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ORIGINAL STUDY

Mini-open versus closed reduction in titanium elastic nailing of paediatric femoral shaft fractures : A comparative study

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The purpose of this study is to compare retrospectively intraoperative fluoroscopy time and clinical-radiological results in pediatric femoral shaft fractures treated with titanium elastic nailing (TEN), with a mini-open "blind-hand" technique versus closed reduction. The study included 87 children (18 girls and 69 boys) who underwent surgical treatment with TEN for femoral shaft fractures. Patients were divided into two groups. Group 1 included 42 patients (mean age : 8.3 ± 2.7 years) treated with a mini-open "blind-hand" technique (a 2-3 cm lateral incision at the level of the fracture ; reduction achieved with one or two fingers, without visualization of the fracture). Group 2 consisted of 45 patients (mean age : 8.8 ± 2.6 years) treated with a closed reduction technique. Duration of surgery and intraoperative fluoroscopy time were recorded in both groups. Clinical and radiologic results were assessed using the TEN scoring system after mean follow-up periods of 21.3 ± 5.8 months and 19.3 ± 5.6 months in group 1 and group 2, respectively. Mean duration of surgery was 31.7 ± 7.6 and 52.1 ± 14.4 minutes, and mean fluoroscopy time 32.9 ± 22.1 and 75.1 ± 31.5 seconds in group 1 and group 2, respectively. Both surgical and fluoroscopy time were significantly longer in group 2 ($p < 0.001$). There was no significant difference between the two groups in terms of clinical and radiological results. All fractures healed with solid union, and there was no complication that was expected to cause permanent disability. Although successful clinical and radiological results were obtained with both techniques, duration of surgery and intraoperative fluoroscopy time were significantly higher in the closed reduction group 2. We suggest the "blind-hand" technique as an alternative to closed reduction to prevent extensive intraoperative radiation exposure and to decrease the length of the surgical procedure.

Keywords : titanium elastic nail ; fluoroscopy time ; treatment outcome ; paediatric femoral fractures.

INTRODUCTION

Titanium elastic nails (TEN) are commonly used for the treatment of femoral fractures in children between the ages of 4 and 16 (*6,17*). Several studies have shown that their use in paediatric femoral fractures results in excellent outcomes with an earlier return to activity, earlier mobilization, a shortened

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hospital stay, and fewer complications (*6,16,18*). The use of TEN is technically easy to learn, facilitates the maintenance of anatomic alignment, and reduces the frequency of complications when nailing is performed correctly. The generally accepted technical option is closed reduction and intramedullary nailing under fluoroscopy control. Furthermore, minimally invasive surgery is often preferred for these fractures due to the reduction in patient morbidity, less soft-tissue trauma, and lower infection rates. However, open reduction is used by several authors in certain situations (*8,10*).

Fluoroscopy is an indispensable tool in orthopaedic surgery. The development of minimally invasive surgical procedures has further increased its usage. On the other hand, closed reduction techniques and the percutaneous intramedullary placement of the TEN increase the need for intraoperative radiological imaging and increase the intraoperative radiation load experienced by the patients, surgeons and staff (*12*). However, certain patients cannot be treated with closed reduction, the “blind-hand” technique, with a mini-skin incision at the fracture level, has therefore been used in several studies (*2,9*). As reduction was achieved with one or two fingers without visualization of the fracture, this technique became known as the "blind hand" technique. Its effectiveness with regard to clinical-radiological results and fluoroscopy time has not yet been determined. We hypothesized that the “blind-hand” technique does not adversely affect the clinical-radiological results, and that it decreases fluoroscopy time, as compared with closed reduction. To our knowledge, there is no clinical comparative study reporting the effectiveness of this technique on clinical-radiological results and fluoroscopy time.

PATIENTS AND METHODS

After approval from the local ethics committee, consecutive children with femoral fractures, treated at our clinic, from January 2004 to May 2009 were reviewed retrospectively. The criteria for inclusion in the study were a unilateral femoral shaft fracture that underwent titanium elastic nailing with a mini-open or a closed reduction and were followed up at our institution until fracture union. Patients whose fractures were treated with other conservative or surgical methods were excluded. Patients with a metabolic bone disorder, a pathological fracture or an open fracture were also excluded, as well as those who were treated with open reduction when closed reduction could not be achieved.

Table 1. — Demographic data, duration of surgery and fluoroscopy time for both groups

	Group 1 Mean±SD	Group 2 Mean±SD	p value
Age (years)	8.3 ± 2.7	8.8 ± 2.6	0.376
Female/Male ratio	32/10	37/8	0.668
Affected limb (Right/Left)	27/15	23/22	0.305
Surgical period (min)	31.7 ± 7.6	52.1 ±1 4.4	< 0.001
Fluoroscopy time (sec)	32.9 ±2 2.1	75.1 ± 31.5	< 0.001
Follow-up (months)	21.3 ± 5.8	19. 3± 5.6	0.099
Partial weight-bearing (weeks)	5.6 ± 1.3	6.0 ± 1.2	0.188
Full weight-bearing (weeks)	10.1 ± 2.4	9.4 ± 2.3	0.195

Table 2. — TEN Outcome Scoring System (2) and results for both groups

	Excellent	Satisfactory	Poor
Limb-length discrepancy	<1.0 cm	< 2.0 cm	> 2.0 cm
Malalignment	< 5 degrees	5-10 degrees	> 10 degrees
Pain	None	None	Present
Complication	None	Minor/resolved	Major/lasting
Results			
Group 1	38	4	0
Group 2	39	6	0

Fig. 1. — Eight-year-old girl, preoperatively : a) antero-posterior and b) lateral radiograph of the right femur.

Fig. 2. — Same patient as Fig. 1, early postoperative : a) antero-posterior and b) lateral radiograph after fixation with TEN.

Among the 87 children, there were 18 girls and 69 boys. The mean age at the time of injury was 8.6 ± 2.7 years (range : 4 to 13 years) ; the mean follow-up period was 20 months (range : 12 to 30 months). Patients were divided into two groups. Group 1 consisted of 42 patients treated with the mini-open "blind-hand" technique and TEN ; Group 2 consisted of 45 patients treated with closed reduction and TEN (table I). The femoral physes were open in all cases, and fracture types were comparable in the two groups.

Because this is a retrospective study and the selection of either mini-open or closed reduction was based on the preference of the attending orthopaedic surgeon, we were not able to randomize the treatment methods. Patients were treated by one of the three most experienced surgeons in the department, one of whom always chose the mini-open "blind-hand" reduction technique while the other two generally preferred the closed reduction technique.

The results were evaluated according to the TEN scoring system used by Flynn *et al* (6) (table II). The intraoperative fluoroscopy time in seconds was extracted from the radiology records, and the surgical time was obtained from the operation records.

Surgical procedure

In this study, the use of TEN was standardized, the patient was in a supine position on a standard radiotransparent table, and all TEN's (Synthes USA, Paoli, PA) were placed in a retrograde fashion through the distal part of the femur. The fractured limb was properly positioned and imaged by the operating surgeon. For implant sizing, the narrowest diameter of the femoral diaphysis was measured ; nails that were 40% of this narrowest diameter were used ; the intramedullary position was verified using fluoroscopy. In all cases, two to three TEN's were inserted in an ascending manner through medial and lateral insertion sites from the distal metaphyseal area of the femur. In group 1, after the level of the fracture was determined using fluoroscopy, a 2-3 cm, mini-lateral incision was performed at the level of the fracture. Using this "blind-hand" technique reduction was achieved with one or two fingers, without visualization of the fracture line, and TEN's were advanced proximally. In group 2, closed reduction was performed under fluoroscopic control in all cases. The lateral nail was fixed subcortically below the trochanteric physis, whereas the medial nail was anchored in the femoral neck, as described elsewhere (*12,18*) (Fig. 1a & b, 2a & b). The extraosseous portions of the nails were cut so that 1-2 cm remained outside the cortex and bent slightly away from the bone so as to prevent soft tissue irritation. In all cases, a hip spica cast was applied for four to six weeks after the injury in order to control pain and prevent weight-bearing. After the cast was removed, the children were referred to physical therapy for initial gait training.

At each postoperative follow-up visit, antero-posterior and lateral radiographs were specifically analyzed by the operating surgeon and a radiologist. For the evaluation of each patient, limb-length discrepancy, limb alignment and rotation, callus formation, implant status, quadriceps strength, the range of motion of the hip and knee, the condition of the wound and skin, and any pain or other symptoms were noted at each follow-up visit. Limb-length discrepancy was determined by physical examination. A scanogram was performed if a clinically significant limb-length discrepancy was noted upon physical examination. Nails were removed when the fracture line was no longer visible radiographically, which was typically six to eight months after the operation. The clinical end point was defined as a healed fracture with a return to full activity. This usually occurred at approximately one year. A patient satisfaction questionnaire was completed at the time of the last follow-up (1 = dissatisfied, 2 = moderate, 3 = good, 4 = satisfied). Satisfied and good were considered to be successful.

Statistical analysis was performed with the SPSS 16 software (SPSS® for Windows 16.0, Chicago, IL). The independent sample t-test (Student's t-test) and chi-square (χ^2) test were used. A p-value of < 0.05 was considered to be significant.

RESULTS

Demographics of the patients concerning age, sex and affected limb were comparable in the two groups, with no statistically significant difference ($p > 0.05$).

Irritation at the nail entry site occurred in four children (9.5%) in group 1 and in two children (4.4%) in group 2. In these patients, we did not need

Fig. 3. — Same patient as Fig 1 & 2 : a) Antero-posterior and b) lateral radiographs show remodeling of the fracture 2 months after TEN removal.

to remove the TEN before adequate healing of the fracture had been achieved. All fractures healed with solid union, and there was no complication that was expected to cause permanent disability. Only 4 patients treated with the mini open "blind-hand" technique (group 1) and 6 patients treated with closed reduction (group 2) had clinically significant limb-length discrepancy. Scanograms of these patients showed that the affected limb was lengthened in nine patients and shortened by less than 2 cm in one at the time of union. At the end of one year after nail removal, all patients had equal limb lengths. No instance of nonunion, malunion or > 10° angulation was observed upon radiological evaluation.

The average surgical time was 31.7 ± 7.6 min. for group 1 ("blind-hand" technique) and 52.1 ± 14.4 min. for group 2 (closed reduction technique). We found a significant prolongation of surgical time in group 2 ($t = -8.207$, $p < 0.001$). The mean intraoperative fluoroscopy time in group 1 was 32.9 ± 22.1 seconds : less than 1 minute in 31 cases ; 1 to 2 minutes in 9 cases ; and more than 2 minutes in 2 cases. In group 2 the average fluoroscopy time was 75.1 ± 31.5 sec : less than 1 minute in 6 cases ; 1 to 2 minutes in 29 cases ; and more than 2 minutes in 10 cases. Statistical analysis showed that there was a significant difference between the groups ($t = -7.169$, $p < 0.001$).

There were two pin-tract infections : one in each group, both of which resolved with antibiotic therapy. Deep infection or osteomyelitis did not occur in any case. There were no intraoperative complications, wound healing problems, or neurological injuries. No loss of reduction or implant failure during the postoperative period was noted in this series. Refracture did not occur in any patient.

As can be seen in table I, the average time to partial weight-bearing and the average time to full weight-bearing did not differ significantly between group 1 and group 2 (5.6 ± 1.3 weeks vs. 6.0 ± 1.2 weeks and 10.1 ± 2.4 weeks vs. 9.4 ± 2.3 weeks, respectively, $p > 0.05$ for all). All TENs were removed without complication after an average of 14.6 months (Fig. 3a & b). No hip and/or knee joint-related complications such as stiffness were encountered in either treatment group. Each patient had a full range of motion.

When rating surgical results, 93% of patients in group 1 and 89% in group 2 were good or satisfied, and no patient was "dissatisfied" with the outcome. We did not find a significant difference between the groups ($\chi^2 = 0.410$, $p = 0.522$). The distribution of the clinical and radiological results for the patient groups according to the TEN outcome scoring system is summarized in table II. There was no significant difference between the groups ($\chi^2 = 0.310$, $p = 0.578$).

DISCUSSION

TEN is commonly used to treat femoral shaft fractures in children between the ages of 4 and 16 years (*6,17*) because it allows rapid mobilization with fewer complications. Advantages of TEN include rapid healing and bone remodeling without risking damage to the physes or to the blood supply of the capital femoral epiphysis. Furthermore, over the past three decades, with the increased awareness of patients and family for the psychosocial and economic effects associated with traction and spica casting, as well as the refracture risk, pin tract complications, and arthrofibrosis associated with external fixation, treatment algorithms have shifted toward intramedullary implants for femoral shaft fractures (*18*). In a prospective study, Flynn *et al* (*7*) showed that children treated with TEN achieve recovery milestones significantly faster than do those treated with traction and a cast.

The most common complication of femoral fractures in children is limb-length discrepancy (*7,9,10*). Gogi *et al* (*8*) found that lengthening following TEN in children is a fairly common phenomenon, although it gradually decreases and limb length symmetry is restored in the majority of children. Shortening is much more important than lengthening and corrects very slowly with time. Likewise, in our study, ten patients had clinically significant limb-length discrepancies. Nine of these patients experienced lengthening, while the other had a shortening of less than 2 cm. At the end of one year after nail removal, all patients had equal limb lengths.

The majority of TEN-related complications were associated with nail prominence and pain. Luhmann *et al* (*13*) found that this complication may be lessened by using the largest possible nail diameter and leaving the nail protruding from the bone less than 2.5 cm. In the current study, for nail diameter sizing, the narrowest diameter of the femoral diaphysis was measured, and nails that were 40% of this narrowest diameter in size were used. Afterward, we cut the extraosseous portion of the nails such that 1-2 cm remained outside the cortex and bent slightly away from the bone so as to prevent soft tissue irritation. We encountered four patients with nail irritations in group 1 and two in group 2, but we did not need to perform early removal of the TENs before the fracture healed. Additionally, although two patients experienced pin-tract infection at the lateral entry side of the TEN, this did not progress to deep infection or osteomyelitis.

Immobilization of the affected limb with a spica cast for four to six weeks is recommended because this limits pain, supports the leg when the quadriceps is weakest and decreases the amount of nail-tip soft-tissue irritation (*6*). Certain studies have concluded that further immobilization with the hip spica cast is not necessary after elastic nailing when stable fixation has been achieved (*1,18*). We applied a hip spica cast for four to six weeks after TEN in order to control pain and prevent weight-bearing. We also believe that it was effective in preventing complications such as implant failure during the early postoperative period.

TEN provides stability with the three-points principle, and the elasticity and stress distribution of nails encourages callus formation. Furthermore, engaging the nails more proximally to aid in the control of rotation and angulation decreases the force at the fracture site and maintains fracture stability (*18*). In this study, the lateral nail was fixed subcortically below the trochanter physis, whereas the medial nail was anchored in the femoral neck. There were no patients with nonunion, malunion or > 10° of angulation of the injured limb in either group.

Fluoroscopy has become a standard tool in orthopedic surgery. The development of minimally invasive surgical procedures has further increased its us due to several advantages, such as the preservation of soft tissues and blood supply, thus reducing direct perioperative morbidity (*3*). However, like every intramedullary fixation technique, TEN requires an increased amount of intraoperative fluoroscopy time (*12,14*). The surgeon's experience level is very important in reducing the radiation dose (*5*). Several studies showed that the presence of a senior surgeon resulted in a 36%-40% decrease in the amount of radiation and radiation exposure time during surgical procedures (*3,4*). Madan *et al* (*14*) found that the participation of trainees and middle-grade surgeons was associated with higher radiation exposure during proximal screening of the long bones to identify the insertion site of the guide pin. They compared the fluoroscopic screening time between the middle-grade surgeons and consultants ; middle-grade surgeons required significantly more time. However, all patients included in this study displayed similar fracture types, and all of the operations were carried out by experienced surgeons of the department. We found that there was a significantly longer surgical period and extended intraoperative fluoroscopy times in group 2 as compared to group 1.

Several studies propose that when the surgical procedure is extremely prolonged, surgeons should shift their surgical technique from closed to open reduction to protect the patient from unnecessary intraoperative radiation exposure (*11,12*). Notably, lead aprons, lead-glass eyewear, thyroid shields and lead-lined gloves can be used to decrease the radiation hazard to patients and surgeons during minimally invasive surgical procedures under fluoroscopy. The long-term effects of radiation on the human body are not yet known. Mastrangelo *et al* (*15*) suggest that surgeons need to be aware of the potential radiation risk in orthopaedics.

In this study, intraoperative radiation exposure was evaluated using fluoroscopy time but not by dosimetry. This may be accepted as a relative weak point of the study.

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