA, Stetson WB. Unstable fractures of the tibia treated with a reamed intramedullary interlocking nail. *Clin Orthop*. 1995;315:56–63.
18. Gaston P, Will E, McQueen MM, et al. Analysis of muscle function in the lower limb after fracture of the diaphysis of the tibia in adults. *J Bone Joint Surg Br*. 2000;82:326–331.
19. Holder-Powell HM, Rutherford OM. Unilateral lower limb injury: its long-term effects on quadriceps, hamstring, and plantarflexor muscle strength. *Arch Phys Med*. 1999;80:717–720.
20. Karladani HA, Svantesson U, Granhed H, et al. Postural control and torque of the knee joint after healed tibial shaft fracture. *Injury*. 2001;32:57–60.
21. Nyland J, Bealle DP, Kaufer H, et al. Long-term quadriceps femoris functional deficits following intramedullary nailing of isolated tibial fractures. *Int Orthop*. 2001;24:342–346.
22. Aitken RC. Measurements of feelings using visual analogue scales. *Proc R Soc Med*. 1969;62:989–993.
23. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on the use of scoring scale. *Am J Sports Med*. 1982;10: 150–154.
24. Tegner Y, Lysholm J, Odensten M, et al. Evaluation of cruciate ligament injuries. a review. *Acta Orthop Scand*. 1988;59:336–341.
25. Merchant TC, Dietz FR. Long-term follow-up after fractures of the tibial and fibular shafts. *J Bone Joint Surg Am*. 1989;71A:599–606.
26. Appel HJ. Muscular atrophy following immobilisation. *Int J Sports Med*. 1990;10:42–58.
27. Honkonen SE, Kannus P, Natri A, et al. Isokinetic performance of the thigh muscles after tibial plateau fractures. *Int Orthop*. 1997;21:323–326.
28. Devitt AT, Coughlan KA, Ward T, et al. Patellofemoral contact forces and pressures during intramedullary tibial nailing. *Int Orthop*. 1998;22:92–96.
29. Hernigou P, Cohen D. Proximal entry for intramedullary nailing of the tibia: the risk of unrecognized articular damage. *J Bone Joint Surg Br*. 2000;82:33–41.
30. Tornetta P 3rd, Riina J, Geller J, et al. Intraarticular risks of tibial nailing. *J Orthop Trauma*. 1999;4:247–251.
31. McConnell T, Tornetta P 3rd, Tilzey J, et al. Tibial portal placement: the radiograph correlate of the anatomic safe zone. *J Orthop Trauma*. 2001; 3:207–209.
32. Samuelson MA, McPherson EJ, Norris L. Anatomic assessment of the proper insertion site for a tibial intramedullary nail. *J Orthop Trauma*. 2002;16:23–25.
33. Lembcke O, Ruter A, Beck A. The nail-insertion point in unreamed tibial nailing and its influence on the axial malalignment in proximal tibial fractures. *Arch Orthop Trauma Surg*. 2001;121:197–200.
34. Kroger H, Kettunen J, Bowditch M, et al. Bone mineral density after the removal of intramedullary nails: a cross-sectional and longitudinal study. *J Orthop Sci*. 2002;7:325–330.
35. Karladani HA, Styf J. Percutaneous intramedullary nailing of tibial shaft fractures: a new approach for prevention of anterior knee pain. *Injury*. 2001;9:736–739.
36. Kyrö A, Tunturi T, Soukka A. Conservative treatment of tibial fractures—results in a series of 163 patients. *Ann Chir Gyn*. 1991;80:294–300.
37. Poehling GG, Pollock FE Jr, Wojtys EM. Reflex sympathetic dystrophy of the knee after sensory nerve injury. *Arthroscopy*. 1988;1:31–35.
38. Mochida H, Kikucki S. Injury to infrapatellar branch of saphenous nerve in arthroscopic knee surgery. *Clin Orthop*. 1995;18:88–94.
39. Järvelä T, Kannus P, Järvinen M. Anterior knee pain 7 years after an anterior cruciate ligament reconstruction with bone-patellar tendon-bone autograft. *Scand J Med Sci Sports*. 2000;10:221–227.
40. Asano H, Muneta T, Shinomiya K. Evaluation of clinical factors affecting knee pain after anterior cruciate ligament reconstruction. *Am J Knee Surg*. 2002;1:23–28.
41. Fulkerson JP, Arendt EA. Anterior knee pain in females. *Clin Orthop*. 2000;23:69–73.
42. Clark DI, Downing N, Mitchell J, et al. Physiotherapy for anterior knee pain: a randomized controlled trial. *Ann Rheum Dis*. 2000;9:700–704.
43. Bleakney R, Maffulli N. Ultrasound changes to intramuscular architecture of the quadriceps following intramedullary nailing. *J Sports Med Phys Fit*. 2002;42:120–125.

Anterior Knee Pain After Intramedullary Nailing of a Tibial Shaft Fracture

An Ultrasound Study of the Patellar Tendons of 36 Patients

Olli Väistö, MD,*† Jarmo Toivanen, MD,*† Timo Paakkala, MD,*‡ Timo Järvelä, MD,*†
Pekka Kannus, MD,*§ and Markku Järvinen, MD*†

Objectives: Chronic anterior knee pain is a common complication following intramedullary nailing of a tibial shaft fracture. The etiology of pain is often not known. This study sonographically examined the patellar tendons of patients with a nailed tibial shaft fracture.

Design: Prospective study.

Setting: University hospital.

Patients: Fifty consecutive patients with a nailed tibial shaft fracture were initially included in the study. Thirty-six of them could be measured at an average of 2.5 ± 0.5 years after nail insertion (1.0 ± 0.3 years after nail extraction).

Intervention: Reamed intramedullary nailing with 2 interlocking bolts at both ends of the nail (Grosse-Kempf-nail, Howmedica).

Main Outcome Measurements: The ultrasound investigation of the patellar tendons of the 36 patients.

Results: Twelve (33%) patients were painless and 24 (67%) patients had anterior knee pain at follow-up. With the reference to the mean difference in the thickness of the distal part of the patellar tendon in the operated limb versus nonoperated limb, the result was 1.4 ± 1.1 mm in the chronic pain group and 2.6 ± 2.5 mm in the painless group (P = 0.135, [95% confidence interval for the group difference = −0.4–2.8]). The corresponding values for the proximal part of the patellar tendon was 1.4 ± 1.3 mm in the chronic pain group and 2.3 ± 2.3 mm in the painless group (P = 0.251, [95% confidence interval for the group difference = −0.7–2.4]). There were no statistically significantly differences between study groups in the blood circulation of the patellar tendon or at the entry point, calcification of the patellar tendon, granulation tissue at the entry point, or occurrence of low echo areas in the patellar tendon.

Conclusion: After intramedullary nailing of a tibial shaft fracture, patients with or without anterior knee pain show similar changes in the ultrasound investigation of their patellar tendons. Based on those findings, it does not appear to make any difference as to the approach used (paratendinous or transtendinous) for intramedullary nailing of the tibia.

Key Words: tibial fracture, intramedullary nailing, anterior knee pain, patellar tendon changes, ultrasound

Many studies have shown that the outcome of treatment of a tibial shaft fracture using locked intramedullary nailing is superior to that of cast treatment.[1–11] After the surgery, complaints of anterior knee pain exacerbated by walking, kneeling, squatting, and stair climbing are common.[5,9,12,13] Anterior knee pain has also been reported following reconstruction of the ruptured anterior cruciate ligament.[4,14] Ligament instability, retropatellar fat necrosis and irritation, meniscal and cartilage damage, gait changes, tendonitis, and inadequate neuromuscular rehabilitation have been suggested as possible causes. Thigh muscle strength deficits has also been reported after intramedullary nailing of tibial shaft fractures.[13,15] However, the true etiology of the most common postoperative problem, chronic anterior knee pain following tibial intramedullary nailing, is still unknown.

A few studies have used ultrasound for monitoring fracture healing after intramedullary nailing of a tibial fracture.[16–18] However, there is only 1 published ultrasound study that looked at chronic anterior knee pain after intramedullary nailing of a tibial shaft fracture. In this retrospective study by Sala et al,[19] the intramedullary nails were still in place at the time of the ultrasound study. The authors reported that the index patellar tendon was thickened compared with the contralateral tendon, but there was no relationship between tendon morphology and structure and chronic anterior knee pain.[19]

The purpose of this study was to find out whether there is an association between sonographic changes in the patellar tendon and occurrence of chronic anterior knee pain in patients with a nailed tibial shaft fracture, in which the ultrasound measurements are done after nail extraction. The question to be answered is whether or not there is something that we can avoid in intramedullary nailing of tibial shaft fracture that can prevent chronic anterior knee pain postoperatively.

MATERIALS AND METHODS

Fifty consecutive patients [23 men and 27 women, mean age of 42 ± 5 (SD) years] with an isolated tibial shaft fracture who were treated with a reamed intramedullary nail with 2 interlocking bolts at both ends of the nail (Grosse-Kempf-nail, Howmedica) between July 1996 and January 1998 formed the basic population of this prospective follow-up study. The inclusion criteria included age of 15 years or more, absence of any major comorbidities, and absence of any fracture line extending up to the knee joint or down to the ankle joint. No patient had previous injuries or symptoms related to either extremity. All patients were informed of the study procedure, purposes, and known risks, and all gave written informed consent. After they gave informed consent, the patients were randomized using sealed envelopes into to 1 of 2 operation groups (closed nailing with use of a transtendinous approach or closed nailing with use of a paratendinous approach).

The patients were divided postoperatively into 2 groups during the study depending on the presence or absence of chronic anterior knee pain: 1) the symptomatic group (patients having chronic anterior knee pain); and 2) the asymptomatic group (patients without chronic anterior knee pain, including visual analogue scale [VAS] scores <10).

Two patients were excluded from the study in the early phase of treatment because the nail had to be removed due to a deep infection. Two patients died during follow-up from causes not related to the tibial shaft fracture. Two patients were initially managed with a cast and then treated by nailing at the time of corrective osteotomy (the first one 6 months, and the second one 18 months after the injury), and they were also excluded from the study. In addition, we were unable to locate and contact 4 patients for the follow-up ultrasound examination, and for unknown reasons, 4 patients never attended the ultrasound investigation. Thus, the final number of patients available for ultrasound investigation was 36.

The intramedullary nailing procedure for acute fractures was performed within 24 hours in 42 patients and between 1 and 12 days in 6 patients. A tourniquet was not used during the operation. The incision for the transtendinous approach was made longitudinally through the midline of the patellar tendon for a distance of 3 to 5 cm. After insertion of nail, the incision was closed with interrupted sutures. In the paratendinous approach, a medial longitudinal incision was made, with care taken not to violate the patellar tendon or its sheath. For all patients, standard proximal and distal locking screws were used. All nails were countersunk below the cortical bone of the proximal tibia. Postoperative immobilization in a cast or brace was not used. Patients were not allowed weight bearing on the operated side until 6 weeks postsurgery, then partial weight bearing on that side for the next 6 weeks, then full weight bearing after 12 weeks postsurgery. All patients were given instructions for thigh muscle rehabilitation preoperatively in the hospital, but no formal physiotherapy was done after intramedullary nailing. Nails were routinely removed regardless of the presence or absence of knee pain, approximately 1.5 years after the nailing, using the same entry incision and approach that was used for the nail insertion. Routine removal of the nail was common practice in Finland during the time of this study. Five patients refused nail extraction, because the nail did not bother them at all during daily activities (2 patients in the pain group and 3 patients in the painless group). After removal of the intramedullary nail, neither instructions for thigh muscle rehabilitation nor physiotherapy were given.

All ultrasound and Power Doppler evaluations of the patellar tendons were done by an experienced senior radiologist from the Department of Radiology. The radiologist was blinded to the clinical results. All ultrasound investigations were performed using an Acuson 512 Ultrasound system and Power Doppler technique (Acuson Sequoia, Mountain View, CA) with a 7.5-MHz real-time linear array transducer (8L5 38-mm linear Multihertz, Acuson). Patients were in a sitting position with the knee joint at 30° of flexion for the examination. Measured parameters were calcification of the patellar tendon, granulation tissue at the nail entry point, and hypoechoic lesions of the patellar tendon. Power Doppler was used to measure the blood flow of the patellar tendon and at the entry point. Lastly, the thickness of the distal and proximal parts of the patellar tendon in the operated limb and nonoperated limb were determined.

Along with the ultrasound investigation, the patients graded their chronic anterior knee pain during rest, walking, running, squatting, kneeling, stair climbing, stair descent, and after long-term sitting on a 100-mm VAS,[20] with 0 denoting no pain and 100 denoting the worst pain that the patient could imagine.

To describe the data, the mean (SD) and the 95% confidence interval (CI) of the differences between the groups are reported for the continuous variables. Differences between the pain and painless groups were tested using the Mann-Whitney U test for the continuous variables because the distributions were skewed. The reporting also included 95% CI for the differences. The differences between categorized variables were tested using the Fisher exact test. The statistical analysis was carried out using the SPSS for Windows program (Version 11.0; SPSS Inc. Chicago, IL). Throughout the study, a P value of <0.05 was considered statistically significant.

RESULTS

Of the 36 patients, none had a surgical complication, such as patellar tendon rupture, compartment syndrome, or broken device. The study groups were comparable with respect to age, body mass index (BMI), nail protrusion, nail-plateau distance, and nail insertion and removal, but there were more women than men in the symptomatic group (Fisher exact test, $P = 0.07$) (Table 1).

The ultrasound investigations were done an average 2.5 ± 0.5 years after nail insertion and 1.0 ± 0.3 years after nail extraction. Twelve (33%) patients were pain free, and 24 (67%) patients had chronic anterior knee pain at the follow-up. The pain was worst on kneeling and ascent of stairs (Table 2). In general, however, the symptoms were classified as minor because no patient was symptomatic during daily activities and no patient had received surgical treatment or physiotherapy for the problem of anterior knee pain. Also, no patient took medication on a regular basis to alleviate the pain. There were no statistically significantly differences between study groups

TABLE 1. Basic Characteristics of Patients With and Without Anterior Knee Pain After Intramedullary Nailing of a Tibial Shaft Fracture

	No Anterior Knee Pain (n = 12)	Anterior Knee Pain (n = 24)	P
BMI (kg/m^2)	26.2 ± 2.9	25.3 ± 5.3	0.835*
Age (yrs)	44 ± 14	42 ± 13	0.370*
Gender			0.08†
Female	2 (17%)	12 (50%)	
Male	10 (83%)	12 (50%)	
Nail insertion			0.481†
Transtendinous	8 (67%)	12 (50%)	
Paratendinous	4 (33%)	12 (50%)	
Protrus (mm)‡	5.4 ± 3.2	4.9 ± 4.1	0.825*
Plateau (mm)§	8.9 ± 9.3	12.5 ± 9.6	0.231*
Nail removal	10 (83%)	21 (88%)	0.581*

*Mann-Whitney test.
†Fisher exact test.
‡Nail protrusion.
§Nail plateau distance.

in blood circulation at the patellar tendon or nail entry point, calcification of the patellar tendon, granulation tissue at the entry point, or occurrence of hypoechoic lesions of the patellar tendon (Table 3). There were no statistical significant differences in the patellar tendon thickness between the 2 different nail entry sites, (paratendinous or transtendinous approach) (Table 4), although the patellar tendon was somewhat thicker in the transtendinous approach (Table 4). This, however, did not explain the between-group difference in the occurrence of the chronic anterior knee pain (Table 1). With reference to the difference of thickness of the distal part of the patellar tendon in the operated versus nonoperated limb, the mean difference was 1.4 ± 1.1 mm in the chronic pain group and 2.6 ± 2.5 mm in the painless group (P = 0.135 [95% CI for the group difference = −0.4–2.8]) (Table 3). The mean difference at the proximal part of the patellar tendon was 1.4 ± 1.3 mm in the chronic pain group and 2.3 ± 2.3 mm in the painless group (P = 0.251 [95% CI for the group difference = −0.7–2.4]), respectively (Table 3).

Using an alpha level of less than 5% (P < 0.05) and using this 1.2-mm difference between the means, the final

TABLE 2. Mean (SD) Intensity of Anterior Knee Pain During Various Activities Among Those Who Reported Pain

Activity	Intensity of Anterior Knee Pain*
Rest	26 (±9), n = 3
Walking	33 (±11), n = 3
Running	47 (±19), n = 4†
Squatting	40 (±23), n = 11
Kneeling	54 (±31), n = 26
Stairs down	58 (±22), n = 4
Stairs up	41 (±16), n = 5
After long-term sitting	23 (±12), n = 5

*Visual analogue scale (0, no pain; 100, worst possible pain).
†Four patients had not started running activity.

number of patients per group (12 and 24) gave a minimum 85% statistical power for the study.

DISCUSSION

It is apparent from the literature that the source of chronic anterior knee pain after intramedullary nailing of a tibial shaft fracture is multifactorial. Devitt et al[21] demonstrated in 8 cadaveric knees that the insertion of an intramedullary nail in the tibia significantly increases contact pressures at the patellofemoral joint.[21] They used 2 different approaches: medial paratendinous and transtendinous. A significant increase in contact pressures was found at the lateral facets of the patella using the medial paratendinous approach and at the medial facet when using the transtendinous approach to the proximal tibia. With the transtendinous approach, the contact pressure increases on both facets suggested that chondral injury is more likely with the transtendinous approach.[21] Lembcke et al[22] showed that lateral insertion of the nail usually results in a varus deformity in the fracture as well as a lateral displacement of the distal fragment. The medial insertion has the opposite effect: valgus deformity with medial displacement of the distal fragment.[22]

Hernigou and Cohen[12] showed that the intra-articular structures particularly at risk for damage during tibial nailing are the medial meniscus, the lateral tibial plateau, and the transverse ligament. Their results demonstrated that in some bones, the safe zone is smaller than the size of standard reamers and the proximal part of some nails. Tornetta et al[23] also studied intra-articular anatomic risks of tibial nailing.[23] A lateral paratendinous approach placed the lateral articular surface, and a medial approach the medial meniscus, at the highest risk. They determined a safe zone for portal placement, which was located 9.1 ± 5 mm lateral to the midline of the plateau and 3 mm lateral to the center of tibial tubercle. The width of the safe zone averaged 22.9 mm and was as narrow as 12.6 mm.[23]

McConnell et al[24] also investigated the radiographic correlate of the anatomic safe zone in the intramedullary nailing of tibia in 20 cadaveric knees. The safe zone for tibial nailing as seen on radiographs was just medial to the lateral tibial spine on the anteroposterior (AP) view and immediately adjacent and anterior to the articular surface as visualized on the lateral radiograph.[24] Samuelson et al's[25] findings support using a medial paratendinous or transtendinous approach for nail insertion while avoiding insertion sites lateral to the tibial tubercle.[25] There is a safe area that avoids the infrapatellar nerve; it is within an approximate 30-mm area from the medial margin of the patella at the level of the midpatella, and within an approximate 10-mm area from the medial margin of the patellar tendon at the level of the distal pole of the patella.[16]

In a retrospective study, in which the nail was inserted via a paratendinous incision in 65 fractures and via a tendon-splitting incision in 36 fractures, Keating et al[26] reported that insertion of an intramedullary nail through the paratendinous incision resulted in a 50% incidence of knee pain (33 patients out of 65 fractures), whereas this incidence in the transtendinous incision group was 77% (28 patients out of 36 fractures). This difference was statistically significant. They

TABLE 3. Patients With and Without Anterior Knee Pain: Ultrasound Measurements and Difference in the Patellar Tendon Thickness Between the Operated and Nonoperated Limbs

	No Anterior Knee Pain (n = 12)	Anterior Knee Pain (n = 24)	*P*	95% CI
Calcification				
Yes	7 (58%)	11 (46%)	0.725*	
No	5 (42%)	13 (54%)		
Hypoechoic lesion				
Yes	7 (58%)	15 (63%)	1.000*	
No	5 (42%)	9 (37%)		
Granulation at the nail entrypoint				
Yes	2 (17%)	7 (29%)	0.685*	
No	10 (83%)	17 (71%)		
Circulation in the patellar tendon				
Yes	3 (25%)	2 (8%)	0.307*	
No	9 (75%)	22 (92%)		
Circulation at the entry point of the tendon				
Yes	2 (17%)	4 (17%)	1.000*	
No	10 (83%)	20 (83%)		
Thickness difference at the distal part of the patellar tendon (mm)	2.6 ± 2.5	1.4 ± 1.1	0.135†	−0.4 to 2.8
Thickness difference at the proximal part of the patellar tendon (mm)	2.3 ± 2.3	1.4 ± 1.3	0.251†	−0.7 to 2.4

*Fisher exact test.
†Mann-Whitney test.

recommended a paratendinous incision for nail insertion, which they had also recommended earlier.[27] Toivanen et al[28] undertook a prospective randomized study in which they found that chronic anterior knee pain occurred similarly after transtendinous and paratendinous approaches.[28] Karladani and Styf[29] describe an approach in which the skin incision is located on either the medial or lateral side of the patella and the nailing is performed percutaneously. They used this percutaneous technique in 13 patients with an isolated tibial shaft fracture. At the final follow-up of 22 months, all patients were able to kneel on the injured side and no patient had dysfunction of the infrapatellar branch of the saphenous nerve.[29]

Lastly, Bennel et al[30] shows that injection of 0.20 to 0.25 mL of 5% hypertonic saline into the medial infrapatellar fat pad produces moderate to severe pain in the anterior knee region. The effects appear to be due to chemical irritation from the hypertonic saline of the nociceptors within the fat pad.[30]

In our study, there were no statistical significant differences in patellar tendon thickness between the entry point using either the paratendinous approach or transtendinous approach. However, the patellar tendon was thicker in the transtendinous group, but this factor alone did not explain the occurrence of the chronic anterior knee pain. There were no statistically significantly differences between the 2 approaches in blood circulation of the patellar tendon and the entry point, calcification of the patellar tendon, granulation of the entry point, or hypoechoic lesions of the patellar tendon. Our

prospective study also showed that both approaches are safe to use in an intramedullary nailing of a tibial shaft fracture.

Sala et al[19] retrospectively investigated chronic anterior knee pain after intramedullary nailing. They did an ultrasound examination on an average 10.9 months after surgery and used the patellar transtendinous access in each case. However, in their study, the intramedullary nails were still in place at the time of the ultrasound examination. They recorded nail-tendon impingement frequently, but this did not achieve statistical significance. The patellar tendon was thickened as compared to the contralateral one. The tendinous morphostructure did not reveal any correlation with the chronic anterior knee pain.[19] As noted above, also in our prospective study, there were no statistical differences between study groups in blood circulation of the patellar tendon and nail entry point, calcification of the patellar tendon, granulation tissue at the entry point, and hypoechoic lesions of the patellar tendon. Also, there were no statistical significant differences between the thicknesses in the distal or proximal parts of the patellar tendon. There were 5 patients who did not have nail removal, because the nail did not bother them (2 out of 12, 17%, in the pain group and 3 out of 24, 12.5%, in the painless group). We evaluated our data with and without these 5 patients and their ultrasonographic changes, and there were no statistically significant changes in our results.

Järvelä et al[14] did ultrasound and Power Doppler evaluation of the remaining patellar tendon after harvesting its central third for reconstruction of the anterior cruciate

TABLE 4. Patients Operated on With the Transtendinous or Paratendinous Technique: Ultrasound Measurements and Difference in the Patellar Tendon Thickness Between Operated and Non Operated Limbs

	Transtendinous (n = 20)	Paratendinous (n = 16)	*P*	95% CI
Calcification				
Yes	13 (65%)	5 (31%)	0.092*	
No	7 (35%)	11 (69%)		
Hypoechoic lesion				
Yes	13 (65%)	9 (81%)	0.734*	
No	7 (35%)	7 (19%)		
Granulation at the entry point of the nail				
Yes	7 (35%)	2 (13%)	0.245*	
No	13 (65%)	14 (87%)		
Blood circulation at the patellar tendon				
Yes	3 (15%)	2 (13%)	1.000*	
No	17 (85%)	14 (87%)		
Blood circulation at the entry point of the nail				
Yes	5 (25%)	1 (6%)	0.196*	
No	15 (75%)	15 (94%)		
Thickness difference at the distal part of the patellar tendon (mm)	2.2 ± 2.0	1.4 ± 1.2	0.179†	−0.4 to 2.0
Thickness difference at the proximal part of the patellar tendon (mm)	2.0 ± 2.1	1.2 ± 1.1	0.173†	−0.4 to 2.0

*Fisher exact test.
†Mann-Whitney test.

ligament. Morphologic changes were very common; only 3 patients (9.7%) had no ultrasound changes. However, there were no differences in the morphologic changes between the patients with or without chronic anterior knee pain.[14]

Interindividual variation exists in the anatomic relationship between the patellar tendon and the lateral tibial spine. Althausen et al[31] stated that individual variations in the patellar tendon should be considered when choosing the proper entry site for tibial nailing, and the routine use of a single approach for all tibial nails may no longer be justified. Further, a preoperative fluoroscopic measurement before incision can guide the surgeon as to whether a medial paratendinous, transtendinous, or lateral paratendinous approach provides the best and most direct access to the entry site. Based on their study, the safest entry point for tibial nail is just medial to the tibial spine at the anterior margin of the articular surface.[31]

Given all the above, it is still unclear what the true causal relationships are among the surgical approach for nail insertion, postoperative patellar tendon changes, and chronic anterior knee pain. After intramedullary nailing of a tibial shaft fracture, there was no ultrasonographic anatomic differences in the patellar tendons of patients with or without chronic anterior knee pain. In conclusion, our study suggests that it seems safe to use either a paratendinous or transtendinous approach for intramedullary nail insertion.

REFERENCES

1. Alho A, Ekeland A, Strömsöe K, et al. Locked intramedullary nailing for displaced tibial shaft fractures. *J Bone Joint Surg Br*. 1990;72:805–809.
2. Bone LW, Sucato D, Stegemann PM, et al. Displaced isolated fractures of the tibial shaft treated with either a cast or intramedullary nailing: an outcome analysis of matched pairs of patients. *J Bone Joint Surg Am*. 1997;79:1336–1341.
3. Court-Brown CM, Christie J, McQueen MM. Closed intramedullary tibial nailing: its use in closed and type I open fractures. *J Bone Joint Surg Br*. 1990;72:605–611.
4. Court-Brown CM, Gustilo T, Shaw AD. Knee pain after intramedullary tibial nailing: its incidence, etiology and outcome. *J Orthop Trauma*. 1997;11:103–105.
5. Ekeland A, Thoresen BO, Alho A, et al. Interlocking intramedullary nailing in the treatment of tibial fractures. *Clin Orthop*. 1988;231:205–215.
6. Hooper GJ, Keddell RG, Penny ID. Conservative management or closed nailing for tibial shaft fractures. *J Bone Joint Surg Br*. 1991;73:83–85.
7. Karladani HA, Granhed H, Edshage B, et al. Displaced tibial shaft fractures—a prospective randomised study of closed intramedullary nailing versus cast treatment in 53 patients. *Acta Orthop Scand*. 2000;71:160–167.
8. Keating JF, O'Brien PJ, Blachut PA, et al. Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft. *J Bone Joint Surg Br*. 1997;79:334–341.
9. Sarmiento A, Gersten LM, Sobol PA, et al. Tibial shaft fractures treated with functional braces. *J Bone Joint Surg Br*. 1989;71:602–609.
10. Toivanen JAK, Honkonen SE, Koivisto A-M, et al. Treatment of low-energy tibial shaft fractures: plaster cast compared with intramedullary nailing. *Int Orthop*. 2001;25:110–113.
11. Yu SW, Tu YK, Fan KF, et al. Anterior knee pain after intramedullary tibial nailing. *Chang Keng I Hsueh Tsa Chih*. 1999;22:604–608.

12. Hernigou P, Cohen D. Proximal entry for intramedullary nailing of the tibia: the risk of unrecognised articular damage. *J Bone Joint Surg Br.* 2000;82:33–41.
13. Väistö OP, Toivanen JAK, Kannus P, et al. Anterior knee pain and thigh muscle strength after intramedullary nailing of tibial shaft fractures. A report of 40 consecutive cases. *J Orthop Trauma.* 2004;18:18–23.
14. Järvelä T, Paakkala T, Kannus P, et al. Ultrasonographic and power doppler evaluation of the patellar tendon ten years after harvesting its central third for reconstruction of the anterior cruciate ligament. Comparison of patients without or with anterior knee pain. *Am J Sports Med.* 2004;32:39–46.
15. Nyland J, Bealle DP, Kaufer H, et al. Long-term quadriceps femoris functional deficits following intramedullary nailing of isolated tibial fractures. *Int Orthop.* 2001;24:342–346.
16. Moed BR, Watson JT, Goldschmidt P, et al. Ultrasound for the early diagnosis of fracture healing after interlocking nailing of the tibia without reaming. *Clin Orthop.* 1995;310:137–144.
17. Moed BR, Subramanian S, van Holsbeeck M, et al. Ultrasound for the early diagnosis of tibial fracture healing a static interlocked nailing without reaming: clinical results. *J Orthop Trauma.* 1998;12:206–213.
18. Moed BR, Kim EC, van Holsbeeck M, et al. Ultrasound for the early diagnosis of tibial fracture healing a static interlocked nailing without reaming: histologic correlation using a canine model. *J Orthop Trauma.* 1998;12:200–205.
19. Sala F, Binda M, Lovisetti G. Anterior gonalgic syndrome after intramedullary nailing: ultrasound and radiologic study. *Chir Organi Mov.* 1998;83:271–275.
20. Aitken RC. Measurements of feelings using visual analogue scales. *Proc R Soc Med.* 1969;62:989–993.
21. Devitt AT, Coughlan KA, Ward T, et al. Patellofemoral contact forces and pressures during intramedullary tibial nailing. *Int Orthop.* 1998;22:92–96.
22. Lembcke O, Ruter A, Beck A. The nail-insertion point in unreamed tibial nailing and its influence on the axial malalignment in proximal tibial fractures. *Arch Orthop Trauma Surg.* 2001;121:197–200.
23. Tornetta P, 3rd, Riina J, Geller J, et al. Intra-articular risks of tibial nailing. *J Orthop Trauma.* 1999;13:247–251.
24. McConnell T, Tornetta P 3rd, Tilzey J, et al. Tibial portal placement: the radiograph correlate of the anatomic safe zone. *J Orthop Trauma.* 2001;15:207–209.
25. Samuelson MA, McPherson EJ, Norris L. Anatomic assessment of the proper insertion site for a tibial intramedullary nail. *J Orthop Trauma.* 2002;16:23–25.
26. Keating JF, Orfaly R, O'Brien PJ. Knee pain after tibial nailing. *J Orthop Trauma.* 1997;11:10–13.
27. Orfaly R, Keating JF, O'Brien PJ. Knee pain after tibial nailing: does the entry point matter? *J Bone Joint Surg Br.* 1995;77:976–977.
28. Toivanen JAK, Väistö O, Kannus P, et al. Anterior knee pain after intramedullary nailing of fractures of the tibial shaft: a prospective, randomized study comparing two different nail-insertion techniques. *J Bone Joint Surg Am.* 2002;4:580–585.
29. Karladani HA, Styf J. Percutaneous intramedullary nailing of tibial shaft fractures: a new approach for prevention of anterior knee pain. *Injury.* 2001;9:736–739.
30. Bennell K, Hodges P, Mellor R, et al. The nature of anterior knee pain following injection of hypertonic saline into the infrapatellar fat pad. *J Orthop Res.* 2004;22:116–121.
31. Althausen PL, Neiman R, Finkemeir CG, et al. Incision placement fot intramedullary tibial nailing: an anatomic study. *J Orthop Trauma.* 2002;16:687–690.

Anterior Knee Pain and Thigh Muscle Strength After Intramedullary Nailing of a Tibial Shaft Fracture: An 8-Year Follow-up of 28 Consecutive Cases

Olli Väistö, MD,*† Jarmo Toivanen, MD,*‡ Pekka Kannus, MD,*§ and Markku Järvinen, MD*‡

Objectives: Chronic anterior knee pain is a common complication after intramedullary nailing of a tibial shaft fracture. The source of pain is often not known, although it correlates with a simultaneous decrease in thigh muscle strength. No long-term follow-up study has assessed whether weakness of the thigh muscles is associated with anterior knee pain after the procedure in question.

Design: Prospective study.

Setting: University Hospital of Tampere, University of Tampere.

Patients: The muscular performance of 40 consecutive patients with a nailed tibial shaft fracture was tested isokinetically in a follow-up examination an average of 3.2 ± 0.4 (SD) years after the initial surgery. An 8-year follow-up was possible in 28 of these cases.

Main Outcome Measurements: Isokinetic muscle strength measurements were made in 28 patients at an average 8.1 ± 0.3 (SD) years after nail insertion and an average 6.6 ± 0.3 (SD) years after nail extraction. All nails were extracted at an average 1.6 ± 0.2 years after the nailing.

Results: Seven patients were painless initially and still were at final follow-up (never pain, or NP). In 13 patients, the previous symptom of anterior knee pain was no longer present at final follow-up [pain, no pain (PNP)], and the remaining 8 had anterior knee pain initially and at final follow-up [always pain group (AP)]. With reference to the hamstring muscles, the mean peak torque difference between the injured and uninjured limb was −2.2% ± 12% in the NP group, 1.6% ± 15% in the PNP group, and 10.3% ± 30% in the AP group at a speed of 60 degrees/second (Kruskal-Wallis test; $\chi^2 = 1.0$; $P = 0.593$). At a speed of 180 degrees/second, the corresponding differences were −2.9% ± 23% and 7.0% ± 19% and 4.4% ± 16% (Kruskal-Wallis test; $\chi^2 = 1.7$; $P = 0.429$). With reference to the quadriceps muscles, the mean peak torque difference was −2.8% ± 9% in the NP group, 5.9% ± 15% in the PNP group, and −13.0% ± 16% in the AP group at a speed of 60 degrees/second (Kruskal-Wallis test; $\chi^2 = 7.9$; $P = 0.019$). At 180 degrees/second, the corresponding differences were −9.4% ± 13% and 4.9% ± 16% and −1.9% ± 9%, respectively (Kruskal-Wallis test; $\chi^2 = 4.8$; $P = 0.092$).

Conclusion: Based on this prospective long-term follow-up study, it appears that the anterior knee pain symptoms that are present after intramedullary nailing of a tibial shaft fracture disappear in a number of patients 3 to 8 years after surgery. Quadriceps, but not hamstring weakness, and lower functional knee scores are associated with anterior knee pain at 8 years.

Key Words: tibial fracture, intramedullary nailing, anterior knee pain, thigh muscle strength, long-term follow-up

(J Orthop Trauma 2007;21:165–171)

INTRODUCTION

A number of studies have shown that the outcome of treatment of a tibial shaft fracture using locked intramedullary nailing is superior to that of cast treatment.[1–8] It is accepted that the main complication associated with intramedullary nailing is knee pain.[9–13] However, the cause of this most common postoperative problem, that is, chronic anterior knee pain, is still unknown. Thigh muscle deficit after tibial fracture has been reported in several articles.[6,14–16] Nyland et al[17] recorded an average 25% extensor and 17% flexor torque deficit in the operated limb more than 1 year (18 ± 6 months) after intramedullary nailing of isolated tibial fractures. In a previous investigation from our institution, the weakness of the thigh muscles was associated with chronic anterior knee pain after intramedullary nailing of tibial shaft fractures.[13]

The first goal of this prospective 8 year follow-up study was to establish whether patients treated with intramedullary nailing for a tibial shaft fracture and who had postoperative anterior knee pain also had associated thigh muscle weakness and decreased functional knee scores at long-term follow-up. The second purpose was to determine the presence or absence of anterior knee pain before and after removal of the intramedullary nail during the same long-term follow-up period. Our hypotheses were that anterior knee pain is associated with thigh muscle strength and that the long-term functional outcome would be better than the short-term functional outcome.

PATIENTS AND METHODS

Fifty consecutive patients [23 men and 27 women; mean age 42 ± 5 (SD) years] with an isolated tibial shaft fracture were treated with a reamed intramedullary nail with 2 interlocking bolts at both ends of the nail (Grosse-Kempf nail; Howmedica, Rutherford, New Jersey) at Tampere University Hospital, Tampere, Finland, between July 1996 and January 1998 and enrolled in this prospective study. Inclusion criteria were the following: age 15 years or older, absence of any major comorbidities, and absence of any fracture line extending proximally into the knee joint or distally into the ankle joint. No patient had previous injuries or symptoms related to either extremity. All were informed of the study procedure, purposes, and known risks, and all gave written informed consent. The study was conducted in conformity with the principles of the Declaration of Helsinki and approved by our institutional ethics committee. Patients were divided postoperatively into 3 groups, depending on the development of chronic anterior knee pain. (1) symptomatic [patients experiencing chronic anterior knee pain or pain, no pain (PNP), and always pain (AP)] and (2) asymptomatic [patients with no chronic anterior knee pain (never pain, NP)]. Two patients were excluded from the study in the early phase of treatment because the nail had to be removed due to a deep infection, leaving 48 patients in the study.

Intramedullary nailing was performed within 24 hours in 42 patients and between 1 and 12 days in 6. A tourniquet was not used during the operation. The patients were randomized, with use of sealed envelopes, into one of 2 groups: closed nailing with use of a patellar tendon-splitting (transtendinous) approach (25 patients) or closed nailing with use of a paratendinous approach (25 patients). The incision for the transtendinous approach was made longitudinally through the midline of the patellar tendon for a distance of 3 to 5 cm. After insertion of the nail, the incision was closed with interrupted sutures. In the paratendinous approach, a medial longitudinal incision was made, care being taken not to violate the patellar tendon or its sheath. In all cases, standard proximal and distal locking screws were used. All nails were countersunk below the cortical bone of the proximal tibia. Postoperative immobilization in a cast or brace was not used. Patients were allowed to progress to 1-leg weight-bearing 6 weeks (leg weight to operative side) and to full weight-bearing 12 weeks postsurgery. All patients received instructions on thigh muscle rehabilitation in the hospital, but no formal physiotherapy was instituted at any time after initial surgery. Nails were routinely removed regardless of the presence or absence of knee pain, on the average 1.6 ± 0.2 years after insertion, using the same entry incision and approach as in nail insertion. After removal of the nail, no instructions on either thigh muscle rehabilitation or physiotherapy were given.

There were 40 patients in the first isokinetic muscle-strength check-up an average 3.2 ± 0.4 (SD) years after the surgery (see our previous article, Väistö et al[13]). Two patients subsequently died from causes not related to the tibial shaft fracture. Five patients sustained a new trauma or acute heart or lung disease and were excluded from the study. Three patients refused further follow-up. Last, 2 patients could not be found

for the 8 year follow-up examination. Thus, 28 patients were available for isokinetic strength testing and pain evaluation at 8 years (average, 8.1 ± 0.3 years after nailing).

The first isokinetic quadriceps and hamstring strength testing was performed using the Cybex system (Cybex 6000; Lumex, Inc, New York, NY). The current long-term check-up was conducted using the Dyna-Com system (Dyna-Com 650; Oy Diter-Elektroniikka Ab). Both tests were made by the same physician, who was not a part of the surgical team.

Before the tests, the patients did warming-up exercise on an ergometer bicycle for 5 minutes and then were fastened to the isokinetic device with straps around the chest, pelvis, thigh, and malleoli. Before testing, the patient was instructed to perform a sufficient number of submaximal and maximal repetitions of knee extension and flexion at both test velocities (60 and 180 degrees/second) to become familiar with the machine. The actual test included knee joint extension and flexion with both legs at these 2 angular velocities. Range of movement was 90 degrees (0–90 degrees). The test included 5 maximal repetitions at both speeds, with a 30 second rest between the 2. Each patient was verbally encouraged to do her or his best. The repetition during which the maximal peak torque was produced was recorded.

Concurrent with the isokinetic testing, the patients graded chronic anterior knee pain during rest, walking, running, squatting, kneeling, stair climbing, and stair descent, and after long-term sitting, on a 100 mm visual-analog scale,[18] with 0 denoting no pain and 100 denoting the worst pain the patient could imagine. All patients also completed standardized knee-scoring scales, as described by Lysholm and Gillquist[19] and Tegner et al.[20] The Iowa Knee Score questionnaire[21] was also completed. All patient interviews were made by the same physician on both occasions.

Statistics

To describe the data, means (SD) are reported for the continuous variables. The mean deficit in thigh muscle strength in the operated limb was compared to the nonoperated limb and reported as a percentage. Because of skewness in data distribution, the differences between the groups were tested using the Kruskal-Wallis test for continuous variables. The differences between categorized variables were tested by χ^2 test.

The original power calculations suggested that, applying less than 5% probability of a type I error ($P < 0.05$) and a power analysis with 80% power, type II error ($P < 0.20$), a sample size of 18 patients (9 patients per group) was necessary to detect a 15% muscle strength difference between the 2 study groups.[13] This 15% was considered a clinically relevant difference because the strength and function of thigh muscles seem to be up to 85% of normal 1 year after fracture of the diaphysis of the tibia,[14] and thigh muscle strength deficits have been reported to be 17% to 25% after intramedullary nailing of isolated tibial fractures.[17]

The statistical analysis was carried out using the SPSS for Windows program (version 12.0; SPSS Inc). Throughout the study, $P < 0.05$ was considered statistically significant.

RESULTS

Of these 40 patients, there were no complications such as deep or superficial infections, patellar tendon rupture, compartment syndrome, or broken hardware; 35 reported anterior knee pain before nail removal on average 1.6 ± 0.2 years after nail insertion. Nineteen (54%) had complete or marked resolution of pain after nail extraction. The first isokinetic quadriceps and hamstring strength test was performed an average of 3.2 ± 0.4 years after nail insertion and 1.7 ± 0.3 years after extraction. Of the remaining 28 patients, 7 (25%) patients were painless and 21 (75%) had reported chronic anterior knee pain at the first follow-up (for details, see our previous article, Väistö et al[13]). The long-term follow-up test was performed an average of 8.1 ± 0.3 years after nail insertion and 6.6 ± 0.3 years after nail extraction (Table 1). Twenty (71%) patients were painless, and only 8 (29%) complained of chronic anterior knee pain at the final check-up. Anterior knee pain had thus disappeared in 13 patients during the second follow-up period. Among the 8 patients with pain, the pain was worse on kneeling and squatting and after long-term sitting (Table 2).

We divided the 28 patients into 3 groups: 7 patients were painless initially and still at follow-up (NP). In 13 patients, the anterior knee pain had disappeared during the follow-up (PNP), and the remaining 8 had anterior knee pain initially and at follow-up (AP).

With reference to the hamstring muscles, the mean peak torque difference between the injured and uninjured limb was −2.2% ± 12% in the NP group, 1.6% ± 15% in the PNP

TABLE 2. Mean (+SD) Intensity of Anterior Knee Pain During Various Activities Among Those who Reported Pain (N = 8)

Activity	Intensity of Anterior Knee Pain*
Rest	30, n = 1
Walking	36 (±1), n = 2
Running	40, n = 1†
Squatting	45 (±24), n = 4
Kneeling	71 (±19), n = 8
Stairs down	35, n = 1
Stairs up	40 (±14), n = 6
After long-term sitting	50, n = 1

*Visual analogue scale (0, no pain; 100 worst possible pain).
†One patient had not started any running activity.

group, and 10.3% ± 30% in the AP group at a speed of 60 degrees/second (Kruskal-Wallis test; $\chi^2 = 1.0$; $P = 0.593$). At a speed of 180 degrees/second, the corresponding differences were −2.9% ± 23% and 7.0% ± 19% and 4.4% ± 16% (Kruskal-Wallis test; $\chi^2 = 1.7$; $P = 0.429$), respectively. In the quadriceps muscles, the mean peak torque difference was −2.8% ± 9% in the NP group, 5.9% ± 15% in the PNP group, and −13.0% ± 16% in the AP group at a speed of 60 degrees/second (Kruskal-Wallis test; $\chi^2 = 7.9$; $P = 0.019$). At 180 degrees/second, the corresponding differences were −9.4% ± 13% and 4.9% ± 16% and −1.9% ± 9% (Kruskal-Wallis test; $\chi^2 = 4.8$; $P = 0.092$), respectively (Table 3).

As noted above, at the long-term check-up there were 7 patients who were painless initially and also at the final follow-up (NP). In 13, the anterior knee pain had disappeared during the follow-up (PNP), and the remaining 8 experienced anterior knee pain initially and at the last follow-up (AP). Symptoms among the latter group were minor, and none received surgical treatment or physiotherapy for the anterior knee pain during the follow-up period. All patients were at work normally after the surgery; only 2 in the AP group did not go to work before 12 months after the accident and operation.

The 3 study groups were comparable with respect to age, body mass index, nail protrusion, operation time, nail insertion site, hospital time, and range of movement in the knee joint. There were clear differences between the groups in the nail-plateau distance (the distance from the plateau surface of the tibia to the proximal tip of the nail), although these differences were not statistically significant ($P = 0.060$) (Table 1). Also, there were statistically significant intergroup differences in the Iowa Knee Score[21] at the first check-up, as well as at long-term follow-up (Kruskal-Wallis test; $\chi^2 = 15.8$, $P = 0.000$ and $\chi^2 = 22.0$, $P = 0.000$), Lysholm and Gillquist's[19] knee score (Kruskal-Wallis test; $\chi^2 = 16.6$, $P = 0.000$ and $\chi^2 = 15.4$, $P = 0.000$) and the Tegner et al[20] knee score (Kruskal-Wallis test; $\chi^2 = 7.3$, $P = 0.026$ and $\chi^2 = 4.7$, $P = 0.093$) (Table 4). No group differences emerged with regard to mode of injury and type of fracture; however, the level of the fracture seemed to be more proximal in the AP group (Table 5).

TABLE 1. Characteristics of Patients who Never had Anterior Knee Pain (NP), Patients for Whom Anterior Knee Pain had Vanished During Follow-up Time (PNP), and Patients With Anterior Knee Pain (AP)

	Never Pain, n = 7	Pain, No Pain, n = 13	Always Pain, n = 8	P Value
BMI (kg/m²)	26.5 ± 3.3	25.5 ± 2.9	25.4 ± 8.3	0.725*
Age, y	44 ± 15	48 ± 9	40 ± 18	0.464*
Sex				
Female	0 (0%)	8 (62%)	5 (63%)	0.018†
Male	7 (100%)	5 (38%)	3 (37%)	
Nail insertion				
Transtendinous	4 (57%)	6 (46%)	4 (50%)	0.896†
Paratendinous	3 (43%)	7 (54%)	4 (50%)	
Smoking				
No	5 (71%)	9 (69%)	5 (63%)	0.924†
Yes	2 (29%)	4 (31%)	3 (37%)	
Plateau (mm)	15.3 ± 8.0	7.2 ± 5.5	12.4 ± 8.1	0.060*
Protrus (mm)	2.7 ± 3.3	5.0 ± 4.2	6.4 ± 4.3	0.220*
Opertime (min)	70 ± 19	84 ± 20	96 ± 66	0.419*
Hospital time (d)	7.6 ± 3.3	5.2 ± 1.7	7.6 ± 3.4	0.162*
ROM‡ (°), first control	139 ± 9	140 ± 7	138 ± 11	0.620*
ROM‡ (°), long term	150 ± 0	150 ± 0	148 ± 5	0.075*

ROM, range of movement.
*Kruskal-Wallis test.
†χ^2 Test.
‡Range of movement in the knee joint (0–150 degrees).

TABLE 3. Difference* (%) in Thigh Muscle Strength Between Operated and Nonoperated Lower Limb Among Patients who Never had Anterior Knee Pain (NP), Patients for Whom Anterior Knee Pain had Vanished During Follow-up Time (PNP), and Patients With Anterior Knee Pain (AP)

	Never Pain, n = 7	Pain, No Pain, n = 13	Always Pain, n = 8	P Value†
Flexion 60° (%)	−2.2 ± 12.0	1.6 ± 15.3	10.3 ± 30.3	$\chi^2 = 1.0$, P = 0.593
Extension 60° (%)	−2.8 ± 8.8	5.9 ± 14.7	−13.0 ± 15.5	$\chi^2 = 7.9$, P = 0.019
Flexion 180° (%)	−2.9 ± 22.5	7.0 ± 18.9	4.4 ± 16.2	$\chi^2 = 1.70$, P = 0.429
Extension 180° (%)	−9.4 ± 13.4	4.9 ± 16.3	−1.9 ± 8.8	$\chi^2 = 4.8$, P = 0.092

*Difference = (operated limb–nonoperated limb)/nonoperated limb × 100%. A negative value indicates that operated limb is weaker than nonoperated limb.
†Kruskal-Wallis test.

DISCUSSION

Our study reports a significant strength difference between the study groups (NP, PNP, and AP groups) in knee extension at a speed of 60 degrees/second (quadriceps muscle), whereas this was not the case in knee flexion (hamstring muscle) (Table 3). Patients who never had anterior knee pain (NP) had almost balanced muscle strength during the follow-up period, the operated limbs being 2% to 9% weaker than nonoperated ones (Table 3). They had almost balanced muscle strength in the first isokinetic test already. There was a clear muscle strength deficit in operated limbs (extension and flexion) with patients in other groups (PNP and AP) in the first isokinetic test. Patients whose anterior knee pain had disappeared during follow-up (PNP) had more strength in knee extension and flexion in the operated than in the nonoperated limbs, perhaps because of painless rehabilitation. Also, the pain group (AP) had better flexion strength in the operated than the nonoperated limb, but extension strength was clearly better in the nonoperated limbs. Järvelä et al[22] investigated occurrence and predicting factors in anterior knee pain after an anterior cruciate ligament reconstruction with a bone-patellar tendon-bone autograft, and the most prominent factor related to the occurrence of anterior knee pain proved to be an extension torque deficit at the speed of 60 degrees/second.

Some patients may thus benefit from specific rehabilitation of the knee and thigh muscles (especially knee extensors) after surgery for a tibial shaft fracture. On the other hand, in all patients the strength of both the quadriceps and hamstring muscle decreases and muscle atrophy rapidly becomes evident after the injury, especially during the first 1 to 2 weeks.[23] If early rehabilitation has been completely forgotten and ignored, it may prove extremely difficult to restore the strength and power of the muscles to normal.[15] In our study, patients who never had anterior knee pain (NP) showed little percentage muscle strength increase during the follow-up period, whereas the 2 other groups, who had anterior knee pain at the first testing, had better improvement. In simple terms, in the first group (NP) the balance between operated and nonoperated leg muscle strengths was already good at the first testing check-up. The second group (PNP) had such a percentage increase in the operated legs that the muscle strength of that leg was better than the nonoperated leg (extension strength). The third group (AP) had continued lower extension strength in the operated leg than nonoperated leg at the second muscle testing. Kobayashi et al[24] showed that 24 months after anterior cruciate ligament reconstruction, quadriceps muscle strength had recovered to approximately 90% of the level of the uninvolved side at both 60 and 180 degrees/second. In contrast, hamstring muscle strength had already recovered to approximately 90% at 6 months.

Clark et al[25] determined the efficacy of the individual components of physiotherapy with in 81 young adults with anterior knee pain (patellofemoral pain syndrome). They noted that the proprioceptive muscle stretching and strengthening aspects of physiotherapy had a beneficial effect on anterior knee pain at 3 months, sufficient to permit discharge from physiotherapy, and these benefits were maintained at 1 year.

TABLE 4. Functional Scores Among Patients who Never had Anterior Knee Pain (NP), Patients for Whom Anterior Knee Pain had Vanished During Follow-up Time (PNP), and Patients With Anterior Knee Pain (AP)

	Never Pain, n = 7	Pain, No Pain, n = 13	Always Pain, n = 8	P Value*
Tegner knee score†	4.9 ± 0.7	3.7 ± 1.3	4.8 ± 2.1	$\chi^2 = 4.2$, P = 0.120
Tegner knee score‡	4.9 ± 1.1	3.7 ± 1.3	3.3 ± 1.3	$\chi^2 = 7.3$, P = 0.026
Tegner score§	5.0 ± 1.1	3.7 ± 1.0	4.5 ± 1.7	$\chi^2 = 4.7$, P = 0.093
Iowa knee score‡	99.0 ± 0.8	98.1 ± 1.8	88.3 ± 11.4	$\chi^2 = 15.8$, P = 0.000
Iowa knee score§	100 ± 0.0	100.0 ± 0.0	95.0 ± 3.4	$\chi^2 = 22.0$, P = 0.000
Lysholm knee score‡	97.9 ± 1.8	96.9 ± 3.4	76.4 ± 16.1	$\chi^2 = 16.6$, P = 0.000
Lysholm knee score§	98.9 ± 1.1	99.7 ± 0.8	84.9 ± 14.6	$\chi^2 = 15.4$, P = 0.000

*Kruskal-Wallis test.
†Patients' Tegner knee score at baseline (before trauma and surgery).
‡Scores at the first follow-up.
§Scores at the long-term follow-up.

TABLE 5. Type of Fracture in Patients who Never had Anterior Knee Pain (NP), Patients for Whom Anterior Knee Pain had Vanished During Follow-up Time (PNP), and Patients With Anterior Knee Pain (AP)

	Never Pain, n = 7	Pain, No Pain, n = 13	Always Pain, n = 8	P Value
Mode of injury				
Low energy	6 (86%)	11 (85%)	6 (75%)	0.821*
High energy	1 (14%)	2 (15%)	2 (25%)	
AO classification				
A1	3 (44%)	9 (68%)	5 (61%)	
A2	0	1 (8%)	1 (13%)	
A3	1 (14%)	1 (8%)	1 (13%)	0.826*
B1	1 (14%)	1 (8%)	0	
B2	1 (14%)	1 (8%)	1 (13%)	
C2	1 (14%)	0	0	
Fibula fracture				
No	0	2 (15%)	2 (25%)	
High	4 (57%)	5 (38%)	0	0.263*
Middle	2 (29%)	2 (15%)	2 (25%)	
Low	1 (14%)	4 (32%)	4 (50%)	
Fracture location				
Middle diaphysis	1 (14%)	2 (15%)	4 (50%)	0.154*
Distal diaphysis	6 (86%)	11 (85%)	4 (50%)	

*χ^2 Test.

On the other hand, taping did not influence the outcome. Thomas et al[26] showed that simple home-based exercise therapy during 2 years can produce a small but significant reduction in knee pain, an average of 12% compared to a nonexercise group, and an exercise program also produced significant improvements in knee range of motion and physical function. Roush et al[27] showed that patients with anterior knee pain may benefit from applying the Muncie method (home rehabilitation with a modified vastus medialis oblique specific straight-leg-raising exercise) in a home therapy program.

Bleakney and Maffulli[28] measured quadriceps musculature and atrophy using high-resolution real-time ultrasonography in 13 skeletally mature male patients with an isolated unilateral diaphyseal fracture of the femur or tibia. They found clear differences in the quadriceps morphology of the nailed and unnailed limbs after interlocked intramedullary nailing.

In a study of muscle strength in patients with chronic pain, strength reduction in the whole limb on the painful side was approximately 20% to 30% more than that on the nonpainful side.[29] This strength reduction may be related to behavioral (psychological) or physical factors. Patients with chronic pain often avoid using the painful limb, which may lead to physiologic changes such as atrophy.[29] In our study, patients who had anterior knee pain at follow-up (AP) also had lower functional knee scores than those whose anterior knee pain had disappeared during follow-up (PNP) or who never had had anterior knee pain (NP) (Table 4). On the other hand, the Tegner et al[20] knee score had returned to preoperative level also in the pain group, which may indicate that anterior knee pain is rarely severe and patients have resumed their preinjury activity levels.

There was a clear difference between the Lysholm and Gillquist[19] knee scores and Iowa knee scores in the respective study groups. Patients whose anterior knee pain had disappeared (PNP) during the follow-up already had statistically significantly better scoring points at the first check-up than those who still complained of anterior knee pain (AP) at the long-term examination (Table 4).

It is obvious that the source of chronic anterior knee pain after intramedullary nailing of a tibial shaft fracture is multifactorial. Devitt et al,[30] using 8 cadaveric knees, demonstrated that insertion of an intramedullary nail in the tibia significantly increases contact pressures at the patellofemoral joint. They used 2 approaches: medial paratendinous and transtendinous. A significant increase in contact pressures was found at the lateral facets with the medial paratendinous approach ($P = 0.01$) and at the medial facet when the transpatellar approach ($P = 0.001$) to the proximal tibia was used. With the transtendinous approach, contact pressure increases were recorded on both facets, suggesting that chondral injury is more likely with this approach.[30]

In a retrospective study in which the nail was inserted via a paratendinous incision in 65 fractures and via a tendon-splitting incision in 36 fractures, Keating et al[10] reported that insertion of an intramedullary nail paratendinously resulted in an incidence of knee pain of 50% (33 patients out of 65 fractures), whereas this incidence in the tendon-splitting incision group was 77% (28 patients out of 36 fractures). This difference was significant ($P < 0.01$). They thus recommend a parapatellar tendon incision for nail insertion. Toivanen et al[12] undertook a prospective randomized study in which they found that chronic anterior knee pain occurred similarly after a trans- and paratendinous approach. Sala et al[31] and Väistö et al[32] showed no relationship between tendon morphology and structure and the chronic anterior knee pain; only the patellar tendon of the operated limb was seen to be thickened compared with the contralateral tendon. Also, on evaluation of the remaining patellar tendon after harvesting its central third for reconstruction of anterior cruciate ligament (ACL), there are morphologic changes in the patellar tendon but no relationship with anterior knee pain.[33] Karladani and Styf[34] describe an approach in which the skin incision is located on either the medial or lateral side of the patella and the nailing is performed percutaneously. They used this percutaneous technique in 13 patients with an isolated tibial shaft fracture. At the final follow-up at 22 months, all patients were able to kneel on the injured side, and none showed dysfunction of the infrapatellar branch of the saphenous nerve.

Samuelson et al[35] investigated the appropriate insertion point for a tibial intramedullary nail in the coronal plane by using 61 embalmed cadaveric lower legs. They placed the nail in retrograde fashion through the proximal cortex, and the exit hole of the nail was measured in relation to the tibial tubercle. The nail ranged from 1 mm lateral to the tibial tubercle to 21 mm medial to the tibial tubercle, with an average of 8 mm ± 6 mm. Their data support the use of a medial or patellar splitting approach for nail insertion, and insertion sites lateral to the tibial tubercle should be avoided. Lembcke et al[36] investigated the relationship between axial shift and nail entry point in unreamed nailing of proximal tibia fractures using

22 formaldehyde-fixed tibiae. Their studies showed that lateral insertion of the nail usually results in a varus deformity in the fracture, as well as a lateral displacement of the distal fragment. Medial insertion has the opposite effect, valgus deformity with medial displacement of the distal fragment.

The trauma itself and damage to the infrapatellar nerve may also cause anterior knee pain.[37] There is a relationship between injury to the infrapatellar nerve and the cause and natural course of reflex sympathetic dystrophy of the knee.[38] There is a safe area that avoids the infrapatellar nerve; it lies within an approximately 30 mm area from the medial margin of the patella at the level of the midpatella and within an approximately 10 mm area from the medial margin of the patellar tendon at the level of the distal pole of the patella.[39] In our study, the mode of injury, the fracture location in the tibia or fibula, and the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification were not statistically different between the groups. However, patients presenting with a high fibula fracture no longer had anterior knee pain at long-term follow-up (Table 5). Groups under Keating et al[10] and Court-Brown et al[40] reported the incidence of anterior knee pain to be more common among younger than older patients, which may be due to a more sedentary lifestyle among elderly patients.

Schmitz et al[41] showed that a tibial shaft fracture requires more time to heal after intramedullary nailing or external fixation in patients who smoke as opposed to those who do not smoke. Our results showed no difference in anterior knee pain between smoking or nonsmoking patients (Table 1).

Nail prominence above the cortex of the proximal part of the tibia may be a contributing factor, and excessive nail prominence irritates the overlying patellar tendon. Groups under Keating et al[10] and Toivanen et al[12] found no association between nail protrusion and anterior knee pain, which was also shown in our long-term follow-up study (Table 1). Merchant and Dietz[21] found no difference in outcome between groups of patients with fractures with 5 degrees, 5 to 10 degrees, or greater than 10 degrees angulation. Kyrö[11] noted decreased subjective and functional outcomes in patients with malalignment of distal-third fractures treated with an intramedullary nail compared to tibia fractures without malalignment. High-energy, greater-prereduction-displacement, and distal-third fractures seem to be predisposed to rotational malreduction.[42] Patients treated by community orthopedic surgeons had a higher incidence of malalignment compared to those treated by orthopedic trauma specialists.[43]

The strengths of our study are a very long follow-up period during 8 years and the randomized, prospective nature of the study design. The limitation of this study is the relatively small number of patients in the current follow-up because of attrition over time.

Taken together, although chronic anterior knee pain is the most common postoperative complication after a nailing procedure in tibial shaft fractures, it is rarely severe, and many patients can return to their previous work and preinjury level of activity. These findings are corroborated in the present study. Fear of postoperative chronic anterior knee pain generally should not hinder the use of intramedullary nails in the treatment of tibial shaft fractures. Our results indicate that anterior knee pain after intramedullary nailing of a tibial shaft fracture is related to strength deficiency in the knee extensor muscles and lower functional knee scores. In the long term, however, the anterior knee pain disappears from many patients.

REFERENCES

1. Alho A, Ekeland A, Strömsöe K, et al. Locked intramedullary nailing for displaced tibial shaft fractures. *J Bone Joint Surg Br.* 1990;72:805–809.
2. Bone LW, Sucato D, Stegemann PM, et al. Displaced isolated fractures of the tibial shaft treated with either a cast or intramedullary nailing: an outcome analysis of matched pairs of patients. *J Bone Joint Surg Am.* 1997;79:1336–1341.
3. Court-Brown CM, Christie J, McQueen MM. Closed intramedullary tibial nailing: its use in closed and type I open fractures. *J Bone Joint Surg Br.* 1990;72:605–611.
4. Ekeland A, Thoresen BO, Alho A, et al. Interlocking intramedullary nailing in the treatment of tibial fractures. *Clin Orthop.* 1988;231:205–215.
5. Hooper GJ, Keddell RG, Penny ID. Conservative management or closed nailing for tibial shaft fractures. *J Bone Joint Surg Br.* 1991;73:83–85.
6. Karladani HA, Granhed H, Edshage B, et al. Displaced tibial shaft fractures: a prospective randomised study of closed intramedullary nailing versus cast treatment in 53 patients. *Acta Orthop Scand.* 2000;71:160–167.
7. Keating JF, O'Brien PJ, Blachut PA, et al. Locking intramedullary nailing with and without reaming for open fractures of the tibial shaft. *J Bone Joint Surg Br.* 1997;79:334–341.
8. Sarmiento A, Gersten LM, Sobol PA, et al. Tibial shaft fractures treated with functional braces. *J Bone Joint Surg Br.* 1989;71:602–609.
9. Court-Brown CM. Reamed intramedullary tibial nailing: an overview and analysis of 1106 cases. *J Orthop Trauma.* 2004;18:96–101.
10. Keating JF, Orfaly R, O'Brien PJ. Knee pain after tibial nailing. *J Orthop Trauma.* 1997;11:10–13.
11. Kyrö A. Malunion after intramedullary nailing of tibial shaft fractures. *Ann Chir Gynaecol.* 1997;86:56–64.
12. Toivanen JAK, Väistö O, Kannus P, et al. Anterior knee pain after intramedullary nailing of fractures of the tibial shaft: a prospective, randomized study comparing two different nail-insertion techniques. *J Bone Joint Surg Am.* 2002;4:580–585.
13. Väistö O, Toivanen JAK, Kannus P, et al. Anterior knee pain and thigh muscle strength after intramedullary nailing of tibial shaft fractures: a report of 40 consecutive cases. *J Orthop Trauma.* 2004;18:18–23.
14. Gaston P, Will E, McQueen MM, et al. Analysis of muscle function in the lower limb after fracture of the diaphysis of the tibia in adults. *J Bone Joint Surg Br.* 2000;82:326–331.
15. Holder-Powell HM, Rutherford OM. Unilateral lower limb injury: its long-term effects on quadriceps, hamstring, and plantar flexor muscle strength. *Arch Phys Med.* 1999;80:717–720.
16. Karladani HA, Svantesson U, Granhed H, et al. Postural control and torque of the knee joint after healed tibial shaft fracture. *Injury.* 2001;32:57–60.
17. Nyland J, Bealle DP, Kaufer H, et al. Long-term quadriceps femoris functional deficits following intramedullary nailing of isolated tibial fractures. *Int Orthop.* 2001;24:342–346.
18. Aitken RC. Measurements of feelings using visual analogue scales. *Proc R Soc Med.* 1969;62:989–993.
19. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on the use of scoring scale. *Am J Sports Med.* 1982;10:150–154.
20. Tegner Y, Lysholm J, Odensten M, et al. Evaluation of cruciate ligament injuries: a review. *Acta Orthop Scand.* 1988;59:336–341.
21. Merchant TC, Dietz FR. Long-term follow-up after fractures of the tibial and fibular shafts. *J Bone Joint Surg.* 1989;71-A:599–606.
22. Järvelä T, Kannus P, Järvinen M. Anterior knee pain 7 years after an anterior cruciate ligament reconstruction with bone-patellar tendon-bone autograft. *Scand J Med Sci Sports.* 2000;10:221–227.
23. Appel HJ. Muscular atrophy following immobilisation. *Int J Sports Med.* 1990;10:42–58.
24. Kobayashi A, Higuchi H, Terauchi M. Muscle performance after anterior cruciate ligament reconstruction. *Int Orthop.* 2004;28:48–51.

25. Clark DI, Downing N, Mitchell J, et al. Physiotherapy for anterior knee pain: a randomized controlled trial. *Ann Rheum Dis*. 2000;9:700–704.
26. Thomas KS, Muir KR, Doherty M, et al. Home based exercise programme for the knee pain and knee osteoarthritis: randomised controlled trial. *BMJ*. 2002;325:752–756.
27. Roush MB, Sevier TL, Wilson JK, et al. Anterior knee pain: a clinical comparison of rehabilitation methods. *Clin J Sport Med*. 2000;10:22–28.
28. Bleakney R, Maffulli N. Ultrasound changes to intramuscular architecture of the quadriceps following intramedullary nailing. *J Sports Med Phys Fitness*. 2002;42:120–125.
29. Wilgen CP, Akkerman L, Wieranga J, et al. Muscle strength in patients with chronic pain. *Clin Rehabil*. 2003;17:885–889.
30. Devitt AT, Coughlan KA, Ward T, et al. Patellofemoral contact forces and pressures during intramedullary tibial nailing. *Int Orthop*. 1998;22:92–96.
31. Sala F, Binda M, Lovisetti G. Anterior gonalgic syndrome after intramedullary nailing: ultrasound and radiologic study. *Chir Organi Mov*. 1998;83:271–275.
32. Väistö O, Toivanen J, Paakkala T, et al. Anterior knee pain after intramedullary nailing of a tibial shaft fracture: an ultrasound study of the patellar tendons of 36 patients. *J Orthop Trauma*. 2005;19:311–316.
33. Järvelä T, Paakkala T, Kannus P, et al. Ultrasonographic and power Doppler evaluation of the patellar tendon ten years after harvesting its central third for reconstruction of the anterior cruciate ligament: comparison of patients without or with anterior knee pain. *Am J Sports Med*. 2004;32:39–46.
34. Karladani HA, Styf J. Percutaneous intramedullary nailing of tibial shaft fractures: a new approach for prevention of anterior knee pain. *Injury*. 2001;9:736–739.
35. Samuelson MA, McPherson EJ, Norris L. Anatomic assessment of the proper insertion site for a tibial intramedullary nail. *J Orthop Trauma*. 2002;16:23–25.
36. Lembcke O, Ruter A, Beck A. The nail-insertion point in unreamed tibial nailing and its influence on the axial malalignment in proximal tibial fractures. *Arch Orthop Trauma Surg*. 2001;121:197–200.
37. Kyrö A, Tunturi T, Soukka A. Conservative treatment of tibial fractures: results in a series of 163 patients. *Ann Chir Gynaecol*. 1991;80:294–300.
38. Poehling GG, Pollock FE Jr, Wojtys EM. Reflex sympathetic dystrophy of the knee after sensory nerve injury. *Arthroscopy*. 1988;1:31–35.
39. Mochida H, Kikucki S. Injury to infrapatellar branch of saphenous nerve in arthoscopic knee surgery. *Clin Orthop*. 1995;18:88–94.
40. Court-Brown CM, Gustilo T, Shaw AD. Knee pain after intramedullary tibial nailing: its incidence, etiology, and outcome. *J Orthop Trauma*. 1997;11:103–105.
41. Schmitz MA, Finnegan M, Natarajan RMA, et al. Effect of smoking on tibial shaft fracture healing. *Clin Orthop*. 1999;365:184–200.
42. Puloski S, Romano C, Buckley R, et al. Rotational malalignment of the tibia following reamed intramedullary nail fixation. *J Orthop Trauma*. 2004;18:397–402.
43. Obremskey WT, Medina M. Comparison of intramedullary nailing of distal third tibial shaft fractures: before and after traumatologists. *Orthopaedics*. 2004;27:1180–1184.

Anterior Knee Pain After Intramedullary Nailing of Fractures of the Tibial Shaft: An Eight-Year Follow-Up of a Prospective, Randomized Study Comparing Two Different Nail-Insertion Techniques

Olli Väistö, MD, Jarmo Toivanen, MD, PhD, Pekka Kannus, MD, PhD, and Markku Järvinen, MD, PhD

Background: Anterior knee pain is the most common complication after intramedullary nailing of the tibia. Dissection of the patellar tendon and its sheath during transtendinous nailing is thought to be a contributing cause of chronic anterior knee pain. The purpose of this long-term follow-up of a prospective, randomized study was to assess whether the prevalence and intensity of anterior knee pain after intramedullary nailing of a tibial shaft fracture is different in transtendinous versus paratendinous incision technique.

Methods: Fifty patients with a tibial shaft fracture requiring intramedullary nailing were randomized equally (25 plus 25) to treatment with paratendinous or transtendinous nailing. Forty-two patients (21 plus 21) were reexamined an average of 3 years after nailing, whereas 28 patients (14 plus 14) could be now reexamined an average of 8 years after the nailing. As in the first reexamination, the patients at the 8-year follow-up used visual analog scales to report the level of anterior knee pain and the impairment caused by the pain. The scales described by Lysholm and Gillquist and by Tegner et al., the Iowa knee scoring system, and simple functional tests were used to quantitate the functional results. Isokinetic thigh-muscle strength was also measured.

Results: Four (29%) of the 14 patients treated with transtendinous nailing reported anterior knee pain at the 8-year follow-up evaluation. The number was the same for patients treated with paratendinous nailing. The Lysholm, Tegner, and Iowa knee scoring systems, the muscle-strength measurements, and the functional tests showed no significant differences between the two groups.

Conclusion: Compared with a transpatellar tendon approach, a paratendinous approach for nail insertion does not reduce the prevalence of chronic anterior knee pain or functional impairment after intramedullary nailing of a tibial shaft fracture. In long term, anterior knee pain seems to disappear from many patients.

Key Words: Tibial shaft fracture, Anterior knee pain, Intramedullary nailing, Operative technique.

J Trauma. 2008;64:1511–1516.

Intramedullary nailing is the treatment of choice for displaced tibial shaft fractures in adults.[1–6] Chronic anterior knee pain at the insertion site of the nail is the most frequently reported complication of closed nailing.[1,3,4,7–12] Up to 56% of patients note some degree of chronic knee pain.[7] The etiology of anterior knee pain after nailing is still unknown.[7–10,12] Some investigators have proposed that a transpatellar tendon approach for nail insertion is associated with a higher prevalence of anterior knee pain than a medial paratendinous approach.[10,12] On the other hand, our random-ized study showed no difference in the anterior knee pain between these two surgical insertion techniques an average of 3 years after nailing.[13]

The purpose of this long-term follow-up was to analyze whether there is a difference in the prevalence of chronic anterior knee pain after these two surgical approaches an average 8 years after the nailing procedure. Functional performance of the knees was also assessed.

PATIENTS AND METHODS

Fifty consecutive patients in whom an isolated, displaced fracture of the tibial shaft was treated with an intramedullary locking nail (Grosse-Kempf nail; Howmedica, Rutherford, NJ) at Tampere University Hospital, Finland, between July 1996 and January 1998, were originally enrolled in this study. There were 23 men and 27 women with a mean age (and standard deviation) of 42 ± 5 years. Inclusion criteria included a patient age of 15 years or more, the absence of any major comorbid illness, and the absence of any fracture lines extending up to the knee joint. All patients were informed of the study procedure, purposes, and known risks, and all gave written informed consent. The study was conducted in conformity with the principles of the Declaration of Helsinki and was approved by our institutional ethics committee. After they gave informed consent, the patients were randomized,

with use of sealed envelopes, into one of two groups: closed nailing with use of a patellar tendon-splitting (transtendinous) approach (25 patients) or closed nailing with use of a paratendinous approach (25 patients).

The intramedullary nailing was performed within 24 hours after the injury in 42 patients and between 1 and 12 days after the injury in six (two patients treated with the transtendinous approach and four treated with the paratendinous approach). Two patients (one in each group) were managed initially with a cast and then were treated with corrective osteotomy and intramedullary nailing (one, at 6 months and the other, at 18 months after the injury). The incision for the transtendinous approach was made longitudinally through the midline of the tendon for a distance of 3 cm to 5 cm. After insertion of the nail, the tendon incision was closed with interrupted suture. For the paratendinous approach, a medial longitudinal incision was made with care taken not to violate the patellar tendon or its sheath. The entry portal in the bone was made immediately behind the patellar tendon in all patients. Proximal and distal locking screws were always used, and all nails were countersunk below the cortical bone of the proximal part of the tibia. Nails were routinely removed, through the same entry incision and approach that were used during nail insertion, approximately 1½ years after fixation.

There were 42 patients available at the first follow-up an average 3 years after nailing.[13] After that, two patients died from causes not related to the tibial shaft fracture. Five patients had new trauma or acute heart or lung disease and were excluded from the long-term follow-up. Five patients refused from further follow-up. In addition, we were unable to trace two patients for the 8-year follow-up examination. Thus, 28 patients were available for the second reexamination at 8 years.

This second reexamination was performed at an average of 8.1 ± 0.3 years after nail insertion and average of 6.6 ± 0.3 after nail extraction. The patients graded anterior knee pain during rest, walking, running, squatting, kneeling, stair climbing, and stair descent and after long-term sitting on a 100-mm visual-analog scale, with 0 denoting no pain and 100 denoting the worst pain that the patient could imagine.[14] The patients also assessed impairment caused by the anterior knee pain with the use of a 100-mm scale, on which 0 meant no impairment, <33 meant mild impairment, 33 to 66 meant moderate impairment, and >66 meant severe impairment. In addition, all patients completed the standardized scoring scales described by Lysholm and Gillquist[15] and by Tegner et al.,[16] as well as the Iowa knee score.[17]

One physician performed a blinded reexamination of all patients. The functional evaluation was performed with use of a modification of the method developed by Kannus et al.[18] The evaluator used a 0- to 3-point scale to rate the patients' ability to perform one-leg jumping and duck-walking (3 points signified the ability to perform without problems and no pain and 0 points signified the inability to perform and intense pain), their ability to perform a 25-repetition full-

squat test (0 signified the inability to perform any squat without pain; 1 point, the ability to perform 1 to 10 squats without pain; 2 points, 11 to 20 squats; and 3 points, more than 20 squats), and their ability to kneel (0 points meant that it was impossible to kneel; 1 point meant that it was possible to kneel for less than 10 seconds without pain; 2 points, for less than 20 seconds; and 3 points, without time limitation). The scores acquired from these tests were summed and averaged for the final between-groups comparison.

Isokinetic quadriceps strength-testing was performed with use of a Cybex machine (Cybex 6000; Division of Lumex, Ronkonkoma, NY) in the first reexamination[13] while the current long-term follow-up was performed using a Dyna-Com strength testing system (Dyna-Com 650; Oy Diter-Elektroniikka Ab, Turku, Finland). Both tests were made by the same physician. The quadriceps and hamstring torques were measured first at a low speed of 60°/s with five maximal repetitions and then, after a 30 seconds rest, at a medium speed of 180°/s with five maximal repetitions. The repetition during which the maximal peak torque was produced was also recorded.

The distance from the plateau surface of the tibia to the proximal tip of the nail and the extent of nail protrusion (nail prominence in relation to the bone cortex in millimeters) was analyzed on the postoperative lateral radiograph. The body mass index was also calculated for all patients.

The impairment scale and the functional testing scale were developed specifically for the purpose of this study. For validation, we calculated the Spearman correlation coefficients between our impairment scale and the Lysholm score[14] at both reexaminations (-506; $p = 0.006$ and -0.740; $p = 0.000$, respectively), between our impairment scale and the standardized Iowa knee score[17] (-0.726; $p = 0.000$ and -0.926; $p = 0.000$), between our functional testing scale and the Lysholm score[15] (0.647; $p = 0.000$ and 0.728; $p = 0.000$), and between our functional testing scale and the Iowa knee score[17] (0.682; $p = 0.000$ and 0.855; $p = 0.000$).

To describe the data, the mean (and standard deviation) are reported for continuous variables. Percentages, as well as the risk ratio and its 95% confidence interval (CI), are reported for categorized variables. In our statistical analyses, differences between the two groups were tested with use of the Mann-Whitney U test for continuous variables and the Fisher's exact test for categorized variables. The statistical analysis was performed with use of the SPSS for Windows program (version 12.0; SPSS, Inc., Chicago, IL). Throughout the study, a p value of <0.05 was considered significant.

RESULTS

The study groups were comparable with respect to sex, age, body mass index, nail protrusion, nail-plateau distance, operation and hospital time, smoking, fracture location, mode of injury (Table 1). Two patients (one treated with the transtendinous approach and one treated with the paratendinous approach) refused to have the nail removed because of the

Table 1 The Basic Characteristics of Patients in the Two Treatment Groups (Transtendinous and Paratendinous) at the 8-yr Follow-Up

	Transtendinous, n = 14	Paratendinous, n = 14	p Value
BMI (kg/m^2)	26.0 ± 6.1	25.4 ± 3.6	0.818*
Age (yrs)	42 ± 13	48 ± 14	0.246*
Sex			0.128†
Female (%)	4 (29%)	9 (64%)	
Male (%)	10 (71%)	5 (36%)	
Plateau (mm)	11.2 ± 8.8	10.2 ± 6.3	0.945*
Protrus (mm)	6.0 ± 4.4	3.7 ± 3.6	0.128*
Opertime (min)	95 ± 50	73 ± 19	0.214*
Hospital time (d)	6.9 ± 3.0	6.1 ± 2.7	0.501*
Smoking			0.420†
No	8 (57%)	11 (79%)	
Yes	6 (43%)	3 (21%)	
Fracture location			1.000†
Middle	3 (21%)	4 (29%)	
Lower	11 (79%)	10 (71%)	
Mode of injury			1.000†
Low energy	11 (79%)	12 (86%)	
High energy	3 (29%)	2 (14%)	
Anterior knee pain			0.800†
Never	4 (29%)	3 (21%)	
Vanished	6 (42%)	7 (50%)	
Still	4 (29%)	4 (29%)	

  * Mann-Whitney *U* test.
  † Fisher's exact test.

absence of any symptoms related to it. No patient had complications, such as infection, patellar tendon rupture, or broken hardware, which might have contributed to any knee pain.

At the time of the 8-year follow-up, four (29%) of the 14 patients treated with the transtendinous approach and four (29%) of the 14 patients treated with the paratendinous ap-

proach reported anterior knee pain during one or more of the activities that they assessed with the visual analog scale (*p* = 1.000, relative risk = 1.00, 95% CI = 0.6 to 1.6). Anterior knee pain had vanished from six (43%) patients in the transtendinous group and seven (50%) patients in the paratendinous group between the two reexaminations (Table 1). Four of the 14 patients treated with the transtendinous approach reported that they experienced pain at the patellar tendon, whereas one patient experienced pain at the medial border of the patellar tendon, too. None of these patients had tenderness on the lateral side of the patellar tendon. One patient in transtendinous group had palpation tenderness in the pain region. One of the 14 patients treated with the paratendinous approach reported pain at the patellar tendon, three had pain at the medial and lateral borders of the tendon. Three patients in the paratendinous group had palpation tenderness in the pain region. With the numbers available, no significant difference was found between the study groups with respect to the prevalence and intensity of anterior knee pain during rest, walking, running, squatting, kneeling, or stair-climbing or descent, or after long-term sitting (Table 2).

Two of the four patients treated with transtendinous approach and two of the four patients treated with paratendinous approach (*p* = 0.721) who experienced anterior knee pain reported that the pain caused mild impairment during daily activities. Two of the four patients treated with the transtendinous approach and one of the four patients treated with the paratendinous approach who had functional impairment, reported that the impairment was moderate, whereas one patient in the paratendinous group reported that it was severe (*p* = 0.721). All patients went normally back at work after the surgery, only two patients in the paratendinous group were long (about 1 year) away from job after the injury and operation (*p* = 0.481).

Table 2 Comparison of the Prevalence [No. (%) of Symptomatic Patients] and the Intensity (Visual Analog Pain Scores) of Anterior Knee Pain During Different Activities Between the Two Treatment Groups

Activity	Transtendinous, n = 14		Paratendinous, n = 14		RR (95% CI)*	Difference (95% CI)†	p Value‡	p Value§
	Prevalence	Intensity	Prevalence	Intensity				
Rest	1 (7%)	2 ± 8.1	0 (0%)	0 ± 0	0.9 (0.8 to 1.1)	2 (−2.3 to 6.5)	1.000	0.317
Walking	0 (0%)	0 ± 0	2 (14%)	5 ± 13.1	1.1 (0.9 to 1.5)	−5 (−12.3 to 2.0)	0.481	0.150
Running	0 (0%)	0 ± 0	1 (7%)	3 ± 10.7	1.0 (0.9 to 1.2)	−3 (−8.7 to 3.0)	1.000	0.317
Kneeling	4 (29%)	21 ± 35.7	4 (29%)	19 ± 33.2	1.0 (0.6 to 1.6)	2 (−25.0 to 28.6)	1.000	0.863
Squatting	2 (14%)	9 ± 21.8	2 (14%)	4 ± 13.4	1.0 (0.7 to 1.4)	5 (−9.8 to 18.3)	1.000	0.880
Stair descent	0 (0%)	0 ± 0	2 (14%)	6 ± 15.0	1.1 (0.9 to 1.5)	−6 (−14.0 to 2.6)	0.481	0.150
Stair ascent	0 (0%)	0 ± 0	1 (7%)	3 ± 9.4	1.0 (0.9 to 1.2)	−3 (−7.6 to 2.6)	1.000	0.317
After long-term sitting	0 (0%)	0 ± 0	1 (7%)	4 ± 13.4	1.0 (0.9 to 1.2)	−4 (−10.9 to 3.8)	1.000	0.317

  Data are expressed as mean ± standard deviation.
  * Group treated with paratendinous approach compared with group treated with transtendinous approach and 95% CI (comparison of the prevalence).
  † Group treated with paratendinous approach compared with group treated with transtendinous approach. A minus value indicates that there is more pain in the paratendinous group. 95% CI (comparison of the intensity).
  ‡ Fisher's exact test (*P* value for the prevalence).
  § Mann-Whitney *U* test (*P* value for the intensity).
  RR, risk ratio.

Table 3 Functional Knee Scores at the First and Second Reexamination 3 and 8 yrs After the Nailing Procedure

	Transdendinous, n = 14	Paratendinous, n = 14	Difference* (95% CI)	p Value[†]
Tegner's knee score[‡]	4.36 ± 1.34	4.21 ± 1.67	0.15 (−1.0 to 1.3)	0.653
Tegner's knee score[§]	3.64 ± 1.22	4.07 ± 1.44	−0.43 (−1.5 to 0.6)	0.538
Tegner's score[¶]	4.21 ± 1.25	4.29 ± 1.49	−0.08 (−1.1 to 1.0)	0.887
Iowa knee score[§]	96.7 ± 3.3	94.3 ± 10.3	2.4 (−3.5 to 8.3)	0.924
Iowa knee score[¶]	98.8 ± 2.4	98.4 ± 3.3	0.4 (−1.8 to 2.7)	0.694
Lysholm's knee score[§]	93.6 ± 8.6	88.9 ± 16.0	4.7 (−5.3 to 14.6)	0.317
Lysholm's knee score[¶]	97.5 ± 4.2	93.0 ± 13.5	4.5 (−3.2 to 12.2)	0.564

Data are expressed as mean ± standard deviation.

* Group treated with paratendinous approach compared with group treated with transtendinous approach. A minus value indicates that there are better scores in the paratendinous group.

[†] Mann-Whitney *U* test.

[‡] Preinjury Tegner's knee score.

[§] Scorings at the first reexamination.

[¶] Scorings at the second reexamination.

Compared with the score before the injury, the mean Tegner score at the time of first reexamination decreased 0.71 ± 1.27 points for the patients treated with the transtendinous approach and 0.14 ± 0.77 point for those treated with the paratendinous approach (p = 0.250, between-groups difference = −0.57 point, 95% CI = −1.39 to 0.24). At the time of the second reexamination, the mean Tegner score had increased back to the preoperative level (Table 3). Respectively, the mean Lysholm activity score had increased to the level of 97.5 ± 4.2 points for the patients treated with the transtendinous approach and 93.0 ± 13.5 points for those treated with the paratendinous approach (p = 0.564, between-groups difference = 4.5 points, 95% CI = −3.2 to 12.2) (Table 3). The Iowa knee scores were 98.8 ± 2.4 and 98.4 ± 3.3 points, respectively (p = 0.694, between-groups difference = 0.4 points, 95% CI = −1.8 to 2.7) (Table 3).

The mean total score for the functional tests at the time of the first reexamination was 10.2 ± 3.4 points for the patients treated with the transtendinous approach and 9.6 ± 3.0 points for those treated with the paratendinous approach (p = 0.272, between-groups difference = 0.6 point, 95% CI = −1.83 to 3.12). Same functional scores at the time of the second reexamination was 10.8 ± 2.6 points for the patients treated with the transtendinous approach and 11.1 ± 1.3 points for those treated with the paratendinous approach (p = 0.648, between-groups difference = −0.3 point, 95% CI = −1.86 to 1.29). Difference between the two reexaminations was thus 0.6 ± 1.0 points for the patients treated with the transtendinous approach and 1.5 ± 2.2 points for those treated with the paratendinous approach (p = 0.295, between-groups difference = −0.9 point, 95% CI = −2.28 to 0.43).

The mean arc of motion of the involved knee was 139° (range, 130°–150°) for the patients treated with the transtendinous approach and 140° (range, 131°–150°) for those treated with the paratendinous approach at the second reexamination (p = 0.850, between-groups difference = 1°, 95% CI = −7.9 to 5.7). The increases in the arc of motion of the involved knee during follow-up time were 11.4° ± 8.9° and

8.9° ± 7.6°, respectively (p = 0.447, between-groups difference = 2.5°, 95% CI = −3.9 to 8.9).

In the quadriceps muscle testing, the mean peak torque deficit of the injured limb at a speed of 60°/s was −1.7% ± 18.5% in the group treated with the transtendinous approach and −1.6% ± 12.6% in the group treated with the paratendinous approach (p = 0.890, between-groups difference = −0.1%, 95% CI = −12.4 to 12.2) at the time of the second reexamination. At a speed of 180°/s, the corresponding deficits were 0.5% ± 17.1% and −1.8% ± 12.2% (p = 0.963, between-groups difference = 2.3%, 95% CI = −9.2 to 13.8). For the hamstring muscles, the mean torque deficit of the injured limb at a speed of 60°/s was −1.1% ± 17.3% in the patients treated with the paratendinous approach and 7.4% ± 22.1% in those treated with the transtendinous approach (p = 0.462, between-groups difference = −8.5%, 95% CI = −23.9 to 6.8) at the time of the second reexamination. At a speed of 180°/s, the corresponding deficits were 5.7% ± 20.3% and 1.9% ± 17.9% (p = 0.435, between-groups difference = 3.8%, 95% CI = −11.0 to 18.7).

DISCUSSION

The first reexamination was performed an average 3.2 ± 0.4 years after nail insertion and an average 1.7 ± 0.3 years after nail extraction. Seven (25%) patients were painless and 21 (75%) patients had chronic anterior knee pain at that follow-up.[13] The current second reexamination was performed an average 8.1 ± 0.3 years after nail insertion and 6.6 ± 0.3 years after nail extraction. Twenty (71%) patients were painless and only eight (29%) patients had chronic anterior knee pain. Anterior knee pain had thus vanished from 13 patients during the second follow-up period. Among those eight who still had pain, the pain was worst on kneeling, squatting and after long-term sitting.

The above noted prevalence of anterior knee pain is the same as that reported in previous retrospective studies.[3,4,7,10,12] With the numbers available, we could not find any association between the entry incision and anterior knee pain. In their retrospective studies, Keating et

al.[10] and Orfaly et al.[12] found a clear association between a transtendinous surgical approach and chronic anterior knee pain, and they recommended the routine use of a medial paratendinous approach. In contrast, Court-Brown et al.[7] did not find any association between the surgical approach and anterior knee pain. Karladani and Styf[19] describe an approach, in which the skin incision is located on either the medial or lateral side of the patella and the nailing is performed percutaneously. They used this percutaneous technique in 13 patients with an isolated tibial shaft fracture. At the final follow-up of 22 months, all patients were able to kneel on the injured side and no patient had dysfunction of the infrapatellar branch of the saphenous nerve.[19]

Samuelson et al.[20] investigated the proper insertion point for a tibial intramedullary nail in the coronal plane with 61 embalmed cadaveric lower legs. They placed a nail in a retrograde fashion through the proximal cortex and the exit hole of the nail was measured in relation to the tibial tubercle. The nail position ranged from 1 mm lateral to the tibial tubercle to 21 mm medial to the tibial tubercle with an average of 8 mm ± 6 mm. The data supported the use of a medial or patellar splitting approach for nail insertion while insertion sites lateral to the tibial tubercle were not advocated.[20] Althausen et al.[21] showed that an ideal entry point for tibial nailing is just medial to the lateral tibial spine (lateral intercondylar tubercle) at the anterior margin of the articular surface. A preoperative fluoroscopic measurement before incision can, in turn, guide the surgeon as to whether a medial parapatellar, transpatellar, or lateral parapatellar approach provides the most direct access to this entry site.[22]

There are many factors other than the surgical approach that may cause anterior knee pain after intramedullary nailing of a tibial shaft fracture. Some authors have identified younger patients as being at greater risk for chronic anterior knee pain.[7,10] This observation may be attributable to the more sedentary lifestyle of elderly patients. Nail prominence above the cortex of the proximal part of the tibia may be a contributing factor. However, although excessive nail prominence clearly irritates the overlying patellar tendon, Keating et al.[10] found no association between nail protrusion and anterior knee pain. We too did not find a relationship between a few millimeters of nail prominence and anterior knee pain in our small series of patients at the second reexamination.

Hernigou et al.[9] investigated 12 pairs of cadaver knees after intramedullary nailing of the tibia. The intraarticular structures particularly at risk of damage during tibial nailing were the medial meniscus, the lateral tibial plateau, and the transverse ligament. Their results showed that in some bones the safety zone is smaller than the size of standard reamers and the proximal part of some nails. They also retrospectively analyzed 30 tibia-nailed patients with radiographs and recorded previously unrecognized, surgery-induced articular penetration and damage in four patients. These patients had pain in the knee and there was a possibility that the pain was linked to this unrecognized articular damage.[9]

Devitt et al.[8] demonstrated with eight cadaveric knees that insertion of an intramedullary nail in the tibia significantly increases contact pressures at the patellofemoral joint. They used two different approaches; medial paratendinous and transtendinous approaches. A significant increase in contact pressures was found at the lateral patellar facets with the medial paratendinous approach ($p = 0.01$).

With the transtendinous approach, the contact pressure increases were recorded on both facets suggesting that chondral injury is more likely with this approach.[8]

Järvelä et al.[22] observed that the most important factor related to the occurrence of anterior knee pain after reconstruction of the anterior cruciate ligament with bone-patellar tendon-bone graft was an extension torque deficit. We found an extension torque deficit of the thigh muscles after tibial nailing, but it was not associated with the type of entry point that had been used. We speculate that additional causes for anterior knee pain may be damage to the infrapatellar nerve or surgically induced scar formation.[13] Nail removal partially lessens anterior knee pain.[7,10]

We conclude that it is not possible to reduce anterior knee pain by using a paratendinous approach rather than a transtendinous incision for closed nailing of tibial shaft fractures. Although chronic anterior knee pain occurs in the majority of the patients, it is rarely severe. In long term, anterior knee pain seems to disappear from many patients and their activities usually come back to the preoperative level. Additional studies to assess the role of other factors in chronic anterior knee pain are warranted. Although our data showed no differences between the groups, the groups were relatively small to accept this null hypothesis with full confidence.

REFERENCES

1. Alho A, Benterud JG, Høgevold HE, Ekeland A, Strømsøe K. Comparison of functional bracing and locked intramedullary nailing in the treatment of displaced tibial shaft fractures. *Clin Orthop Relat Res*. 1992;277:243–250.
2. Bone LB, Sucato D, Stegemann PM, Rohrbacher BJ. Displaced isolated fractures of the tibial shaft treated with either a cast or intramedullary nailing. An outcome analysis of matched pairs of patients. *J Bone Joint Surg Am*. 1997;79:1336–1341.
3. Court-Brown CM, Christie J, McQueen MM. Closed intramedullary tibial nailing. Its use in closed and type I open fractures. *J Bone Joint Surg Br*. 1990;72:605–611.
4. Karladani AH, Granhed H, Edshage B, Jerre R, Styf J. Displaced tibial shaft fractures: a prospective randomized study of closed intramedullary nailing versus cast treatment in 53 patients. *Acta Orthop Scand*. 2000;71:160–167.
5. Toivanen JA, Hirvonen M, Auvinen O, et al. Cast treatment and intramedullary locking nailing for simple and spiral wedge tibial shaft fractures—a cost benefit analysis. *Ann Chir Gynaecol*. 2000;89:138–142.
6. Toivanen JA, Kyrö A, Heiskanen T, Koivisto AM, Mattila P, Järvinen MJ. Which displaced spiral tibial shaft fractures can be managed conservatively? *Int Orthop*. 2000;24:151–154.
7. Court-Brown CM, Gustilo T, Shaw AD. Knee pain after intramedullary tibial nailing: its incidence, etiology, and outcome. *J Orthop Trauma*. 1997;11:103–105.

8. Devitt AT, Coughlan KA, Ward T, et al. Patellofemoral contact forces and pressures during intramedullary tibial nailing. *Int Orthop.* 1998;22:92–96.

9. Hernigou P, Cohen D. Proximal entry for intramedullary nailing of the tibia. The risk of unrecognised articular damage. *J Bone Joint Surg Br.* 2000;82:33–41.

10. Keating JF, Orfaly R, O'Brien PJ. Knee pain after tibial nailing. *J Orthop Trauma.* 1997;11:10–13.

11. Koval KJ, Clapper MF, Brumback RJ, et al. Complications of reamed intramedullary nailing of the tibia. *J Orthop Trauma.* 1991; 5:184–189.

12. Orfaly R, Keating JE, O'Brien PJ. Knee pain after tibial nailing: does the entry point matter? *J Bone Joint Surg Br.* 1995;77:976–977.

13. Toivanen JAK, Väistö O, Kannus P, Latvala K, Honkonen S, Järvinen M. Anterior knee pain after intramedullary nailing of fractures of the tibial shaft: a prospective, randomized study comparing two different nail-insertion techniques. *J Bone Joint Surg Am.* 2002;4:580–585.

14. Aitken RC. Measurements of feelings using visual analogue scales. *Proc R Soc Med.* 1969;62:989–993.

15. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on the use of a scoring scale. *Am J Sports Med.* 1982;10:150–154.

16. Tegner Y, Lysholm J, Odensten M, Gillquist J. Evaluation of cruciate ligament injuries. A review. *Acta Orthop Scand.* 1988; 59:336–341.

17. Merchant TC, Dietz FR. Long-term follow-up after fractures of the tibial and fibular shafts. *J Bone Joint Surg Am.* 1989;71:599–606.

18. Kannus P, Natri A, Niittymäki S, Järvinen M. Effect of intraarticular glycosaminoglycan polysulfate treatment on patellofemoral pain syndrome. A prospective, randomized double-blind trial comparing glycosaminoglycan polysulfate with placebo and quadriceps muscle exercises. *Arthritis Rheum.* 1992;35:1053–1061.

19. Karladani HA, Styf J. Percutaneous intramedullary nailing of tibial shaft fractures: a new approach for prevention of anterior knee pain. *Injury.* 2001;9:736–739.

20. Samuelson MA, McPherson EJ, Norris L. Anatomic assessment of the proper insertion site for a tibial intramedullary nail. *J Orthop Trauma.* 2002;16:23–25.

21. Althausen PL, Neiman R, Finkemeier CG, Olson SA. Incision placement for intramedullary tibial nailing: an anatomic study. *J Orthop Trauma.* 2002;16:687–690.

22. Järvelä T, Kannus P, Järvinen M. Anterior knee pain 7 years after an anterior cruciate ligament reconstruction with bone-patellar tendon-bone autograft. *Scand J Med Sci Sports.* 2000;10:221–227.