Treatment of pediatric diaphyseal femoral fractures with intramedullary fixation

Leczenie złamań trzonu kości udowej u dzieci zespoleniem śródszpikowym

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Abstract

Femoral fractures are found in the daily practice of pediatric orthopedic traumatologists. This is related to the specificity of the child's skeletal system, different biology and methods used to treat these injuries. Diaphyseal femoral fractures account for approximately 3% of all long bone fractures in children and adolescents. They usually occur as a result of high energy injuries. This type of damage to the musculoskeletal system is a consequence of traffic accidents, falls from a height and practicing sports, including extreme sports. The treatment of femoral fractures during the development period depends on the type of injury, child's age and weight, associated injuries, and the experience and preferences of the treating physician. At present, it is assumed that in children over 5 years of age it is advisable to apply a minimally invasive surgical procedure. The fixation method should be simple and effectively stabilize the fracture. Currently, the use of titanium elastic nails (TENs) is standard in pediatric traumatology.

Key words: diaphyseal femoral fracture, ESIN method, ALFN fixation

Streszczenie

Złamania kości udowej są często spotykane w codziennej praktyce ortopedzy i traumatologa dziecięcego. Ma to związek ze specyficzną układ kostno-szkieletowego dziecka, inną biologią i stosowanymi metodami leczenia tychże urazów. Złamania trzonu kości udowej stanowią ok. 3% wszystkich złamań kości długich u dzieci i młodzieży. Zazwyczaj są skutkiem urazów wysokoenergetycznych. Taki typ uszkodzenia narządu ruchu bywa następczem wyypadków komunikacyjnych, upadków z wysokości oraz uprawiania sportów, w tym także ekstremalnych. Leczenie takich złamów w okresie rozwojowym zależy od rodzaju urazu, wieku i wagi dziecka, towarzyszących obrażeń oraz od doświadczenia i preferencji lekarza leczącego. Obecnie przyjmuje się, że u dzieci powyżej 5 roku życia wskazane jest wdrożenie mało inwazyjnego postępowania operacyjnego. Metoda zespolenia winna być prosta, a jednocześnie skutecznie stabilizująca złamanie. Aktualnie w traumatologii dziecięcej standardem jest stosowanie tytanowych elastycznych gwoździ TEN.

Słowa kluczowe: złamanie trzonu kości udowej, metoda ESIN, zespolenie z wykorzystaniem gwoździ TEN

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Introduction

When looking at the development of methods of treating diaphyseal femoral fractures in children, it is worth highlighting that in the last twenty years there has been a change in the management of the above-mentioned injuries in the pediatric population. A pediatric orthopedic surgeon should be familiar with the descriptions of such injuries. This is invariably linked to the characteristics of the child's osteoskeletal system and a slightly different biology of the healing. Diaphyseal femoral fractures account for approximately 3% of all long bone fractures in children and adolescents. They usually occur as a result of high energy injuries. The treatment of such fractures in patients with non-closed growth cartilages depends on the type of injury, child's age and weight, and associated injuries. Currently, the use of titanium elastic nails (TENs) is standard in pediatric traumatology. In the case of long bone fractures in children, the approach adopted in the 20th was to treat the injuries non-operatively. It consisted in a closed reduction, placing a cast, using an adhesive tape traction or skin (indirect) traction or skeletal (direct) traction. The surgical treatment administered then involved an open reduction of bone fragments and their immobilization with a metal plate, screws or ZESPOL or POLFIX stabilizer [1].

The apparent differences in morphology and bone healing in children led to the development of pediatric traumatology in the first half of the 20th century. The adopted view was that one must not unquestioningly use the methods of fracture treatment applied in adults when treating fractures in children.

Using the concepts developed by Firiki, a Romanian surgeon, Metaizeau demonstrated that the insertion of two elastic titanium nails into the intramedullary canal of a broken femoral diaphysis produces counterforces to stabilize the fracture. Together with Ligier and Presvot, Metaizeau published his findings in the early 1980s.

The effect of the intramedullary osteosynthesis is that the stabilizing implant can carry the forces that occur during the patient's daily activities involving movement until the union is achieved. With the proper stabilization of the damaged bone, it is not necessary to immobilize it with a cast. It is also possible to shorten patient's hospitalization and restore patient's mobility more quickly.

1. Non-operative treatment

Closed reduction and limb immobilization using indirect or direct traction were widely used methods in treating diaphyseal femoral fractures in children in the 20th century. In indirect traction, the weight is attached with a cord (sometimes through a block system) to the skin of the limb using adhesive tape or an adhesive dressing (Fig. 1). In direct traction the weight is fastened to a metal rod, usually a Kirschner wire, led through the bone. The latter was most often led through the femoral epicondyles, tibial tuberosity, both shins (above the ankles) or heel bone (Fig. 2). The reduction of the fracture on the traction was obtained within several days or weeks after the injury. After achieving the initial union, further treatment can be provided by putting a well-molded cast, while remembering to relieve the stress on the eminence (preventing bedsores).

2. Surgical treatment

Today, elastic stable intramedullary nailing (ESIN) is the most popular method of treating diaphyseal femoral fractures in children; the nails are made of titanium alloy Ti-6Al-7Nb. Their advantage over materials used in the past is that they are biologically inert when implanted in the human...
body. They do not cause allergic reactions. Additionally, the titanium alloy used is elastic, has a high modulus of elasticity and is resistant to stresses and forces acting inside the marrow cavity (Fig. 3).

In 1976, the first such operational procedure was performed in France. Good treatment outcomes have led to its further development as well as broadening of indications for the use of elastic nails in fracture stabilization [2]. In 2001 at University Children’s Hospital in Lublin, one of the first of such surgical procedures was performed involving the stabilization of a forearm fracture in a 6-year-old child.

To date, ESIN is the gold standard in pediatric orthopedics, especially in the case of diaphyseal femoral fractures. This procedure is also used in treating forearm and tibial fractures in children. By inserting two titanium elastic nails into the marrow cavity, which support each other in a three-point-supported structure, we achieve a stable osteosynthesis in the coronal, sagittal and horizontal planes. When operative technique is applied correctly, we also obtain rotational stability. Elastic nails are used in patients weighing up to 55 kg. The width of the bone marrow cavity of a broken femoral diaphysis is also important. The nails should fill the cavity in 90% [3]. Once the desired nail size has been selected, the surgeons perform a closed reduction through axial traction and manual manipulation. The internal fixation of diaphyseal femoral fracture involves two nails being inserted into the bone marrow cavity, starting from the distal femoral metaphysis (Fig. 4). Through small cuts on both sides of the distal end of femur we expose the cortical layer. Using the initiator, we open the marrow cavity and insert the selected nails.

It is important to bend TENs so that they expand at the fracture site (Fig. 5).

In accordance with the principle of three-point support, we anchor TENs in the greater trochanter and the femoral neck (Fig. 6). The surgical procedure is performed under the guidance of the X-ray and with the traction table.
In older children and adolescents, the commonly used method of treating femoral fractures is the surgical fixation of the fracture with a specifically customized intramedullary blocked nail called ALFN. It is inserted from the lateral end of the proximal femur near the greater trochanter. The surgical procedure itself involves a closed reduction of bone fragments, insertion of the nail into the marrow cavity and locking it further by special locking screws. These are necessary conditions to ensure the stability of fixation. It is important that the nails have proper shape, length and diameter corresponding to the size of the bone marrow cavity. The fixation material should be made of special metal alloys, biologically inert for the body. Intramedullary fixation effectively stabilizes fracture until bone union occurs. It facilitates and accelerates the union of fractured bone. It is important as well as beneficial that the insertion site for the intramedullary nail is not in the vicinity of the fracture. No contact between the fracture site and the external environment prevents possible infection, thus facilitating and accelerating the union. No excessive damage is done to the surrounding tissues, blood vessels, and nerves during the procedure. It is essential to use the traction table and X-ray equipment to ensure accurate reduction and correct insertion of the stabilizing material. In the next treatment stage the patient’s fast motor rehabilitation plays an important role, since after the operation, cast immobilization is not necessary, allowing fast patient ambulation (Fig. 7).

3. Complications in the treatment of diaphyseal femoral fractures

Early complications of the diaphyseal femoral fractures include hypovolemic shock. Therefore, it is very important that the child receives a sufficient amount of fluid to fill the vascular bed during the first period after fracture and then, and after restoring the dynamics of blood flow, the surgical procedure may start [4].

Late but not very frequent complications of the diaphyseal femoral fracture in children include contractures, pseudoarthroses and breakdown of fixation material. Contractures can be avoided by performing all rehabilitation exercises, including those performed at home, without the assistance of a physical therapist, during and after hospitalization. Other complications require surgical treatment.

It is important to know that the fixation of bone fractures with an intramedullary nail may be a long and difficult procedure, depending on the type of fracture, and may involve blood loss and be detrimental to the patient’s health. Despite the obvious benefits for the patient, this surgery, even when performed with due diligence and caution, carries a risk of complications that can significantly affect the patient’s health and life.

Other complications that may occur during the treatment include:
1. Complications related to general anesthesia or spinal anesthesia.
2. Incorrect implant placement.
3. Inability to insert the implant components due to increased bone damage and the need to change to ‘open’ treatment or use other types of implants than those intended prior to treatment.
4. Bone fracture when inserting an implant requiring additional fixation.
5. Elongation, shortening or rotation of the axis of the operated limb.
6. Neurological complications including damage and paralysis of peripheral nerves (e.g., femoral, sciatic) that are responsible for the normal motor and sensory function of the lower limb.
7. Damage to large arteries and veins leading to massive bleeding (the need to extend the procedure and perform vascular reconstruction surgery).

Postoperative complications include:
1. Abnormal wound healing or its infection.
2. Increased bleeding from the wound, hematoma in the operated region.
3. Necrosis of tissues around the wound.
4. Nonunion, delayed or malunion which may require a repeat surgery and a change in the surgical method of fracture stabilization or application of cast immobilization.
5. Deep bone infection around the implant requiring repeat surgery and removal of implants, long-term pharmacological and surgical treatment, a change in the surgical method of fracture stabilization or application of cast immobilization.
6. Breakdown of implant, especially of the locking screws (it may be necessary to replace them with new ones or to leave the damaged implant components for the rest of the patient’s life).
7. Allergic reactions to the components of the implant (removal of implants).
8. Persistent pain [5, 6].

Diagnostic workup of diaphyseal femoral fractures in a child is based on medical history, physical examination and radiological studies. AP and lateral X-rays of the femur are the primary imaging studies that help to make a correct diagnosis.

The treatment of diaphyseal femoral fractures during the development period depends on the type of fracture, patient’s age and weight. Most fractures in children under 5 years of age are treated non-operatively. Surgical treatment is used in children older than 5 years. When selecting the proper surgical method, the presence of growth cartilages, whose damage may cause serious complications should be considered. It is also extremely important to have the smallest surgical approach and to use proper stabilizing material.

The operative method using intramedullary fixation using elastic titanium nails and rods seems to meet the above-mentioned conditions and criteria at the moment (Fig. 8).

Conclusions

The rise in the number of road accidents and the growing tendency of children and adolescents to engage in extreme sports contribute to the increased incidence of injuries to the skeleton. In view of the above, many authors have demonstrated that the percentage of bone fractures in children has increased significantly in recent years [7]. During the day-to-day work in the Orthopedics Department, problems caused by such fractures are increasingly common to find. Their correct treatment is essential. Especially, given that this concerns a specific group of patients - children. At present, surgeries using intramedullary fixation have become the ‘gold standard’ in treating diaphyseal femoral fractures in children [8].

In 1983, a team from Nancy, under the direction of prof. Metaizeau published a study on the treatment of long bone fractures in children using titanium elastic nails. Since then, intramedullary fixation in treating diaphyseal femoral fractures in children has almost completely replaced other surgical or non-operative methods [9]. Only patients under 3 years of age can and are treated with cast, an overhead traction[10]. This age is characterized by the ability to bone remodeling, which, according to the Wolff’s law, leads to a spontaneous correction of the angular settings of the bone fragments. The biological repair and remodeling processes are very effective and dynamic, leading to rapid union and restoration of the proper limb function [11].
Relevant literature includes descriptions and analyses of the results of the treatment of diaphyseal femoral fractures in children using other bone stabilizers such as LCPs, one-plane external stabilizers or Ilizarov apparatus. The use of external stabilization must be applied if there is a multifragmentary or open fracture. In multifragmentary diaphyseal femoral fractures in children there is no possibility of an anatomical reduction of the bone fragments. This is due to damage to the cortical layer of the bone along a large section of the diaphysis. Therefore, the possibility to use the ESIN method is excluded. The absence of three-point support of the nails can cause fixation instability. In open Gustillo-Anderson diaphyseal femoral fractures grades IIIA to IIIC, with severe soft tissue damage, there is a high risk of post-operative infections. This may lead to bacterial bone infection [12]. External fixation has become a highly useful method to treat such fractures. This is due to a good stabilization of bone fragments and the possibility to start early weight-bearing of the limb [13].

The use of LCPs in pediatric diaphyseal femoral fracture fixation is allowed during childhood [14]. Allen et al. as well as Luo et al. emphasize the increased effectiveness of intramedullary fixations.

Stabilization with a plate produces good treatment outcomes. The patient is ambulated and begins early weight-bearing. Most pediatric traumatologists prefer and recommend the ESIN method due to low invasiveness and shorter duration of the surgical procedure, lower blood loss, lower treatment costs, and significant reduction of pain [15].

It is worth mentioning that by the mid-1980s, the use of traction and casts was the primary method of treating diaphyseal femoral fractures in children [16]. A number of studies have demonstrated the superiority of the operative method over the non-operative treatment both from medical and social perspective [17]. The authors point out that fast ambulation of the patient, the introduction of early hip and knee joint movements and short hospitalization make the ESIN method a better choice for treatment. The postoperative patient care is easier and requires fewer follow-up outpatient visits. More X-rays studies in the case of patients treated with a cast is also of great importance. Numerous studies indicate a much higher proportion of late complications in children treated using non-invasive methods. These are repeated fractures, late abnormalities in the axis and limb length [18]. The economic aspect is still under discussion. It cannot determine the choice of treatment, but it is now an important element primarily considered by the administrations of the health care units. The studies carried out so far in many centers indicated lower costs in the case of operative treatment [19]. At present, the authors point to an increase in treatment costs. This is due to increasing perioperative costs and high costs of the implants [20]. Consequently, the growing group of supporters includes more and more traumatologists using stainless steel intramedullary nails. Many authors have analyzed in detail both the effectiveness of this treatment and the inherent economic aspect. Wall et al. in their study compared the outcomes of treating diaphyseal femoral fractures using TENs in 56 children to 48 patients treated with elastic stainless steel nails. He observed that in the first group of patients treated with titanium nails, complications were four times more common than in the group where steel nails were used (TEN 23% - SS ESIN 6%). The most common complica-

Fig. 10. Stabilization of the femoral diaphysis with a plate and screws.
Source https://www.semanticscholar.org/paper/Bridge-Plating-Length-Unstable-Pediatric-Femoral-Sutphen-Beebe
tions observed were delayed union, major axis abnormalities and inflammations in the vicinity of nail insertion. Additionally, given the four-times lower price of stainless steel nails, the author strongly recommends their use [21].

Apart from the undeniable advantages, ESIN is not free of defects. The use of intramedullary nails involves repeat anesthesia of the patient to remove the nails. Thus, we expose the child to additional adverse events and complications [22]. There have been reports in the literature on the use of intramedullary nails made of biodegradable material. Korhonen et al., after analyzing a patient group, demonstrate that the use of such materials does not increase the risk of additional complications. The availability of such nails is limited, so an in-depth analysis and evaluation of treatment outcomes will be possible in the future [23].

One of the most common complications of using titanium elastic intramedullary nails for fixation of diaphyseal femoral fractures is their migration. This causes discomfort and pain in the knee joint, inflammations and sometimes requires reoperation and repeat insertion of the nails in the marrow cavity [24]. Windolf et al. in their study evaluated the usefulness of the so-called end cap, that is additional elements. With this solution, the distal end of the titanium nail will be attached to the cortical layer of the bone thus preventing its migration. Based on an analysis of 15 femur models, the author has demonstrated that such a solution is highly effective. He did not observe nail migration and, moreover, noted an increased fixation stability. Due to the high cost of end caps in Poland, end cap is not an element often used to stabilize the diaphyseal femoral fracture in children (Fig. 11).

The ESIN method also has some limitations. It should be used in patients whose weight does not exceed 55 kg. This principle is first and foremost followed in the treatment of injuries to the weight-bearing skeleton. With the worldwide increase in the percentage of children with obesity, this is a particularly important aspect, as pediatric orthopedists are increasingly forced to choose a different treatment method. Rapp et al. analyzed early and late treatment outcomes of 54 patients who weighed more than 50 kg and who suffered diaphyseal femoral fractures. In 42 of them, the growth cartilages were active. This group was originally treated using two or three TENs, as well as ALFN. Most patients in the subgroup treated with two nails experienced complications related to nails instability and those in the subgroup where ALFN was used observed abnormal limb growth. In a subgroup of children with a fracture treated with three TENs, the percentage of the complications described was the lowest. The authors point out that these complications led to reoperation and the late results obtained were unsatisfactory [25].

The treatment of patients with active growth cartilages whose body weight is more than 55 kg is part of a continuous discussion, but it seems that the most effective treatment method in using blocked nails, or ALFN. Despite these complications, it should be stressed that ESIN treatment of diaphyseal femoral fractures in children is highly effective, with minor axis or limb length abnormalities having no impact on the patient’s functioning in the future. However, fixation using ALFN does not involve the risk of AVN of the femoral head, axis and limb length abnormalities, but only early local complications: infection and pain. The use of intramedullary fixation using TENs and ALFN blocked nails is a milestone in treating traumas to a child’s skeleton since the obtained treatment outcomes have been much better, patient’s comfort has improved and, most importantly, the fast ambulation of the child and early rehabilitation.

References
Łukasz Matuszewski and Andrzej Ciszewski: Treatment of pediatric diaphyseal femoral fractures with intramedullary fixation


