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REVIEW ARTICLE

Diaphyseal femur fractures in children. Treatment update

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Abstract
The treatment of diaphyseal femur fractures in children is a subject of great controversy due to the procedures employed in adults not being applicable during the growth period. However, there appears to be some consensus in that the method we choose must lead to shortening the hospital stay, is comfortable for the patient, provides suitable stability to the fracture and has less complications and after effects. There is some unanimity in that the methods of choice should be conservative in children less than 5 years-old (Pavlik harness, early cast), except in complex situations. It is from 6 years to 13 years, the period in which one method or the other that should be discussed more. Nowadays, elastic intramedullary nailing is the method preferred by many authors, particularly for transverse fractures and those located in the middle third, except in cases of great instability. In these situations of comminuted or oblique fractures with monolateral external fixation, the rigid nails introduced from the trochanteric region and percutaneous plating can be a good option. There is currently no method that could be applied to all the different types of fracture. The chosen therapeutic option should be based on the clinical stability of the patient, the characteristics of the fracture, diameter of the medullary cavity and weight of the patient.

PALABRAS CLAVE
Fractura fémur;
Clavos elásticos;
Fijación externa;
Clavo intramedular;
Placa percutánea;
Hipercrecimiento;
Remodelación

Fracturas diafisarias del fémur en el niño: actualización en el tratamiento

Resumen
El tratamiento de las fracturas de la diáfisis del fémur en el niño, está sometido a una gran controversia, debido a que los procedimientos que se emplean en los adultos no son aplicables durante el período de crecimiento. No obstante, parece que existe un cierto consenso en que el método que elijamos debe ir encaminado a acortar el tiempo de estancia hospitalaria, que sea confortable para el paciente, que proporcione una adecuada estabilidad a la fractura y origine en menor número de complicaciones y secuelas. Parece

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existir cierta unanimidad en que en menores de 5 años los métodos conservadores (arnés de Pavlik, yeso precoz,...) son los métodos de elección salvo en situaciones complejas. Es a partir de los 6 años y hasta los 13 años, el período en el cual la indicación de un método u otro puede estar más en discusión, si bien hoy en día el enclavado intramedular elástico es el método de predilección por parte de la mayoría de los autores, sobre todo para fracturas transversales y que asientan en el tercio medio, excepto en casos de gran inestabilidad. En estas situaciones de fracturas conminutas o con trazos oblícuos, la fijación externa monolateral, los clavos rígidos introducidos desde la región trocantérica y las placas atornilladas percutáneas submuscular pueden ser una buena opción. En la actualidad no existe un método que pueda aplicarse a la totalidad de los diferentes tipos de fractura. La opción terapéutica elegida deberá basarse en la estabilidad clínica del paciente, características de la fractura, diámetro de la cavidad medular y peso del paciente.

Introduction

One of the most common reasons for hospitalization in a Paediatric Traumatology Unit is fracture of the femoral diaphysis. The vast majority of these cases resolve satisfactorily with orthopaedic treatment, both quickly and without any evident sequelae. Until recent decades, standard treatment, and a method that is still widely used in many hospitals, consisted in the placement of a system of soft or skeletal traction for a period of 3-4 weeks, before proceeding later with the placement, under sedation, of a spica cast for a period of approximately one month.

In cases of children with multiple trauma, there are life-saving priorities that force the stabilization of limb fractures to be considered as secondary. Once vital signs are controlled, something that can consume the first hours or even days, and once the patient is haemodynamically stable with adequate ventilation, fracture synthesis becomes an emergency with the aim of freeing the patient from assisted ventilation, skeletal traction or large scale immobilizations as soon as possible, thereby allowing the patient to leave the ICU and initiate rehabilitative treatment and physical and psychological re-adaptation to daily life. The complications derived from polytrauma during childhood are different from those that may be seen in adults. PTE, fat embolism, etc. are not common in children. On the other hand, issues surrounding respiratory ventilation due to prolonged intubation time, shortening or axial deviations of the limbs, and joint stiffness are frequent complications in these cases owing to an unnecessary delay in making treatment decisions and may require surgical treatment if they are to be overcome and the child left without any permanent sequelae.[1,2]

The classic orthopaedic treatment has been falling by the wayside in favour of modifications in orthopaedic/conservative treatment or other surgical procedures that avoid the period of time in traction or cast immobilization with the aim of shortening the length of hospitalization and decreasing the incidence of defective consolidations. These surgical procedures are very appealing to orthopaedic surgeons and "a priori" have tremendous advantages if we compare them with the traditional conservative method, but they do not all have the same indications, complications, learning curve, and economic costs. Some have been implemented initially on the basis of the good outcomes observed in the adult population, in the excitement of "surgical fads" and have also been abandoned as a result of the complications that have arisen and due to the "excellence" of other new surgical trends.

It might be said that the indication for treatment of fractures of the femoral diaphysis should not be based solely on the type and location of the fracture and the expertise of a given surgical technique. Other aspects must also be factored in, including age, associated trauma, bone quality, knowledge of different surgical techniques, bone diameter and the medullary cavity of the femur involved, the patient's weight, economic costs, etc. There is no one method devoid of complications; some are more demanding than others from a technical perspective, but among all surgical treatments, some are capable of making up for the lacks of another and, at the end of the day, can offer the patient the best treatment option available with the lowest number of complications or sequelae over the medium to long term. This is, in short, what should concern and guide us.

Therefore, not all surgical treatment alternatives are valid for all different types of fractures. These modalities should respect a series of "precepts" such as: 1) they should not alter the fracture focus; 2) they should use minimally invasive procedures, and 3) they should spare growth cartilage, as well as the vascular integrity of the femoral head.

This work reviews the current guidelines for treatment of diaphyseal fractures of the femur in childhood, their advantages and disadvantages, as well as the common and specific complications of each of the different methods.

General considerations

Fractures of the femoral shaft are more common in males with a 3:1 ratio. In terms of age, 11%involve a child under

the age of 2 years; 21% occur in children between the ages of 3 and 5 years; 33% are seen in children aged 6 to 12 years, and 35% in children between the ages of 13 and 18 years. The most common location is at the level of the middle third and are transverse (60%) fractures, followed by those that occur in the proximal third (20%); the most uncommon are those involving the distal third (10%). The incidence of open fractures is low, fewer than 5%.

The most usual fracture mechanism in children under the age of 3 years are casual falls in the home or recreational areas, or are due to physical abuse. In older children, motor vehicle accidents or sporting accidents are the most frequent cause. On occasion, the fracture is located in diseased bone (osteogenesis imperfecta, essential bone cysts, ...).[3]

The patient's age confers certain typical characteristics that are different from those found in fractures in adult patients: fast consolidation with abundant bone callus, the phenomenon of overgrowth of the femur for some 12-18 months following fracture, as well as the possibility of spontaneous correction of residual deformities by means of remodelling, with the exception of rotational deformities, although these deformities may be masked by the tremendous rotational mobility of the coxofemoral joint.

Treatment

The ideal treatment would be one that would control fracture reduction; it would be comfortable for the child and have the slightest psychological impact possible; it would allow and facilitate the care dispensed by nursing staff and hygiene, and would leave no after-effects.

As previously mentioned, there is no single treatment for all fractures of the femoral diaphysis. It will depend on a series of factors, such as age; weight; soft tissue injuries; type and location of fracture; head, thoracic, or abdominal trauma, or other associated fractures. It will also depend on the surgeon's expertise and the characteristics of the hospital. It is also important to have a keen understanding of the family's psychosocial situation.[4,5]

Treatment can be divided into two main groups:

A. Conservative treatment

Many procedures have been described depending on the application of traction (cutaneous or bone) and its direction (horizontal, vertical, or oblique) with subsequent immobilization by plaster casting. For the last several years, traction has also been falling into disuse, in favour of early immobilization of the fractured limb with a cast or with a variety of devices.

1. Bryant's traction or zenith traction

When applied properly and with meticulous monitoring, it is indicated in children weighing less than 18 kg (approximately 40 lbs) and less than 2 years of age with displaced fracture. This type of traction is efficacious, as long as there is no spasticity or contracture of the hamstring muscles and as long as the hips can be easily flexed to 90° with extended knees. This treatment should therefore be avoided in children with infantile cerebral palsy, arthrogryposis, or any other pathology coursing with decreased hip mobility.

Cutaneous traction is applied to both legs, placing a weight that generally varies around 15-20% of the body weight on each leg or the weight needed to elevate the child's pelvis off the surface of the bed. It is a good idea to attach the child's pelvis and trunk to the crib with a modified diaper or sheet.

In infants, a bone callus forms very quickly and 2 or 3 weeks after the trauma, the pain disappears and the fracture will be stable enough to allow traction to be removed and a spica cast to be applied (or not) for a period of 3-4 weeks. This can also be done in the home if there is appropriate collaboration on the part of the parents, thereby shortening the hospital stay and treatment costs.

The patient's extremities must be monitored at all times for the possibility of skin, vascular, or neurological complications. Circulatory problems are rare, but are the most severe (Volkmann's ischaemic contracture). Another danger is the paralysis of the external popliteal sciatic nerve. It is important that circulation, temperature, mobility, sensitivity in the toes be checked at regular intervals. Care must be taken in placing dressings and adhesive strips of the traction so as to avoid causing soft tissue injuries, particularly bedsores in the area of the heel, blisters on the skin.[6,7]

2. Cutaneous or skeletal traction and subsequent spica cast

For some orthopaedists, this is the system of choice for fractures of the femoral shaft in children between the ages of 2 years and 13 years, as it avoids surgical intervention, a situation sometimes due to the lack of infrastructure in some of the smaller hospitals in our country in which anaesthesia in children under the age of 8 years is an impediment difficult to understand for the surgeon.

Soft or skeletal traction is placed in the region of the femoral suprachondyle or the tibial infratuberosity. The weight to be used ranges from 2 to 4 kg with the lower limb resting on pillows or Braun's splint. The time traction will last for between 2 and 4 weeks, with weekly radiographic controls to check for shortening, angular deviations, and the appearance of a periosteal callus that will enable us to remove the system of traction and immobilize the patient using a spica cast with or without sedation.

In those cases where traction is temporary until scheduled surgical stabilization of the fracture and with the patient clinically stable, it is preferable to use soft traction, since it does not require added analgesia to control pain, can be applied without sedation, and does not contaminate a possible surgical entry in the event that elastic nails are to be placed in the suprachondylar region.[8]

The complications reported for this system of treatment include angular, rotational deviations and excessive shortening of the fracture, paralysis of the external popliteal sciatic nerve (generally due to sustained support and compression at the level of the neck of the fibula), difficult management of the patient suffering from polytrauma, and

Figure 1 11-year old male. Spiroid fracture in the right femur, treated conservatively by means of traction and subsequent spica cast. Consolidation in malrotation. Clinical control at 10 years of follow-up reveals the limb in a position of external rotation and decreased internal rotation of the hip.

poor tolerance of both the period of traction as well as that of immobilization in most cases (fig. 1).

Many types of traction have been described to improve control of the bone fragments (90º-90º skeletal traction) and relax the muscles of the calf, the back of the knee, and the iliac psoas, by the 90º position of both the hip and the knee. Nevertheless, traction should be placed under general anaesthesia, using a Steinmann pin or Kirschner wire inserted above the adductor tubercle, at the union of the third posterior and the two anterior tubercles of the femoral diaphysis, thereby avoiding injury to the growth cartilage and the suprapatellar bursa. The nail should be inserted perpendicular to the longitudinal axis of the femur, i.e. parallel to the articular axis of the knee. In the opinion of some authors, failure to meet this requirement would cause sequelae, such as axial deviations and dyssymetries. Transtibial traction at the level of the anterior tibial tuberosity should not be used in the light of the risk of damaging that portion of the proximal tibial physis, giving rise to a physeal bridge and a recurvatum deformity of the knee.[9]

3. Closed reduction and immediate immobilization with a spica cast

This is generally indicated in children under the age of 6 years. The main advantage of this type of treatment is that it shortens hospital stay, with clear beneficial repercussions in both social and economic terms.[10] However, it is hard to maintain the reduction achieved by this system and it requires frequent supervision, as well as repeated X-ray control during the first weeks, with the possibility of correcting secondary deviations by creating windows in the plaster cast.

This procedure should be carried out under general anaesthesia. The estimated time of immobilization in weeks is calculated by adding "3" to the patient's age (in years), so that, for example, the cast should be maintained for 7 weeks in a 4-year-old child.

Good outcomes are attained with this technique, although they are similar to the ones seen with traction and subsequent casting. Obesity, oedema, shortening and comminution of the fracture focus are all factors advising against the use of this method given the difficulty in maintaining the reduction.

Among the complications reported, the most common ones are defective consolidations and shortening of the extremity, mild excoriations and skin ulcers due to improper cushioning or rubbing on the edges, as well as frequent hospital visits due to deterioration of the cast (breakage, softening, the cast gets wet, etc.).

Variations on this method have been described, such as early immobilization with a spica cast with hips and knees set at 90º, or early immobilization as per Irani's technique, which consists of immediate reduction under general anaesthesia and simple traction, followed by immobilization with a bilateral spica cast with the knee flexed between 40 and 60º, including the feet so that the patient cannot place any weight on the cast and thereby avoid secondary displacements of the fracture.[11,12]

Simple immobilization with a Pavlik harness

This can be used in newborns and infants up to the age of one year. In the case of displaced fractures in newborns, it avoids the need to place the child in overhead traction or, in somewhat older children, it avoids the placement of an early cast.[13] The proximal fragment in these fractures is

Figure 2 Right obstetric femoral fracture in a newborn. The proximal fragment is displaced in flexion. Treatment with Pavlik harness.

generally in a significantly flexed position due to the physiological flexed position of the lower limbs present in newborns. The placement of the harness brings the distal fragment closer to the proximal fragment in flexion (fig. 2). Immobilization is usually necessary for a period of 4 weeks, and the deformity in antecurvatum and shortening that normally appears will gradually disappear over the course of the subsequent follow-ups thanks to the great remodelling capacity in children at these ages. However, among the disadvantages of this method is that there is greater pain during the first few days with the harness in comparison with placing the limb in overhead traction or in a spica cast.[5,14]

B. Surgical treatment

The classic indications for surgical treatment are patient with polytrauma, soft tissue injury, multiple fractures of the same limb, vascular injury, pathological fracture, associated brain injury, or isolated fracture in which reduction or stabilization are not achieved by orthopaedic means. However, these indications have been increasing in recent decades to cover all open or closed displaced diaphyseal fractures in children older than 5 years, since conventional treatment consisting of traction followed by casting leads to a high rate of malunions in addition to other disadvantages, such as prolonged hospital stay, increased economic costs, disturbance of family life and parents' work, as well as the child's schooling.[15]

The advantages contributed by the bloody treatment with respect to conservative methods include being able to achieve an anatomical reduction and/or stabilization of the fracture without axial or rotational deviations. Moreover, medical management and nursing care for the patient with polytrauma is better, making early mobilization possible with a lower rate of malunions, shorter hospital stay, and, hence, lower costs and better family and social re-adaptation.[16,17]

1. Screw-plates

The AO system with screw-plates was used decades ago with some outstanding immediate results. The need for open reduction and a second intervention to remove the material, entailing further deperiostization, may trigger excessive femoral overgrowth, on occasion of up to 4 cm. As a result of this situation, this procedure was replaced by other less invasive techniques.[18]

Nevertheless, a good indication of this method of osteosynthesis are sub-trochanteric fractures, which are

Figure 3 Five-year-old female. Diaphyseal fracture of the proximal third of the left femur. Reduction and synthesis with DHS Richards plate. X-ray control after removal of the osteosynthesis material.

Figure 4 Eight-year-old male, fracture of the medial third of the femoral diaphysis treated by means of intramedullary Kuntscher nailing. Long-term effect as a consequence of the epiphysiodesis of the trochanteric-cervical growth plate, leading to coxa valga, thinning of the femoral neck, and increased articular-trochanteric distance.

hard to manage with orthopaedic methods, as well as with other surgical methods. The opening of the focus of fracture and stabilization with AO or Richards plates greatly simplifies management of this hard to control type of fracture by the action of the powerful muscle groups (psoas and gluteals) surrounding it (fig. 3).

At present, AO plates have been gaining in popularity thanks to the fact that they can be placed percutaneously, although it does not appear to constitute a method that will become widespread, owing to the persistence of some uncertainties, such as the need to remove the material percutaneously and the associated difficulty, the dose of exposure to ionizing radiations for both the child as well as the surgeon, and the fact that as yet, there are no long-term studies to ascertain what degree of overgrowth can be expected with this percutaneous technique.[5,19-21]

2. Locking or non-locking rigid intramedullary nail

The rigid intramedullary nail started to be used in the paediatric population in the light of the satisfactory outcomes achieved in adults with Kuntscher nails in countries under German influence. As with the previously mentioned method, the immediate results are excellent[22] and the procedure does not require opening of the focus of fracture; nonetheless, long-term studies have been able to verify that the entry of the nail through the tip of the greater trochanter or the pyriform sinus brings about significant alterations in the growth of the proximal femur (coxa valga, growth arrest of the greater trochanter and thinning of the diameter of the femoral neck) (fig. 4).[23] Moreover, and more importantly, the case analyses recorded in the literature have shown that the risk of necrosis of the femoral head resulting from injury to the vascularization when inserting the nail through the pyriform sinus is between 1%and 2%[24] As a result, this method has also been abandoned given the importance of the sequelae it can potentially cause. Most authors recommend it in patients who are close to the end of their growth period or who have ceased to grow, starting at the age of 13 years.

Currently, new models of nails with angulation in the proximal portion similar to that of tibial or humeral nails are being used in children over the age of 10 years in an attempt to keep the retinacular vessels of the femoral neck from entering the femoral medullary cavity after a trochanteric or sub-trochanteric approach. As yet, there are no long-term results that enable us to know whether they injure the trochanteric-cervical growth plate of the proximal femur.[25,26]

3. Elastic intramedullary nailing

Elastic intramedullary nailing is the method of choice when treating displaced shaft fractures in children. It calls on different gauged titanium or steel nails based on the diameter of the diaphyseal medullary cavity with diameters ranging from 2 to 4 mm. In adolescents, 3-4 mm nails can be used, depending on the patient's weight, the diameter of the medullary cavity, and remaining growth period. In children aged 7-10 years, nails from 2.5-3 mm can be used.

A simple to recall formula is to measure the diameter of the medullary cavity and multiply it by the coefficient 0.4, so as to occupy 80% of the medullary space in the middle third of the femur.

The larger diameter of the elastic nail makes it more resistant to deforming the fracture focus due to compression and axial torsion according to experimental studies, although the use of the nails having the largest diameter possible can greatly impede its insertion. The authors of these experimental studies recommend using 3.5-mm nails for an endomedullary cavity of 9 mm.[27]

The nails are inserted a distance from the fracture focus, sparing the physis, either retrograde using a bilateral suprachondyle approach in the case of fractures of the middle and upper third, or with an external sub-trochanteric approach if the fractures are low. The nails are shaped according to a previously established curve so that there are always a minimum of three points of support in the bone, providing elastic stability to the assembly. An

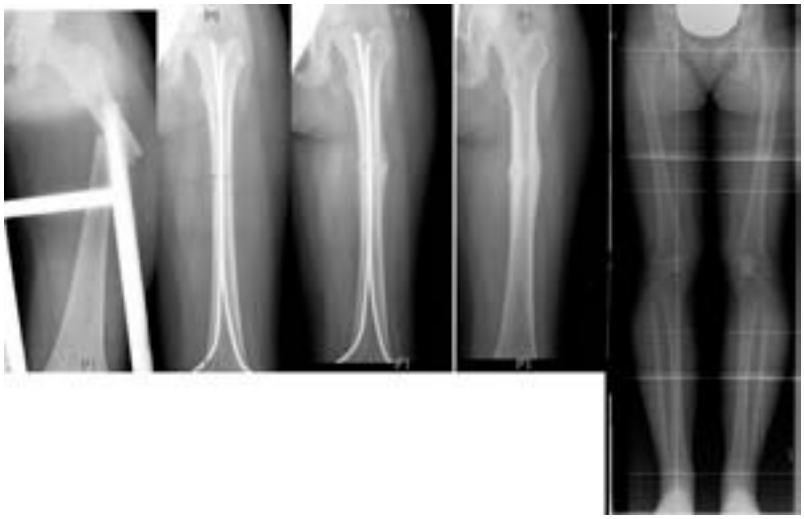

Figure 5 Thirteen-year-old female with a fracture of the left middle third of the femur. Treatment with TENS nails. X-ray control at one month, 3 months, one year, and at 2 years after fracture showed perfect consolidation without femoral overgrowth.

orthopaedic table can be used and an orthopaedic reduction attempted prior to inserting the wires. The limb is not subjected to load-bearing for 2 to 3 weeks, after which time partial load-bearing is allowed until the sixth week, when full load-bearing is allowed depending also on what is seen on the radiographic control.[28]

This procedure achieves very good results in short transverse or oblique fractures located in the middle third of the shaft, which accounts for the majority[29] (fig. 5). Nevertheless, in comminuted fractures or those that have great instability at the fracture focus, elastic intramedullary synthesis may not suffice to control the shortening, axial or rotational angulation, and a spica cast may also be needed for 3-5 weeks.[30] Likewise, fractures located in the sub-trochanteric region and distal metaphyseal-diaphyseal fractures do not constitute a good indication for this method, nor do adolescents having a medullary cavity greater of than 10 mm or who weigh more than 50 kg. Obese patients present a complication rate that is more than twofold that of non-obese patients.[31,32]

Among the most common problems presented by elastic intramedullary nailing are the discomfort suffered in the knee caused by nails that are a few centimetres too long to facilitate removal; thus, removal should not be undertaken before allowing 6-9 months to elapse so as to avoid new fractures. These nails, which are easily palpated in the subcutaneous tissue, often cause sero-haematomas or ulcerations with the consequent risk of infection. When the time comes to remove the material, it may sometimes be especially difficult because the ends have been trimmed too much or because the nails may have become intertwined in the intramedullary space or nails having the largest diameter possible have been used, filling more than 90% of the medullary cavity. On occasion, the time spent removing the nails is much greater than the time it took to place them in the first place.[33]

This method entails any number of advantages: it is easy to perform; it is associated with a low risk of infection; it does not interfere with the fracture focus; it does not produce any physeal insult, and it consolidates quickly. The disadvantages of this system are also well known: discomfort when moving the knee due to protrusion of the elastic nails. This generally occurs in oblique fractures that, after traction on the orthopaedic table or early weight-bearing, cause partial collapse of the focus of the fracture. In the case of comminuted fractures or fractures of the distal third, particularly if it follows an oblique trajectory, secondary displacement is to be expected; hence, a spica cast is usually associated for 3-5 weeks. The use of small gauge needles for the patient's medullary space, a medullary cavity of more than 10 mm or adolescents weighing more than 50 kg also cause secondary displacement.

Recent studies have demonstrated the advantage of steel nails in comparison with titanium nails. The greater stiffness afforded by the steel provides greater stability with fewer defective consolidations.[34]

4. External fixation

There are classical indications for external fixation in open diaphyseal fractures; for instance, patients with polytrauma, comminuted fractures, fractures with loss of bone substance, as well as certain pathological fractures.[35] In distal metaphyseal-diaphyseal fractures, placing the fixator in such a way as to bridge the physis temporarily makes it possible to stabilize and control the fracture until it has healed (fig. 6). Other authors have broadened the indications for this type of fixation as primary treatment for all femoral fractures in children or as rescue treatment when conservative treatment fails beginning at the age of 4 years.

When applying an external fixator treatment model, the use of modular, monolateral systems is the most widely recommended practice as it enables different configurations to be created with the intrinsic resistance providing sufficient stability until the fracture can heal. Nevertheless,

Figure 6 Two and a half-year-old female with polytrauma. Comminuted metaphyseal-diaphyseal fracture of the right femur. Reduction and synthesis by means of external monolateral fixation for 50 days. X-ray control at 3 months after removing external fixation.

in the suprachondylar region, the placement of rings assembled on wires can sometimes provide us with a more appropriate set-up in the case of fractures with an interchondylar course or with distal shattering that makes it impossible to insert the 5-6 mm screws of a conventional monolateral external fixator apparatus. In special situations, in the acute setting or when dealing with sequelae from a previous fracture in which there was substantial bone loss, we should set up an assembly to perform a conventional bone transfer (defects greater than 4 cm) or to apply compression to the fracture focus and compensate the residual dissymmetry with a proximal or distal osteotomy by means of callotasis (in the case of defects measuring less than 4 cm).

As far as the type of screw that should be used is concerned, they should be between 5 and 6 mm, except in small children with a diaphyseal femoral diameter of less than 2 cm. In this situation, the recommended screw calibre is 4-5 mm. The screws are a basic element and as such, deserve great attention with respect to the insertion technique, avoiding the use of high revolution motors (<500 rpm), due to the risk of thermal necrosis and secondary osteolysis that will surely give rise to infection or uncomfortable osteitis. For some years now, self-tapping screws or hydroxyapatite-coated screws have also been used with the aim of decreasing the incidence of osteolysis around the screw. Six screws at the level of the femur are recommended, whenever possible, so as to confer the greatest stiffness in the initial stage of fracture consolidation (the first 4-6 weeks) and because it is difficult to bring the fixator any closer than 4 cm due to the soft tissue in the thigh. This is why a monolateral assembly at a distance of more than 6 cm from the bone of a patient weighing more than 60 kg may be unstable and allow for a certain degree of varus angulation in axial weight-bearing according to biomechanical studies.

When the radiographic control reveals that there is incipient periosteal consolidation, greater weight-bearing is allowed on the limb. In cases in which the assembly is too stiff, it is possible that no periosteal reaction is seen. This would advise controlled movement of the external fixation system.

Unlike what occurs in adults, children do not generally require conversion of external fixation to internal fixation, since consolidation takes place more quickly. Once the fracture has been seen to have consolidated, usually by the third month, removal of the external fixation system is scheduled. Sequential removal of the equipment is recommended; first, the fixating body is removed and 10 days later, the screws. During this stage, caution must be taken during the mobilization manoeuvres of the knee given the risk of femoral refracture, of provoking a distal metaphyseal fracture as a result of the osteoporosis due to lack of use, or dislocation and/or fracture of the patella, due to the parapatellar external fibrous adhesions. Thus, if a refracture of the femur occurs during the period in which the patient still has the fixator screws in place, the solution is both simple and fast: the body of the external fixation system is put back in place. If it should take place several weeks after removing the screws, new surgery may be needed including osteotomy and osteosynthesis or the placement of a spica cast.

The incidence of refracture following removal of the external fixator is one of the most critical aspects associated with this treatment model.[36]

Other, more common complications include infection around the screws (which tends to be low-grade and generally responds well to local cleaning and oral antibiotics), axial deviations (usually varus and antecurvatum), and the phenomenon of overgrowth of the limb. The umbilicated, anti-aesthetic scars at the insertion site of the screws are of scant functional importance, but it may take several months for aesthetic repair after the material has been removed. Stiffness of the knee, commonplace while the fixator is in place due to transfixion of the external shaft, ordinarily disappears after 3 months following removal of the external fixation apparatus and without the need for specific rehabilitative treatment. In

the light of these disadvantages and to achieve greater comfort for the patient with open fractures and low risk of infectious complications, most surgeons opt for elastic or rigid intramedullary nailing.[37]

Complications

As previously mentioned, under the heading of "early complications", we would highlight that there is quite a difference between paediatric and adult patients. "Thromboembolism" is exceptional, although it has been reported during puberty and in patients who are especially prone (anti-thrombin III deficiency). In these cases, we must establish preventive guidelines with platelet anti-aggregants or low molecular weight heparins. "Fat embolism" reported by some authors during the first 72 hours after fracture is uncommon in children under the age of 10 years or may go unnoticed, although it may appear in adolescents.[38] "Hypovolaemic shock", present above all when there is polytrauma, does constitute a common occurrence in this type of accident patient. "Infection" (<2%) is occasionally seen when the fracture is open and there is accompanying soft tissue injury or when the focus must be opened in order to reduce the fracture or synthesize it. Antibiotic prophylaxis, anti-tetanus, and surgical debridement measures should be performed on these wounds. At these ages, "osteomyelitis" can contribute unfavourably to overgrowth of the limb.

"Late complications" present throughout the entire process of consolidation or during the subsequent course of the injury. They will be influenced by the characteristics of the fracture, of the person suffering the injury, and by the treatment system chosen. Among the most common late complications, the following stand out:

1. Limb length discrepancy

This is usually a result of the overgrowth of the affected leg. It is the most common complication and is typical in fractures of the femoral shaft in the children. The increased growth witnessed after this type of fracture may lead to a significant difference in leg length (>1.5 cm), causing the patient to suffer from a gait disorder, compensatory scoliosis, or low back pain. The maximum acceleration of growth is seen in the first 18 months following fracture. The degree of overgrowth is impossible to predict, although it is usually between 5 mm and 2 cm. Certain aspects can foster this complication to a greater or lesser degree, such as age, with a higher incidence in children between 2 and 8 years of age, according to some authors. This would be explained by the fact that in early childhood, fractures consolidate too fast for significant overgrowth to develop, and in the case of fractures that occur at later ages, growth potential is minimal. According to the location and course of the fracture; those that are located at the level of the proximal third and have a transverse fracture line are associated with greater overgrowth.

As far as treatment is concerned, some authors believe that the initial displacement of the fracture is a decisive factor in the final overgrowth. The discrepancy in limb length, a consequence of fractures of the femoral shaft, may be due to reduction with shortening, separation of the fragments, or to stimulation of linear growth. Several authors have deemed that a shortening of up to 3 cm is correct. Others consider that the most realistic figure would be around 1 cm. However, in children under the age of 2 years and in adolescents, growth stimulation is not as spectacular as in the intermediate ages of childhood; as a result, only minimal overlapping would be accepted.

As regards the side of the body the fracture is located on with respect to the patient's handedness, if the fracture is on the same side of the body as the dominant hand, the limb presents a mean amount of overgrowth of 8 mm, in comparison with an average of 14 mm when the fracture was located on the opposite side of the body from the patient's dominant hand. The surgical treatment applied is of foremost importance insofar as this phenomenon is concerned. The anatomical reduction and separation of the periostium with certain open techniques, such as the placement of screw-plates, has caused them to be relegated for a long time to the management of complex fractures or fractures with associated disease, particularly neurological pathologies. Some papers have compared the incidence of overgrowth on the basis of the type of treatment employed, finding that this complication is similar in patients who underwent bloody or non-bloody techniques, except when AO plates were used.[39]

Shortening of the affected limb due to accepting reductions with overlapping greater than recommended is less common than overgrowth. This has also been seen in highly shattered fractures treated by means of intramedullary fixation without a locking nail or diaphyseal fractures with associated physeal injuries around the knee, which initially went unnoticed and then manifest months or even years later[40,41] (fig. 8).

2. Axial deviations

Axial deviations represent a frequent complication, particularly when orthopaedic treatment is performed, with an incidence rate of 40% of all cases. The normal femur presents a natural curve in the sagittal and frontal planes and causes difficulties in the assessment, treatment, and measurement of angular deformities after consolidation.

There are several different opinions regarding the possibility of remodelling, depending on the degree of angulation and of the plane. In young children, this capacity is maximum of up to 30° in children younger than 10 years and up to 20° in those older than 10.[42]

The mechanism by which bone is capable of correcting angular deformities as it grows lengthwise is not fully known. According to Wolff's law, bone remodels depending on the loads it is subject to, in such a way that there is an effect of bone apposition on the concave side of the deformity and resorption is seen on the convex side. This remodelling reaches its peak in the main plane of movement of the proximal and distal joints to the fracture and when the fracture is close to the ends of the bone or close to the physis where, according to the Hueter-Volkmann law, the

Figure 7 Fracture of the middle third of the right femoral shaft in a 12-year old male treated by means of open reduction and synthesis with elastic nails. Pandiaphysitis (*Staphylococcus epidermidis*) and pseudoarthrosis at 4 months of follow-up that required removal of the osteosynthesis material, a 3-cm resection at the level of the focus of pseudoarthrosis and reconstruction of the bony defect by means of external fixation.

area of cartilage supporting the greatest mechanical load inhibits its growth and the area of cartilage supporting the smallest mechanical load accelerates or stimulates its growth. Remodelling of the deviations in antecurvatum and recurvatum are corrected better than those in varus-valgus. It has been seen that remodelling can continue for more than 5 years after the fracture.

These concepts have led different authors to consider angulation between 20º and 30º as acceptable in any plane, whereas others, bearing in mind the smaller remodelling capacity of the varus-valgus angulation, advise not accepting deformities in excess of 30º in the sagittal plane (antecurvatum-recurvatum) and 10º-15º in the frontal plane (varus-valgus).

When consolidation presents with angular deviations in excess of the limits described above, any possible surgical correction should be deferred at least one year, since remodelling might make surgery unnecessary. This happens, above all, in children under the age of 10 years, in fractures located close to the growth areas and when the axis of the deformity coincides with the axes of movement of the joints proximal and distal to the fracture.[43]

3. Rotational deformity

Rotational deformity is the third most common complication and can occur in any treatment type, albeit conservative methods are the most prone. It generally presents as increased femoral anteversion, presumably because of the action of the rotators on the proximal fragment. It is accepted that this type of deformity exists when the difference with the contralateral femoral anteversion is greater than 10º-15º, and this is translated into increased internal rotation at the level of the hip. Its spontaneous correction over time is a matter of significant controversy. For the vast majority of authors, there is no correction of this type while for others, spontaneous correction would occur only partially. When this defect does not exceed 20º, there is generally no resulting functional disorder.[44,45]

4. Refracture

Refracture is a rare complication. It is seen in older children and adolescents or in patients with pathological fracture due to osteopenia or neurological injury (ICP, myelomeningocele, ...). In some cases, refracture occurs despite the presence of a large fracture callus. When the decision is to do away with immobilization, a good clinical assessment is needed. The radiological criteria for appropriate consolidation are hard to define. Some cases of refracture can achieve good posterior consolidation by maintaining the initial treatment for a longer period of time, simple traction, or with intramedullary nailing. The use of external fixation is the treatment of femoral fractures that has been associated with the highest rate of refractures, although these have also been reported with the use of conservative methods and after the removal of osteosynthesis material when screw-plates or rigid or elastic intramedullary nails have been used.[36]

5. Delayed consolidation or pseudoarthrosis

Delayed consolidation or pseudoarthrosis is very rare, especially in children under the age of 10 years and for the most part only occurs in severe fractures requiring surgical treatment from the outset, in complicated cases with infection and/or in fractures produced by high energy trauma and with extensive soft tissue injury. The treatment decision in these situations must be made on a case-to-case basis and treatment will almost always be surgical,

Figure 8 Twelve-year-old female presenting femoral length discrepancy with 3 cm shortening, *genu valgum* and recurvatum. History of left femoral fracture in a motor vehicle accident, treated orthopaedically by means of transtibial skeletal traction and posterior placement of spica cast. The pre-operative radiological study shows the existence of an external physeal bridge in the distal femur responsible for the shortening and deformity in valgus, and a physeal bridge in the anterior portion of the proximal tibia, at the level of the insertion of the Kirscher wire for traction, responsible for the recurvatum deformity. Reconstruction of the deformities with external fixation systems at the level of the femur (double osteotomy) and tibia.

with freshening of the focus and bone grafts or reconstructive procedures of the segmental bony defects with external fixation systems (fig. 7), intramedullary systems, or AO.

6. Sciatic nerve injury

Sciatic nerve injury does not affect fracture consolidation, but it does delay the functional recovery of the limb and osteopenia in the rest of the bone, making it prone to refracture. Injuries to the external popliteal sciatic nerve have also been reported, all of them as a result of 90º-90º tractions with subsequent casting; this would be due to reduction manoeuvres or to pressure on the nerve as a result of a large haematoma and early cast placement, or to compression of the EPS nerve at the level of the neck of the fibula as a consequence of poor cushioning of the Braun splint. The injury generally consists of neuroapraxia that usually evolves favourably, although it requires supervision and treatment with a "rancho de los amigos" type orthesis that keeps the patient's foot properly positioned and avoids clubbing sequelae.

7. Premature physeal closure

A fracture of the femoral shaft can become complicated and injure the growth of the distal femoral cartilage or it can be a treatment complication (intramedullary nailing) and involve the physis of the greater trochanter and femoral neck.[23] In both cases, they tend to go unnoticed and are diagnosed late. The recurvatum deformity of the knee has been reported as a late sequela following tibial traction for fractures of the femoral diaphysis, although it can also appear without there having been prior traction caused by the pressure of the cast on the anterior tuberosity or direct traumatic injury in this area. Early fusion of the anterior portion of the tibial epiphyseal plate has been seen to derive into bowing and inversion of the posterior fall angle of the articular surface, with respect to the longitudinal axis of the tibia, possibly requiring surgical correction by means of osteotomy (fig. 8).

Conclusions

The treatment of femur fractures in childhood is controversial. There is no general consensus regarding the ideal treatment nor is there a treatment method capable of handling all types of fractures.

It is obvious that a diaphyseal fracture in an infant of just a few months of age has absolutely nothing to do with the same fracture in a 14-year-old adolescent. The mechanism of production, time of consolidation, remodelling capacity, and treatment make them very different situations. In the infant, management is conservative in practically all cases, whereas in the adolescent, treatment is surgical and relies on methods similar to those used in adults.

Doubt and controversy set in starting at the age when children start walking, when they begin schooling, have working parents, hospitals that examine the duration of hospitalization; that is, between 3 and 13 years of age. It is in this age group, which is the age at which most displaced

femoral shaft fractures occur, that there is great diversity of methods of treatment, both conservative and surgical. It appears that there is a general consensus in patients with polytrauma, open fractures, and pathological fractures, all candidates for surgical treatment. This bloody type of treatment is being extended to cover all displaced fractures of the femur, albeit not evenly spread over the hospital environment we are dealing with. In reality, if we are in a tertiary hospital, a child with a fracture of the femur has a greater chance of being treated surgically. In contrast, if we're working at a level 1 or intermediate hospital that does not have a paediatric ICU or where, for reasons the surgeon may be unaware of, the patient cannot be anesthetized because they are not of a given age or weight, the femoral fracture will be managed conservatively: traction for 2-3 weeks and subsequent placement of a spica cast.

Orthopaedic methods of treatment continue to be used in clinical practice. They achieve outcomes similar to those attained by means of surgical treatment, although the incidence of defective consolidations is higher compared to surgical treatments,[1,2] albeit children's tremendous innate capacity for remodelling will go a long way to ameliorating alignment defects following the consolidation of the fracture.

Each of the different modalities of surgical treatment has its advantages and disadvantages. Some are more indicated than others for the management of different fractures and all have their small learning curve, albeit they are procedures that are technically straightforward for orthopaedic surgeons accustomed to treating adults or with special dedication to paediatrics. In general, all these procedures should spare the physis and not alter the vascularization of the femoral head; they should be performed as percutaneous or minimally invasive procedures in order to avoid interfering with the consolidation process or the focus of fracture and be stable enough as to not require additional casting for immobilization.

Bearing in mind that the majority of the fractures are located in the middle third, have a transverse or oblique fracture line, and are short (60% of the cases), "stable elastic intramedullary nailing" is the most widely-used surgical procedure and is the treatment of choice, with excellent outcomes. However, this should not be the only treatment resource available to us nor should we abuse its indication.[30] In a certain percentage of cases, this method does not control the fracture adequately, such as the case of long, oblique, spiral, comminuted, pathological fractures with a medullary cavity greater than 10 mm, overweight children, and sub-trochanteric fractures or fractures that are close to the distal femoral metaphysis. In these situations, we should take other procedures into consideration, such as intramedullary nailing with proximal angulation inserted through the trochanteric region, percutaneous AO plates, Richards plates, and monolateral external fixation.

Level of evidence

Expert opinion. Level of evidence V.

Conflict of interests

The authors state that they have no conflict of interest.

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