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ORIGINAL STUDY

External fixation for high energy paediatric diaphyseal tibial fractures : Taylor Spatial Frame versus Uniplanar Fixator

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The purpose is to compare the outcomes of the Taylor Spatial Frame (TSF) versus the Unipolar External Fixator (UEF) (Hoffman) in children's tibial diaphyseal fractures.

Forty-two children with high-energy diaphyseal tibial fractures underwent surgical treatment from January 2006 to December 2013 were divided in 2 groups based on type of fixation. Paley's criteria were used to evaluate obstacles and complications from surgery until one year after frame removal. Statistical analysis was performed using Cohen's d test and Student T-test.

Mean follow-up for both groups was 2,4 years. No intraoperative complications, neuromuscular injury, re-fracture, leg length discrepancy, malrotation and post-operative complications according to Paley's criteria were recorded.

No statistical differences were observed regarding correction after treatment and time to union between open and close fractures in each group. However, statistically significant differences were observed regarding the incidence of problems, obstacles and time to union when TSF was applied.

Keywords : Tibial diaphyseal fracture ; external fixation ; TSF.

INTRODUCTION

Tibial fractures constitute the second most common type of paediatric trauma settings, after femoral fractures, representing 10-15% of all paediatric fractures *(4)*. The majority of them are not complicated and are treated by simple manipulation and immobilization when deviation is absent *(17)*. However, in case of displaced tibial fractures

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with soft tissue damage and comminution surgical treatment is recommended *(9,10)*.

Various surgical treatment options have been proposed according to children's age, type of injury, stability and concomitant soft tissue injuries. Intramedullary rigid nails can be used after closed reduction ; however, the presence of open epiphyses (growth plates) represents a limitation for their use *(8,14,15,19)*. Compression or bridge plate fixation is suitable only in case of tibial fractures with slight skin injury *(13)*. External fixators are traditionally used in case of high energy injuries associated with polytrauma, open fractures and unstable fracture patterns. Nowadays, flexible intramedullary nailing is considered the best fixation method of paediatric fractures but, randomized prospective studies comparing flexible nails to external fixation should still be performed for confirmation *(10,11,16)*.

External fixation offers anatomic fracture reduction and is the best treatment solution in case of complicated tibial fractures, severe soft tissue damage and multiple traumas, even if the risk of infection is higher. Uniplanar fixators, compared to circular external fixators, are well accepted by surgeons because they are easy to assemble. However, they present less biomechanical stiffness and versatility for postoperatively adjustments *(1,7,10,11,16)*.

The purpose of this retrospective study was to compare the effectiveness of two different types of external fixators (TSF versus UF) for paediatric tibial diaphyseal fractures.

MATERIALS AND METHODS

Study was performed according to the ethical standards of the Declaration of Helsinki (1964) and its later amendments. From January 2006 to December 2013 the medical records of two different paediatric hospitals of two different countries following the same follow-up protocol (Iaso Children's Hospital in Greece and Alessandro Manzoni Hospital in Italy) were reviewed retrospectively. Demographic data, mechanism of injury, type of external fixation used in each hospital (Taylor Spatial Frame (TSF) in Greece vs Uniplanar Fixator (UF) Hoffmann® II in Italy), cost, complications and functional outcomes were recorded. All patients were followed monthly until hardware's removal ; then at 1, 6 and 12 months until radiographic/clinical healing and/or complete physical function was regained. Radiograms were performed to assess the characteristics of the diaphyseal tibial fractures, deviation and displacement, as well as bone healing and the final limb alignment.

Inclusion criteria were : consecutive paediatric patients with tibial diaphyseal fractures treated surgically by the same surgeon in each hospital using in all cases the same type of fixator ; age from 10 to 15 years ; high energy injury fractures and written consensus given.

The exclusion criteria were : patients who were treated by immobilization and casting or using plates, intramedullary and or elastic nails and no written consensus given. Pathological fractures were also excluded from the study

Patients were divided in two groups according to the type of external fixator applied.

Group A composed by 11 M and 10 F for a total of 21 tibial fractures treated with TSF. The average age was 12.83 years (range : 10-15y) and BMI 20,14 (range : 16.5-25.3). Children hit by a motor vehicle (pedestrian or cycling) represented the most frequent cause of injury (16/21 fractures ; 76,2%). The remaining fractures were caused by high-energy injuries during sports (5/21 ; 23.8%). Significant intra-abdominal bleeding was present in 6 patients, while closed head injury in 7. Regarding the type of fracture, 16 were open, classified according to Gustilo-Andersson as grade I (6/16), grade II (7/16) and grade IIIB (3/16), while the remain 5 were closed. Radiographically, fractures were spiral in 6 cases, comminute in 8, transverse in 4, segmental in 1 and oblique in 2.

Group B composed by 10 M and 11 F for a total of 21 tibial fractures treated with UF. The average age at surgery was 12,25 years (range 10-15y) and BMI 21,9 (range 18,2-24,9). Children hit by a motor vehicle (pedestrian or cycling) represented the most frequent cause of (14/21 fractures, 66,7%). The remaining fractures were caused by high-energy injuries during sports (7/21 fractures 33,3%). Significant closed head injury was present in 4 patients. Regarding the type of fracture, 18 were

open, classified according to Gustilo-Andersson as grade I (9/18), grade II (6/18) and grade IIIA (3/18), while the remain 3 were closed. Radiographically fractures were spiral in 7 cases, comminute in 3, transverse in 6, segmental in 1 and oblique in 4.

The radiographic evidence of remodelling bone callus in at least 3 of the 4 tibial cortices within 3 months after fracture occurring was defined as radiographic bone union. The absence of tenderness at the fracture site without pain in the upright standing full weight-bearing position was defined as clinical union. The number of days until radiographic and/or clinical union was defined as time to union. Fracture line persistence and radiographic scarsity or absence of callus formation within 5 months of fracture occurring was defined as delayed union. No radiographic progress of healing within 6 months of fracture occurring was defined as non-union. In both groups Paley's criteria were used to evaluate difficulties in using the two types of external fixators, including postoperative assessment of all problems, obstacles and complications from the time of surgery until the latest follow up *(12)*. Problems are defined as any potential difficulties arising during the treatment period, but completely resolved without any need of further surgery, such as pin track infection, wound breakdown, software changes (only for group A) and delayed consolidation. Obstacles are defined as any potential difficulties arising during the period of treatment but completely resolved by further surgery, such as non-union, joint contracture, recurrences of deformation and fractures. The hardware removal, performed after the initial fixation, was not considered as further surgery. Complications are defined as any local or systemic complication (intra/postoperative) or difficulty present during the stretching or stabilization period that remains unresolved until the end of the treatment period.

Statistical analysis was performed using SAS statistical package v 9.2 (SAS institute Inc., North Carolina). T student test with a level of significance set at $p<0.05$ and d Cohen's coefficient were used to assess differences between the 2 groups.

Table I. — Problems, obstacles and complications observed in the two different groups according to Paley's criteria

		Group A (TSF)	Group B (UF)
Problems	Pin track infection	4	6
	Change of software	2	0
	Delayed union	0	2
Obstacles	Loss of reduction	0	3
	Non-union	0	1
Complications		0	0
Total		6	12

RESULTS

Forty-two consecutive paediatric patients with tibial diaphyseal fracture treated in two different hospitals using two different external fixators (TSF and UF) were recruited. Mean time to union was 102 days (range : 83-136) for group A (TSF) and 132,34 days (range : 121-142) for group B (UF), while the mean follow-up was 2,4 years (range : 2-4y) in both groups.

Statistically significant differences between the two different fixators were observed regarding the incidence of problems, obstacles and complications according to Paley's criteria (Table 1).

Pin tract infection was reported in both groups (4 in group A and 6 in group B) treated successfully by oral antibiotics (Cephalosporine third generation 20mg/kg).

Delayed union was recorded only in group B (2 cases) and dynamic load and compression were applied without any need of further surgery. Also, in the same group, 3 patients presented loss of reduction, treated by fracture's re-manipulation and 1 patient with non-union was treated with bone grafting, application of growth factors and circular fixator. None of the patients of the TSF group required further surgery due to loss of reduction or non-union, and only in 2 patients software modification was necessary.

Regarding the time to union (number of days until radiographic and clinical evidence of union) statistical significant differences were observed when open and close fractures were compared. Lesser time to union was observed in case of closed fractures in both groups ($p=0.067$). No statistical

Table 2. — Comparison of the final radiographic results and time to union between the two different groups

Patients	Anterior Deformity		Lateral Deformity		Lateral Displacement	Rotation	Shortening	Time to union (days)
	Valgus	Varus	Anterior angulation	Posterior angulation				
Fractures UF								
Average Post Treatment	0.91	0.16	0.16	0.5	0.75	0.16	0.75	132.34 (120-155)
Standard deviation Post Treatment	1.56	0.58	0.58	0.90	1.42	0.58	1.42	7.25
Fractures TSF								
Average Post Treatment	0.75	0.08	0.41	0.58	0	0.08	1	102 (90-110)
Standard deviation Post Treatment	1.29	0.29	1.00	1.08	0	0.29	2	21.38
Cohen's d	0.11	0.17	-0.31	-0.08	0.75	0.17	-0.14	1.90

differences in time to union were observed between the different types of tibial fractures (p=0.85) in each group.

Regarding the final radiographic correction, no statistically significant differences were ob-served between the two groups (Cohen's d : 0.1 for valgus, 0.17 for varus, -0.31 for anterior angulation, - 0.08 for posterior angulation, 0.75 for lateral displacement, 0.17 for the rotation, -0.14 for shortening). However, statistically significant differences were observed when the two types of fixators were compared (less time to union observed in the Group A ; Cohen's d = 1.90) (Table II).

No intraoperative complications, differences in length of hospital stay, functional leg length discrepancy, malrotation, neurovascular injury, re-fracture, osteolysis or ring sequestrum were recorded for the entire follow up period. At the latest follow- up visit all patients had full weight bearing without crutches, normal knee and ankle range of motion and they were all able to perform their daily living activities, including sports.

DISCUSSION

Paediatric tibial diaphyseal fractures are relatively common and are often associated with good clinical and radiographic results when treated conservatively. However, unstable, extensive comminute, multiple or contralateral leg fractures, polytrauma and open fractures are treated surgically to provide stability, permit early mobilisation and facilitate children's care *(4,8-10,14,15,17,19)*.

The aim of our retrospective study was to compare the effectiveness of two different types of fixators (TSF versus UF) used in two different paediatric hospitals of two different countries for the surgical management of paediatric tibial diaphyseal fractures. The Hoffmann® II is a uniplanar fixator commonly used by orthopaedic surgeons due to its ease of application compared to circular external fixators. The TSF uses a series of 6 telescopic struts in the manner of a Stewart platform along with the help of a computer software program to help a gradual correction post operatively, with a greater biomechanical stiffness and versatility respect to uniplanar fixators. Both TSF and UF are considered appropriate methods of fixation of various types of paediatric tibial shaft fractures, but in literature, there are few studies comparing the two types of fixators *(2,6)*.

Eindelmanand and Katzaman *(3)* reported their experience in treating tibial fractures with cast, unilateral fixator or TSF reporting a lesser time to union in anatomic alignment when TSF was applied, comparable to our findings**.** Regarding time to union Shore et al. *(18)* reported no statistical differences between the two types of fixators (UF 14wk, TSF 12Wk) similar to our results (102 days for TSF versus 132,34 days for UF). Further, regardless the

type of external fixator no statistically differences for time to union between the different radiographic types of tibial fractures (p=0.85) were observed, while closed fractures appeared to heal quicker than open (p=0.067), similar to other studies (18). These data should always be considered when external fixation is used.

Pin site infection (4 cases group A and 6 group B) treated successfully by oral antibiotics, delayed union (2 cases in group B treated by dynamic load and compression), loss of reduction (3 cases group B treated with a new fracture's manipulation), non-union (1 case group B treated by bone grafting and application of growth factors and circular external fixator), software modification (2 cases group A) observed in our study are comparable to those described in other studies when external fixation is performed for surgical fracture stabilisation *(10,18,20)*.

Complication according to Paley's criteria they were not observed in none of the groups, even if re-fracture, limb overgrowth, malicious union and joint stiffness are frequently reported as complications when an external fixator is used *(1,12,18,20)*.

Shore et al in their study concluded that the use of TSF is more expensive *(18)*. This is true only when the initial cost is considered as the frame's body can easily be recycled and patients are charged only with the effective cost of the k wires and half pins used to assemble fixator.

Our study presents some limitations. First, inherent bias due the retrospective nature of the study using data of two different hospitals consists a limitation. Another fact which should be considered is that although the two groups were matched according to age, sex, type of injury, some undetectable difference may be exist, due to the confounding. Furthermore, the total number of open fractures was higher in the TSF group although the fracture distribution was similar indicative for similar injury severity.

According to the experience and common sense of each orthopaedic surgeon, osteosynthesis in children is still controversial and not yet totally accepted. Plating could provide good immobilization, but requires sometimes extensive incisions with need for additional surgery for their removal. Intramedullary nails could be considered as a safe surgical method, but they can be used only in adolescents after growth plates closure *(8-10,14,15,19)*. Flexible intramedullary nails could be considered as a valid fixation method for the majority of paediatric fractures but, randomized prospective studies comparing flexible nails to external fixation should still be performed *(10,11,16)*. External fixators (uniplanar and/or circular) are the preferable methods of surgical stabilisation for a variety of fractures, mostly those following a high energy trauma, such as comminute open fractures with soft-tissue damage associated with a high risk of infection *(1,3,6,10,11,18)*.

Authors conclude that TSF seems to be a valid method to treat paediatric tibial fractures when compared to UF due to less difficulties calculated according to Paley's criteria, better anatomic reduction and with the advantages of early mobilization, active motion of adjacent joints, early weight bearing and post-operative manipulation of the fracture's site. The fracture site can be manipulated post operatively over a few days into excellent alignment without any need for re-manipulation in the operating room. This device also results well accepted by children making them more secure and confident during mobilization and weight bearing, even if it is cumbersome.

Further prospective studies should be performed comparing the various stabilization methods for the different types of tibial fractures to define treatment strategies in children. Until then, choice of fixation remains influenced by the orthopedic surgeon's experience and preferences.

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