

Submuscular bridge plating of length-unstable paediatric femoral shaft fractures in children between the ages of 6 and 13

by

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Declaration

I, Rael Salkinder, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is submitted for another degree in this or any other university.

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List of Abbreviations

TENS	Titanium Elastic Nailing System
AP	Anteroposterior
mLDFA	Mechanical Lateral Distal Femoral Angle

Literature Review

Epidemiology

Paediatric diaphyseal femoral fractures are common injuries and account for between 1.4 to 1.7% of all fractures seen in this population.¹ The annual rate of children who present with femoral shaft fractures is estimated at 19 per 100000 in USA and Europe², while femoral shaft fractures are 2.6% more common among boys than girls.² The peak incidence is distributed bimodally at 2 and 17 years of age, while femoral shaft fractures are more commonly seen in summer months.³

Anatomy and Development

The femur is the strongest bone in the adult human skeleton and is surrounded by the largest muscle mass.⁴ It is formed from 1 primary ossification centre (femoral body) and 4 secondary ossification centres: the head, greater and lesser trochanters and the distal epiphysis. Of all the long bones, except the clavicle, it is the first to show traces of ossification.⁴ This commences in the middle of the femoral body, at about the 7th week of fetal life, and rapidly extends proximally and distally. The distal ossification centre is the last to fuse at around the twentieth year of life.⁴

During childhood, remodeling of the femur causes a change from primarily weaker woven bone to the stronger lamellar bone.³ There is a geometric increase in the femoral shaft diameter and relative cortical thickness up to 16 years of age.³ This results in markedly increased strength.³

The main vascular supply to the femoral head originates from the medial and lateral femoral circumflex arteries, branches of the profunda femoral artery.³ The medial circumflex femoral artery contributes the main blood supply.³ An extracapsular vascular ring is formed at the base of the femoral neck with ascending cervical branches that pierce the hip joint at the capsular insertion.³ These branches enter the femoral head just inferior to the cartilage. The artery of the ligamentum teres, a branch of the obturator artery, contributes a small percentage of the total blood supply.³ With the insertion of a locked intramedullary device, particularly with the

piriformis entry point, a high incidence of avascular necrosis of the femoral head was noted.⁵ This is a devastating complication.

The vascular supply to the femoral shaft is also derived mainly from the profunda femoris artery.⁶ The nutrient vessels enter the bone proximally and posteriorly along the linea aspera.⁶ The artery branches proximally and distally to provide the endosteal circulation which supplies the inner two thirds of the cortex.⁶ The periosteal vessels also enter the bone at the linea aspera and supply the outer one third of the cortex.⁶

When performing an open femoral fixation, it is important to avoid excessive periosteal stripping, especially posteriorly, as these are the areas where the arteries enter the bone. Stripping the periosteum excessively could result in delayed and non-unions.

Mechanism of Injury

Femoral fractures can be caused by direct trauma, indirect trauma as well as pathologic processes. Examples of direct trauma include motor vehicle accidents, paedestrian injuries, falls and physical abuse. Rotational type forces can result in indirect trauma to the femur. Causes of pathologic femoral fractures in the paediatric population include: osteogenesis imperfecta, non-ossifying fibromas, bone cysts and malignancies.³

The mechanism of injury of paediatric femoral shaft fractures also vary according to the age of the child. Physical abuse is a probable mechanism in up to 42% of infants but in only around 3% of children of walking age.⁷ Up to 42% of fractures in infants have been reported to be caused by physical abuse.⁷ As mentioned earlier the weaker woven bone is replaced by the stronger lamellar bone as the child matures and a much greater force is required to result in a fracture.⁸ Fractures in children over 6 years are largely due to high energy trauma, with motor vehicle accidents accounting for more than 90% of the injuries in adolescents.⁸ Femoral shaft fractures in older children and adolescents seem to be on the rise because of the increasing popularity of high speed recreational activities as well as full contact sports.

Clinical Evaluation

Age and mechanism of injury are key elements of the history. Although the majority of femoral shaft fractures in children are isolated injuries, children with high energy trauma frequently have associated intra-abdominal, chest and intracranial injuries. Thus, a full primary and secondary survey utilising the “Advanced Trauma and Life Support Protocol” should be followed in order not to overlook any injuries. The thigh and knee should be examined for any swelling or bruising suggestive of a fracture or dislocation. Skin integrity, circulation, signs of compartment syndrome and nerve function should be evaluated.

The orthopaedic surgeon should be vigilant of the possibility of physical abuse resulting in the fracture especially when the child’s age, history and radiographic findings suggest a non-accidental injury. Appropriate referral to social services should be made.

Radiographic Assessment

Anteroposterior and lateral radiographs of the femur should be obtained.⁹ Radiographs should include both the hip and the knee joint in order to rule out any associated injuries such as intertrochanteric fractures, femoral neck fractures and distal femoral physeal injuries.⁹ Fracture location, pattern, displacement, angulation and shortening should be noted.

A skeletal survey should be obtained if there is any suspicion of physical abuse.

MRI and bone scintigraphy are generally unnecessary but may aid in the diagnosis of occult undisplaced, buckle or stress fractures.³

Classification

Femoral shaft fractures in children can be classified using a descriptive or anatomic analysis.³

Descriptive

Open vs. Closed

Level of Fracture: proximal, middle or distal thirds

Fracture pattern: transverse, spiral, short oblique +/- butterfly fragment, long oblique +/- butterfly fragment, comminuted

Displacement – axial and translational

Angulation

Anatomic

Sub-trochanteric

Shaft

Supracondylar

Decision Making and Treatment Options

The treatment of paediatric femoral shaft fractures depends on many factors including the child's age, child's size, fracture pattern, whether the fracture is open or closed, associated injuries and the ability to obtain and maintain an age-appropriate reduction.^{10, 11}

Initially determining if the fracture is an isolated injury or part of polytrauma is critical in decision making.¹¹ A surgical approach is preferred for polytrauma patients to allow better nursing care and earlier mobilisation as well as to decrease complications associated with immobility.¹²

It is also important to remember that the child is part of a family and thus the family must also be taken into consideration when deciding on the appropriate treatment. Economic concerns and the family's ability to care for the child in a hip spica or external fixator are all extremely important factors to take into consideration. It is vital to decide on a treatment plan that minimizes the time period that the parent or carer would require to be absent from work in order to care for the child. Psychological effects are also important to consider especially in the adolescent age group. Prolonged hospitalisation also alters a child's self image and interrupts social and educational development.¹³ A surgical approach is therefore recommended in this age group.

Non-surgical treatment options include Pavlik harness, Gallows traction, immediate spica casting, initial traction followed by spica casting and prolonged traction.

Surgical options include flexible intramedullary nailing, external fixation, compression plating, rigid intramedullary nailing and submuscular bridge plating.

The main consideration when deciding on treatment of an isolated paediatric femoral shaft fracture is the age of the child. Children are grouped into the following age categories:

- Neonatal period to 2 years
- 3 – 5 years
- 6 – 11 years
- 12 years to skeletal maturity

Neonatal Period to 2 years

As mentioned previously, the highest incidence of child-abuse related causes of femur fractures occur in this age group.¹⁴⁻¹⁷ It is therefore imperative that the orthopaedic surgeon evaluates the child for this possibility.

A non-surgical approach is the treatment of choice in this age group. For infants up to 6 months, a Pavlik harness or spica cast may be used. Although both methods achieve union, a higher rate of skin complications occur in patients treated with a spica cast.¹⁸

For children between 6 months to 2 years with an isolated femoral shaft fracture with initial shortening of less than 1-2cm, early spica cast application is used. With shortening of more than 2cm, the child should be placed in skin traction for 3 – 10 days before the spica is applied.¹¹

In many public institutions in South Africa, overhead (Gallows or Bryant) traction is still utilized for children weighing less than 12.5kg with very few, if any, neurovascular complications.

Age 3 to 5 Years

Children in this age group with isolated femoral shaft fractures and with shortening of less than 1–2cm on initial radiographs can be placed in a double or 1½ spica cast. The child should be followed up within a week to check reduction.¹¹ The cast should be wedged to an acceptable alignment of 5 – 10 degrees in all planes if significant angulation is present.

In patients with isolated femoral shaft fractures with more than 2cm of shortening, 5 – 10 days of traction with delayed spica casting application is indicated. Again the cast should be wedged if angulation is unacceptable at follow up.¹¹

The 2 major concerns regarding spica casting are the risk of skin complications and the potential for loss of reduction, leg length discrepancies and malunion.

Based on a study by Illge et al¹⁹ the following recommendations are made in order to minimise the risk of loss of reduction in the spica cast:

- the knee should be flexed to > 50°
- the child should be followed up closely for the first 2 weeks
- Although not a contraindication for spica casting, initial shortening of > 2cm is a risk factor for loss of reduction

Leg length discrepancies are difficult to predict after femur fractures. This is not only due to the initial ability to obtain and maintain reduction but also due to the unique element of overgrowth experienced after fractures in the paediatric population. In a study by Martin-Ferrero et al²⁰ an average of 8.63 mm of overgrowth was found in children under 14 years of age. More overgrowth was found to occur in children between 3 and 9 years, in severely displaced fractures and in fractures where there was minimal overriding. Overgrowth took place mainly during the first year post fracture.

Another option for the treatment of isolated closed femoral shaft fractures in this age group is prolonged traction, either skin traction or skeletal traction. In many public health care centres in South Africa, prolonged balanced Thomas Traction is employed. The traction is applied until there is bridging callus on 3 of the 4 cortices

and there is clinically no pain or movement at the fracture site. In general the time spent in traction is one week per year of age plus one week; for example a 5-year-old child will be in traction for an average of 6 weeks. The rationale for utilizing this technique in South Africa is manifold. Most parents of the children admitted to the public health institutions with femur fractures stem from poor socioeconomic backgrounds and are often the sole income provider for the entire extended family. They are thus unable to spend any prolonged period of time at home to care for their child. Spending such a prolonged period away from their workplace would also jeopardize their jobs. Added to this is the great difficulty with access to public transport for follow up visits.

The presence of an open fracture or multiple fractures may preclude the use of a spica cast or traction and external fixation may be necessary in the acute setting.¹⁰

Age 6 to 11 Years

The most controversy surrounding the treatment of paediatric femoral shaft fractures lies in this age group.

The treatment of femoral shaft fractures in the 6 to 11 year age group has traditionally been a conservative one consisting of prolonged traction followed by casting. Recently, however, a trend towards a more surgical approach has been developing. Many authors argue that a more aggressive approach:

- Reduces residual angulation and shortening
- Decreased the cost of treatment by decreasing hospital stay
- Allows the child's parents or carer to return to their place of employment sooner
- Decreases the psychological and emotional effects of prolonged hospitalisation on the child and allows the child to return to school sooner

The various surgical options include: external fixation, flexible intramedullary nailing, traditional compression plating, bridge plating and the newer lateral entry nail for the older child in this age group.

The choice of treatment depends on the clinical situation, fracture configuration, surgeon's expertise and the family's preference and social circumstances.

Conservative

The primary concern with the conservative approach is the shortening and angulation at the fracture site. This complicates many fractures in this age group especially those caused by high energy trauma where the periosteal sleeve is disrupted. Up to 50% of fractures caused by high energy trauma require repeat reduction or other forms of treatment to correct the shortening and angulation.²¹

For fractures caused by low energy trauma and that have <2cm of shortening, immediate spica casting may be utilized. Fractures caused by high energy trauma or where there is over 2cm shortening may be placed in skeletal traction for 7 – 21 days prior to spica casting application.^{9, 11}

For the reasons stated above, there has been a general trend towards more surgical options to manage these fractures. It is also imperative to consider that a 10 year old child will be hospitalized for approximately 11 weeks with balanced traction as a treatment option. Placing a 10 year old child in a spica cast can also potentially lead to skin related complications. Added to this, parents would have to carry the heavy child around and a permanent caregiver would be needed at home for the duration of the casting. Public transport is another major limitation in treating these patients in spica casts.

External Fixation

There is still considerable debate whether the proposed advantages of the utilization of external fixation outweigh the potential complications thereof. Proposed advantages include earlier return to weight bearing, the ability to achieve satisfactory alignment and rapid stabilization without long incisions and periosteal stripping and the excellent access for wound care in open fractures.^{9, 22} Many surgeons steer away from this form of treatment due to the complications of delayed and non-union, leg length discrepancies, pin tract related infections and refractures.²³

The problem of pin tract inflammation and drainage is the most common complication of external fixation.²⁴ The use of systemic antibiotics range from 3.7%²⁴ to 35.7%²⁵. Most pin tract infections are however successfully treated with antibiotics and very few result in osteomyelitis.

The refracture rate has been reported to be between 2.1% and 21%.²³ Although it has been reported that dynamisation of the external fixator reduces the refracture rate, studies by both Skaggs et al²³ and Domb et al²⁶ disprove this. Skaggs et al²³ did however find that the refracture rate was related to the number of cortices demonstrating bridging callus at the time of fixator removal. The authors recommended fixator removal only once there was radiological evidence of bridging callus on 3 out of the 4 cortices.

External fixation is a useful option in open femur fractures, polytrauma patients as damage control surgery, as well as ipsilateral femur and tibia fractures. Whether it is the best option for isolated closed femur fractures is still controversial with conflicting reports. Hayek et al²⁷ supports external fixation for open femur fractures only whereas Krettek et al²⁸, Davis et al²⁵, Hedin et al and Blasier et al²⁹ have reported good results in isolated femur fractures.

Flexible Intramedullary Nails

Flexible intramedullary nailing using either stainless steel (Ender) or titanium (TENS) nails have gained much popularity for the treatment of paediatric diaphyseal femur fractures over the past 10 years. Stainless steel nails are much less flexible than titanium nails and therefore the biomechanical principles behind their use differ somewhat.

Stainless steel nails are “stacked” to improve canal fill and obtain semi rigid fixation whereas titanium nails balance the forces of the 2 opposing flexible implants. The titanium allows controlled micromotion at the fracture site, thereby stimulating callus formation and healing.³⁰

These devices have many advantages compared to other forms of treatment. They are inserted percutaneously, resulting in a minimal scar, they avoid open physes and they allow early mobilization with minimal hospitalization.¹⁰

Although many studies report good to excellent results with titanium elastic nails, it is not without complication. Ho et al³¹ reports a complication rate of 17% with complications ranging from skin breakdown and infection, non-union, refracture and leg length discrepancies to hardware malpositioning and peroneal nerve palsies.

The other complication related to titanium elastic nails that is of major concern is that of loss of reduction particularly femur length. Sink et al³² recommends that an alternative method of fixation be considered for length unstable fractures (long oblique, spiral or comminuted). 6 out of the 8 patients that required unplanned surgery for either loss of reduction or prominent nails prior to fracture union fell into the category of length unstable fractures.

The weight of the patient also has a bearing on loss of reduction. In a biomechanical study, Li et al³³ found an increased risk of loss of reduction in the sagittal and coronal planes in children weighing over 40 to 45kg.

In summary, flexible intramedullary nails are the treatment of choice for length stable femoral shaft fractures in children who weigh below 40 to 45 kg.

Plate Fixation

Compression Plating

Open reduction and plate fixation offers the advantage of anatomic reduction without the need for fluoroscopy, ease of insertion, applicability to any size of the medullary canal and early mobilization.³⁴ A long incision and consequent scar, possible increased blood loss and risk of infection are all reported disadvantages.³⁵ All plates used in children in lower limb fractures also need to be removed once the fracture has united (usually between 9 to 12 months post fixation) due to the risk of stress risers being created and the bone fracturing at the plate ends.

Bridge Plating

This newer method uses fluoroscopically assisted and percutaneous bridge plating through small incisions exposing the distal and proximal fragments and insertion of at least 2 screws in each fragment. The main advantage that has been cited by some authors is avoiding the need for major periosteal stripping, thereby allowing earlier and quicker bone healing.^{30, 36} Also important is that the fracture haematoma is not disrupted or removed as is the case with the traditional plating methodology. Other advantages over compression plating include less pain, more rapid return to normal functioning, less scarring and better cosmetic results.³⁶

Both Sink et al³² and Kanlic et al³⁶ found favourable results in children with unstable femur fractures treated by submuscular bridge plating with only 6 complications out of 51 patients in Kanlic et al's³⁶ study.

Age 12 to Skeletal Maturity

The complications associated with conservative management of femoral diaphyseal fractures in adolescents make surgical stabilization the most viable option. In a comparative study of conservative versus internal fixation, Reeves et al¹³ noted 4 delayed unions and 5 malunions in patients treated with traction and casting. There were comparatively no malunions or delayed unions in patients treated surgically.

Operative options include external fixation, flexible intramedullary nailing, locked intramedullary nailing, submuscular bridge plating and compression plating.

External fixation is especially indicated for adolescents who are haemodynamically unstable on admission to the trauma unit with or without pelvic or abdominal injuries.¹¹

Although it is well known that locked rigid intramedullary nailing is the treatment of choice for adults with femur fractures, their use in adolescent population still remains controversial.

Locked femoral intramedullary nailing provides good axial and rotational control and can be used for any fracture pattern. It also allows early mobilization with malunion, nonunion and infection being uncommon occurrences.⁵

The main concern with reamed locked intramedullary nailing is the risk of avascular necrosis of the femoral head as well as developing femoral overgrowth with the need for an epiphysiodesis at a later stage.

From all the cases reported of osteonecrosis of the femoral head, the majority are reported after using the piriformis fossa entry point.⁵ This is due to the smaller proximal femur being in close proximity to the medial circumflex femoral artery which is injured during insertion.¹⁰ Newer techniques, using the lateral greater trochanter as an entry point without straying medially, has decreased the risk of osteonecrosis by avoiding the critical blood supply.

Reports of femoral neck valgus and narrowing have been made after trochanteric nail placement in children of at least 9 years old. Gordon et al³⁷, however, found no evidence of this complication.

Research study

Introduction

Femoral shaft fractures are the most common major paediatric injuries managed by the orthopaedic surgeon.⁹ They account for between 1.4 and 1.7% of all fractures seen in this population.¹ Despite this, there has been much controversy surrounding the management of these fractures, most notably in the 6 – 13 year of age group, with a plethora of research failing to reach a consensus regarding the treatment strategy of choice.⁵

Historically the vast majority of paediatric femoral shaft fractures have been managed conservatively.³⁸ Conservative measures include harnesses, hip spicas as well as applying traction to the femur. Although most femoral fractures unite regardless of fracture configuration, displacement and treatment method used, complications are not infrequent. These include delayed unions, non-unions, leg length discrepancies as well as angular and torsional deformities.¹¹ These factors as well as economic pressures and hospital resources have driven this traditionally conservative approach towards a more surgical one. The most appropriate surgical option, particularly in children between 6 and 13 years, is still however, controversial.

Titanium Elastic Nailing System (TENS) is the most appropriate option for length stable fractures (transverse or short oblique) in children who weigh below 45kg.^{33, 39} However, larger patients with length unstable fractures remain a challenge, given the ability of flexible nails to maintain fracture length in these cases may be less than optimal.⁴⁰

External fixation has been advocated by some as safe and effective^{29, 41, 42}, yet others have noted significant refracture rates, pin tract infections, quadriceps contractures and unsightly scars.⁴³ Traditional compression plating provides excellent stability and maintains fracture length and alignment. It is complicated by a high risk of hardware failure as well as a non-union rate as high as 10%.^{44, 45} These disadvantages as well as the necessity for a large incision and with considerable blood loss have limited its acceptance.^{34, 45}

Although the traditional locked intramedullary nailing technique is the treatment of choice in adults, reports of avascular necrosis of the femoral head in children using the piriformis entry point makes its use difficult to justify.⁴⁶ Studies using the relatively new lateral trochanteric entry nails for children older than 8 years of age are proving promising with no reports of avascular necrosis or significant alteration in the neck shaft angle.⁴⁷ Further studies as well as long term follow up are, however needed.

Submuscular bridge plating is a minimally invasive technique that provides relative stability to the fractured diaphysis while maintaining length and angulation.³⁶ There is minimal disruption of the healing milieu at the fracture site.³⁰ It avoids the growth plates and does not disrupt the blood supply to the femoral head.³⁰ This technique potentially avoids the complications associated with the other surgical methods of treatment, such as the suboptimal stability with titanium elastic nails in length unstable fractures; the refracture rate and pin site infections with external fixation; the wound complications as well as non-union rates with traditional compression plating as well as the potential for avascular necrosis with the piriformis-entry intramedullary nail.

The aim of the study was to prospectively and comprehensively evaluate the outcome of submuscular bridge plating of length unstable femoral shaft fractures in children between 6 and 13 years of age.

After evaluating all the available literature, we hypothesized that submuscular bridge plating is a viable and reliable option to treat these fracture. We postulate that this technique should allow earlier mobility and discharge from hospital with excellent union rates and relatively few complications, particular malunions, sepsis and refractures post hardware removal.

Methodology

Study Population, Sample Size & Inclusion / Exclusion Criteria

The study was conducted at Tygerberg Hospital's Paediatric Orthopaedic Department in Cape Town, South Africa. All children between the ages of 6 and 13 who were admitted to the orthopaedic department with a length unstable femoral shaft fractures, were asked to participate in the study.

All the available treatment options (conservative and surgical) and the advantages and disadvantages of each option were discussed parents or legal guardians so that an informed decision could be made. Informed consent was obtained from all the parents and/or legal guardians before the children could participate in the study. The Health Research Ethics Committee of Stellenbosch University South Africa granted ethical approval for the study. (Ref no: N10/11/350). The study was conducted over a period of 2 years, starting on the 1st January 2011 and finishing on the 31st December 2012.

Operative intervention details

Patients were assessed on admission and kept in balanced Thomas traction until the surgical intervention. All patients were treated by the specialized pediatric orthopaedic surgeon and/or any of the other senior (post-intermediate examinations) registrars within 4 days after the admission to the hospital.

All patients were fasted for 6 hours prior to the surgical intervention. The correct weight appropriate doses of prophylactic intravenous cefazolin (1st generation cephalosporin antibiotic) and general anaesthesia without muscle relaxant was given and monitored by an anaesthetist. The patient was positioned on the traction table and preoperative fluoroscopy was used to reduce the fracture as best as possible. (Figure 1)



Figure 1: The use of a fluoroscopy to most optimally reduce the femur fracture with the traction table.

The operation site was then sterilized and draped. An incision of about 5 cm was made at the location of the greater trochanter (Figure 2) or at the lateral distal femoral metaphysis depending on the fracture site. A greater trochanteric incision was used when the fracture was more proximal and a distal incision for a more distal fracture. Blunt dissection was performed to the plane between the periosteum and surrounding musculature.



Figure 2: An incision of about 5 cm made at the location of the greater trochanter.

A Synthes® 4.5mm staggered Low Contact-Dynamic Compression (LC-DC) plate with locking options was used. It was bent using a bending press to the shape of the femur using the preoperative radiographs as well as the intraoperative screening radiographs as templates. (Figure 3)



Figure 3: Bending the Synthes® 4.5mm plate in the shape of the femur.

The plate was then advanced submuscularly along the femoral shaft. (Figure 4)



Figure 4: Advancing the plate submuscularly along the femoral shaft

After ensuring that the plate was in the centre of the bone, screws were inserted through stab incisions placed over the desired holes using fluoroscopy. The fracture was reduced to the plate. (Figure 5)



Figure 5: Fracture reduction to the plate using cortical screws through stab incisions.

The aim was to obtain fixation into 6 cortices on either side of the fracture. Compression screws were used unless the fracture extended into the metaphysis and the desired 6 cortices could not be obtained. In these cases locked screws were used on that side. The wounds were closed meticulously in layers with subcutaneous absorbable sutures for the skin. The surgical wounds were dressed with an adhesive dressing.

A postoperative radiograph was taken prior to discharge to assess the initial fixation. Patients were discharged once they were able to mobilize partial weight bearing with either crutches or a walking frame. Progressive weight bearing was allowed once fracture callus was seen on follow up radiographs.

The children were followed up at 2 weeks post surgery for a wound inspection and then at 6 weeks; 3 months and 6 months post procedure. X-rays as well as physical examinations were performed. The plates were removed at 6 months post surgery. Final follow up was at 9 months post surgery.

Assessment

Both AP and lateral radiographs were taken on admission as well as after the application of the balanced Thomas traction. The fractures were classified according to the anatomic and descriptive classification systems described above.³ Theatre time, blood loss, the length of the surgical wound, screening time and intra-operative complications were recorded during the operation. At 2 weeks, 6 weeks and 3 months, patients returned to the hospital for follow-up assessments. During these visits the wound was inspected and an X-ray was taken to assess for union of the fracture and check for any hardware complications. Six months post-operatively patients returned to the hospital for the removal of the plate during a second surgical intervention. During this operation, theatre time, blood loss, screening time and complications were again recorded.

A final follow assessment was performed at 9 months post surgery. In addition to the normal clinical assessment of range of motion and rotational profile, long leg standing AP and lateral X-rays were taken to assess the mechanical lateral distal femoral angle (mLDFA). These were compared to the non-operated side using the PACS system. Leg length differences between the operated and non-operated side were also assessed with the use of these x-rays as well as clinically, while any wound related complication were also recorded.

Statistical Analysis

STATISTICA version 11.0 (Sta-soft Inc., Tulsa, OK, USA). Mean basic descriptive statistics were used to describe pre-and postsurgical outcomes. All data were expressed as mean \pm standard deviation. Differences between the affected and unaffected side were analyzed with a T-test for independent samples. A significant difference was accepted at a $p < 0.05$.

Summary statistics were used to describe the variables. Medians or means were used as the measure of central location for ordinal and continuous responses and standard deviations and quartiles as indicators of spread. \pm Furthermore, complication

rates were analyzed using proportions and appropriate 95% confidence intervals were given for all measured and dichotomous outcomes.

The relation between two nominal variables was investigated with contingency tables and likelihood ratio chi-square tests.

Results

Thirty consecutive patients between the ages of 6 and 13 with length unstable femoral shaft fractures participated in the study. 1 child could not be contacted for final follow up and was excluded from the results. The descriptive statistics of the remaining 29 participants are shown in Table 1.

Table 1. Descriptive statistics of the participants (n=29)

Variable	Mean \pm SD (%)
Age (years)	9 \pm 2
Gender (male / female)	20 (69 %) / 9 (31 %)
Fractured side (right / left)	17 (59%) / 12 (41 %)
Mechanism causing the fracture	
Low-energy fall	12 (41%)
Struck by an inanimate object	6 (21%)
Vehicle accidents	5 (17%);
Sports injury	4 (14%)
Altercation	2 (7%).
Fracture type	
Spiral fracture	15 (52%)
Oblique fracture	6 (20%);
Long oblique fracture	2 (7%)
Comminuted fracture	4 (14%)
Transverse fracture	2 (7%).

All children were admitted to the hospital with closed fractures except for one patient who sustained a Gustillo and Anderson grade 1 open femur fracture. Most children (59%) waited over 72 hours in balanced traction before the surgery. The mean operating time was 66 \pm 15 minutes with average total incision length of 10.4 \pm 2.7 cm (6 – 16 cm), while the average radiation exposure amounted to 88 \pm 28 seconds (23 – 138 s). 13-hole plates were used most frequently. The average blood loss

during the procedure amounted to 121 ± 83 ml (20 – 400ml). Children were discharged at an average of 8 days post surgery and ranged from 4 to 31 days.

Unfortunately 1 fracture site (3%) had to be opened in order to obtain reduction as indirect reduction was deemed impossible.

Follow up assessments:

All 30 patients revisited the hospital for their 2 week, 6 week and 3 month follow-up assessment. X-ray's showed that all fractures were fully united by 3 months post surgery.

Plate removal

Plates were removed at an average of 8 ± 3 months post plating. Average surgical time was 32 ± 9 minutes and blood loss 48 ± 39 ml. Screening time ranged from 0.01 to 60 seconds with the average being 6 ± 12 seconds.

Nine month follow up assessment

No significant overall leg length discrepancy ($p=0.94$) or mechanical axis deviation ($p=0.51$) were found between the affected and unaffected lower limbs at 9 months post surgery. There was no significant mechanical axis discrepancy between the operated and non operated sides. (Figure 6)

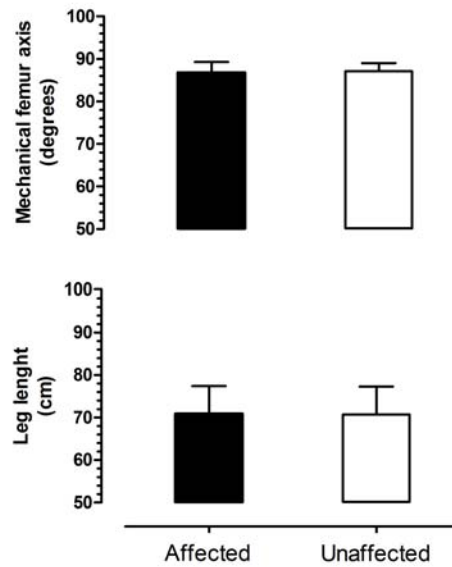


Figure 6: Differences in leg length and mechanical femur axis between the operated (black columns) and non-operated side (white columns).

Clinical assessment at 9 months showed no significant differences in hip flexion ($126 \pm 14^\circ$ vs $127 \pm 13^\circ$, $p=0.88$), hip external rotation ($32 \pm 12^\circ$ vs $35 \pm 11^\circ$, $p=0.36$), hip internal rotation ($50 \pm 10^\circ$ vs $46 \pm 9^\circ$, $p=0.12$) and knee flexion ($147 \pm 13^\circ$ vs $148 \pm 13^\circ$, $p=0.96$) between the operated and non-operated side. (Figure 7)

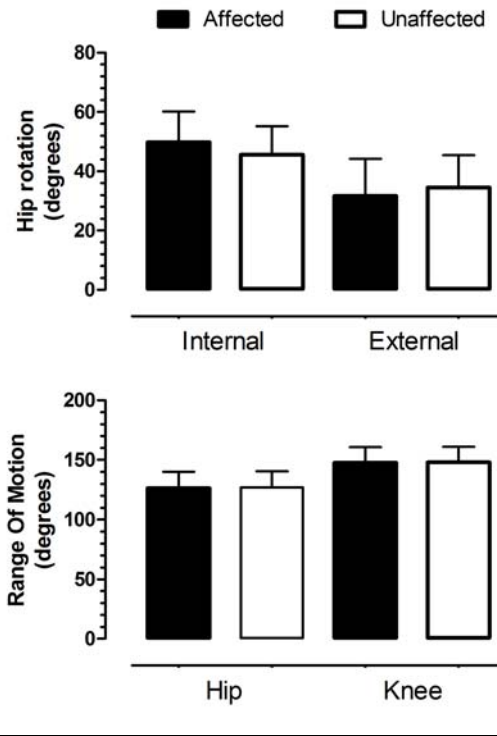


Figure 7: Differences in range of motion and rotation between the operated (black columns) and non-operated side (white columns)

Complications

There was difficulty removing 1 plate that was inserted 10 months prior due to severe bony overgrowth, necessitating the prolonged screening time of 60 seconds. One minor and 1 major complication were found at final follow up. 1 child developed hypertrophic scars which did not cause the patient any concern and was treated conservatively.

The major complication was that one child's femur was plated in 25 degrees of internal rotation. This did not, however, cause the child any functional disturbance.

Discussion

The treatment of paediatric femoral shaft fractures, particularly in the 6 to 13 year age group, has in recent times moved away from the traditionally conservative approach to a more surgical one.¹⁰ Depending on the fracture pattern and other patient and economic factors, several different methods of fixation are available, including flexible intramedullary nailing, external fixation, open compression plating, lateral entry intramedullary nails and submuscular bridge plating.

Given our results, we conclude that submuscular bridge plating is a viable and predictable method of fixation for more complex length-unstable paediatric femoral shaft fractures. Bridge plating was utilized in 30 patients with length unstable fractures where other methods were deemed to be less effective. Fracture reduction was maintained and no significant leg length discrepancy or malalignment in the axial or coronal plane was found. There were also very few complications.

The mean operating time for the index procedure in this study was 67 ± 14 minutes with the average total incision length being 10.4 ± 2.7 cm and average radiation exposure of 90 seconds. This series compares favourably to a study by Kanlic et al³⁶ where 51 patients had surgical times of 106 minutes on average. A study by Bar-on et al⁴⁸ comparing external fixation and TENS nails in a similar cohort (19 children with 20 fractures) found an average surgical time in the external fixation group of 56 minutes and in the TENS nails group of 74 minutes. Fluoroscopy averaged 84 seconds in the external fixation group and 156 seconds in the TENS group. Open compression plating allows minimal radiation exposure due to direct reduction¹⁰, however the large surgical incision and consequent scar makes its use unfavourable particularly with the development of newer techniques available nowadays.

We found the average blood loss during the index procedure to be 130ml (40 – 400 ml) with no requirements for blood transfusions. In the largest compression plating series to date of 60 children, Caird et al⁴⁵ found an average of 200ml (40 – 1500ml) blood loss with 2 polytrauma patients requiring blood transfusions.

All fractures in our series united by 3 months post surgery. This was comparable to similar bridge plating studies by Sink et al⁴⁹ and Agus et al⁵⁰ where bridging callus on 3 of 4 cortices was noted at 11.7 and 12.4 weeks respectively.

Plates in our series were removed at an average of 8 ± 3 months. The average surgical time was 32 minutes and blood loss 48 ml. In a similar study by Sink et al⁴⁹ an average of 56 minutes was taken for plate removal.

At final follow up (9 month) there was no significant difference between the operated and non-operated sides in terms leg length discrepancy; range of motion of the hip and knee as well as alignment in the axial and coronal planes. These results are similar to the series by Kanlic et al.³⁶

Other fixation methods used to treat length unstable femoral shaft fractures do not compare as favourably.

TENS nails are the treatment of choice for length stable fractures.³² A proven complication in length unstable fracture configurations is that of loss of reduction, particularly femur length. A study by Sink et al³² proved that titanium elastic nails are not appropriate in length-unstable fracture types. It was found that 6 out of the 8 patients that required unplanned surgery for either loss of reduction or prominent nails prior to fracture union fell into the category of length-unstable fractures.

In our view external fixation should be reserved for polytrauma patients or in patients with high-grade open femur fractures. In a study by Aronson and Tursky⁴¹ of 42 patients who underwent external fixation, 20% had greater than 5 degrees varus or valgus malalignment, 66% experienced malrotation averaging 10 degrees and 42% had a leg length discrepancy averaging 6.5mm.

As a result of the difficulty encountered in removing 1 plate that had been in situ for 10 months, we recommend removal at 6 months post surgery provided there is

union. We experienced no refractures, hardware failures or wound infections in our series. We did, however, experience 1 minor and 1 major complication.

One child's femur was plated in 25 degrees of internal rotation. This patient was one of the first in our series and was performed by a registrar. In critical review of the case, it was determined that during placement of the child on the traction table, the hip fell off the table into external rotation while the knee was maintained with patella facing anterior. This inadvertently caused the deformity. In order to avoid this complication, we conclude that it is imperative to ensure during patient set up that both the hip and knee face directly anteriorly. In addition, fluoroscopy can aid by ensuring that a true AP image of both the hip and knee are obtained prior to the surgery. We found that there was somewhat of a learning curve to master this minimally invasive technique.

3 significant complications were experienced in Kanlic et al's³⁶ bridge plating study: 1 hardware failure of a small fragment titanium plate; 1 refracture through a non-ossifying fibroma and 1 peroneal nerve neuropraxia.

External fixation techniques have significantly greater complication rates in most series. They have high rates of delayed and non-unions; refracture rates of up to 21%²³ and pin tract infections of up to 73%.⁴³

TENS nails are also not without complications. Ho et al³¹ reports a complication rate of 17% with complications ranging from skin breakdown and infection, non-union, refracture and leg length discrepancies to hardware malpositioning and peroneal nerve palsies.

In Caird et al⁴⁵ series on compression plating, 1 early hardware failure, 2 refractures post plate removal and one patient with a 2.8 cm leg length discrepancy were experienced.

This series indicates that submuscular bridge plating is an alternative to treat length-unstable femoral It makes use of a minimally invasive technique with resultant small

well-accepted scars and does not disrupt the fracture biology. It allows for early mobilization and discharge. Bridge plating was performed in 30 patients in this study with good results. The reduction was maintained and all fractures went onto complete union within 3 months. There were no symptomatic malalignments or leg length discrepancies and all patients returned to full activities. The 1 major complication of rotational malalignment was due to a preventable technical error. Weaknesses in our study include lack of a comparison group.

In conclusion, this series provides evidence supporting the use of submuscular bridge plating in length-unstable femoral shaft fractures in children between the ages of 6 and 13

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