SYSTEMATIC REVIEW

Titanium Elastic Nails Versus Spica Cast in Pediatric Femoral Shaft Fractures: A Systematic Review and Meta-analysis of 1012 Patients

Mohamed A. Imam, MD, PhD, FRCS; Ahmed S. Negida, MBBC; Ahmed Elgebaly, MBBCH; Amr Samy Hussain, MRCS, MSc; Lukas Ernstbrunner, MD; Saqib Javed, MD, FRCS; Joshua Jacob, FRCS; Mark Churchill, FRCS; Paul Trikha, FRCS; Kevin Newman, FRCS; David Elliott, FRCS; Arshad Khaleel, FRCS

Research performed at Ashford and St Peter's NHS Trust, Chertsey, UK

Received: 16 September 2017 *Accepted: 21 January 2018*

Abstract

Background: There is a general consensus on the management of femoral fractures in children younger than two years and adolescents older than sixteen years. The best treatment for patients younger than sixteen years of age is still debatable. Titanium Elastic Nails (TEN), is widely used with some evidence, nonetheless, we undertook a systematic meta-analysis to assess the efficacy of TEN compared to Spica cast for the management of femoral shaft fracture in children aged between 2 to 16 years old.

Methods: A computer literature search of PubMed, Scopus, Web of Science, CINAHL and Cochrane Central was conducted using relevant keywords. We included clinical trials and observational studies that compared TEN versus Spica cast; Records were screened for eligible studies and data were extracted and synthesized using Review Manager version 5.3 for Windows. Our search found 573 unique articles. After screening the abstract and relevant full text, 12 studies with a total of 1012 patients were suitable for the final analysis.

Results: In terms terms of union (in weeks), the reported effect sizes favoured the TEN group in two included studies only. Moreover, the overall standardized mean difference in sagittal (SMD -0.48, 95% CI [-0.70 to -0.26], *P<0.001*) and coronal angulations (SMD -0.66, 95% CI [-1.00 to -0.31], *P<0.001*) favored TEN fixation in management of femoral fractures younger than 16 years. The reported length of hospital stay was not consistent across studies. The overall risk ratio of malalignment (RR=0.39, 95% CI [0.27 to 0.57], *P<0.001*) favored the TEN as well as walking independently. Based on our analysis, TEN treatment is superior to traction and hip spica for femoral fractures in patients younger than 16 years old.

Conclusion: Based on our analysis we recommend the use of TEN fixation in management of pediatric femoral fractures in patients younger than 16 years.

Level of evidence: II

Keywords: Femoral fractures, Flexible nails, Spica cast, Titanium elastic nails

Introduction

Fractures of the shaft of the femur represent 1.4 % to 1.7 % of all pediatric fractures (1). There is a bimodal pattern being more in early childhood and mid-adolescence and more common in males compared with females (2). The reported annual incidence is up to 1/5000- they represent the most

Corresponding Author: Mohamed A. Imam, Department of Trauma and Orthopaedics, Suez Canal University, Circular road, Ismailia, Egypt
Email: Mohamed.imam@aol.com

THE ONLINE VERSION OF THIS ARTICLE ABJS.MUMS.AC.IR

frequently pediatric fracture requiring a hospital admission. There are different mechanisms of injury described; this includes but not limited to road traffic accidents, falls, Non-accidental injuries, incidental findings, sports related injuries and pathologic fractures (3, 4). In those younger than 4 years, non-accidental injuries constitute a major concern (5). In mid-adolescence motor vehicle accidents represent a common cause (6).

When choosing the treatment modality in this age group, several issues including the final outcome ought to be considered; as they have impact on psychological and developmental effects: on the child, family and social ramifications and financial implications (if a parent has to take time off work).

There is a global consensus on the management of these fractures in children younger than two years and adolescents aged 16 or more (7). The ideal treatment for patients between two and sixteen years of age is debatable (8, 9). Closed reduction and Spica cast (CRSC), external fixation, plate and screws, intramedullary nails and flexible intramedullary nails have been described for the treatment of these injuries (7, 10-32).

Titanium Elastic Nails (TEN) is used globally for the operative fixation of femoral fractures in those younger than 16 years old, despite the paucity of studies evaluating their risks and benefits (29-32). TEN have been used in Europe since the eighties and historically stainless-steel Ender nails have been used elsewhere (33, 34). The surge of TEN in North America has led to an over- spill in their use (35).

We undertook a systematic review and meta-analysis to analyse the evidence about the efficacy of flexible nails compared to Spica cast for the management of femoral shaft fracture in patients younger than 16 years old.

Materials and Methods

We used the PRISMA statement guidelines for the undertaking of this review and meta-analysis.

Inclusion and Exclusion criteria

Those studies satisfying the ensuing criteria were included in the current study: 1 Clinical trials and observational studies that compared titanium elastic nails versus hip spica; 2 studies whose population was patients younger than 16 years with femoral shaft fractures; 3 studies where the experimental/ observation group underwent titanium elastic nails/ flexible intramedullary nails; 4 studies with control group receiving hip Spica cast or traction followed by Spica; 5-studies that were prospective or retrospective studies; and 6 studies whose outcomes were presented as continuous outcomes reliable for analysis; and 7 studies reporting the outcomes of hospital stay, union duration, sagittal angulations, malunion, complications, parents satisfaction, coronal angulations, malalignment, and independent walking milestones. We excluded publications that were not written in English, theses, conference abstracts, and studies whose data were not reliable for extraction and analysis.

Literature Search Strategy

A computerised literature search of PubMed, Scopus, Web of Science, CINAL and Cochrane Central was conducted using the following keywords: (((“Bone Nails”OR “Titanium” OR (titanium elastic nailing)) AND (“Casts, Surgical” OR (hip spica casting) OR (spica cast) OR “Traction” OR (conservative management)) AND (“Femur” OR pediatric femur fracture OR femur shaft fracture)) OR ((Bone Nails AND Traction AND “Fractures, Bone”)). Furthermore, we hand-searched references of the identified articles. Two instigators screened the titles as well as the abstracts of the selected citations. Eligibility criteria were performed in two steps. An initial abstract screening was commissioned followed by a full-text retrieval of eligible articles and further screening for eligibility to meta-analysis.

Data Extraction

Using an online extraction form, two authors independently obtained the data using. The extracted data included the design of the study, the population, the risk of bias domains; and outcomes. The outcomes included the hospital stay, time to union, sagittal angulations, coronal angulations, malalignment, and walking independently; Disagreements were resolved by consensus.

Quality assessment

The quality of the Randomized Clinical Trials was evaluated as per the guidance of the Cochrane Handbook for Systematic Reviews of Interventions 5.1.0 (updated March 2011) utilizing the quality assessment table presented in that handbook (Part 2, Chapter 8.5). The Cochrane risk of bias assessment tool comprises the subsequent domains: sequence production (selection bias), allocation selection concealment (selection bias), blindfolding of participants and personnel (performance bias), blinding of outcome assessment (detection bias), inadequate outcome data (attrition bias), selective outcome reporting (reporting bias) and additional possible causes of bias. The authors’ interpretation is graded as ‘Low risk’, ‘High risk’ or ‘Unclear risk’ of bias. The NOS comprises 8 items, classified into three dimensions including selection, comparability, and—based on the study category—outcome (cohort studies) or exposure (case-control reports). For each feature, a set of response potentialities is implemented. For observational investigations, we applied the Newcastle-Ottawa Scale (NOS) for quality appraisal (36). NOS is based on a star system and is utilized to permit a semi-quantitative assessment of the study quality; it ranges between 0 up to 9 stars.

Measures of treatment effect

The primary outcomes were the time to union, malunion rate, the length of stay, independent walking, angulations (Sagittal and coronal) in both groups. The secondary outcomes were: complications and parents’ satisfaction.

Dealing with missing data

In the event of the lack of Standard deviation (SD) of change from baseline, estimates were conducted employing the standard error or 95% confidence interval (CI), according to Altman (37).

Data Synthesis

Hospital stay, time to union, sagittal angulations, coronal angulations, malunion and walking independently were pooled as standardized mean difference (SMD) in the random effect model meta-analysis described by Der-Simonian and Laird (38). The incidence of malalignment in both groups was pooled as relative risk (RR) in the meta-analysis model using the Mantel-Haenszel (M-H) method. Statistical analyses were conducted using Review Manager 5.3 for Windows.

Assessment of heterogeneity

Heterogeneity was assessed by visual inspection of the forest plots and measured by I-square and Chi-Squared tests. According to the Cochrane Handbook of Systematic Reviews and Meta-analysis of interventional studies, the Chi-squared test assesses whether observed differences in results are compatible with chance alone. According to Higgins 2002 and Higgins 2003, the heterogeneity test I-squared is calculated from the following equation: [(Q-df)/Q]x100% where Q is the chi-squared statistic and df is its degrees of freedom (39, 40). I-squared test can be interpreted as follows: 0% to 40%: might not be important; 30% to 60%: may represent moderate heterogeneity; 50% to 90%: may represent substantial heterogeneity; and 75% to 100%: considerable heterogeneity.

Publication bias

According to Egger et al. publication bias evaluation is not suitable for less than 10 pooled studies (41). Hence, in the current study, we could not assess the existence of publication bias by Egger's test for funnel plot asymmetry.

Results

Search results

Our search retrieved 573 unique articles. after screening of the abstract and full-text, 12 studies with a sum of 1012 patients were included for the concluding analysis (See PRISMA flow diagram; [Figure 1]) (31, 35, 42-52). The reasons for study exclusion are shown in Supplementary File no.1.

Of the 12 included studies, two studies were randomized controlled studies; the summary of the

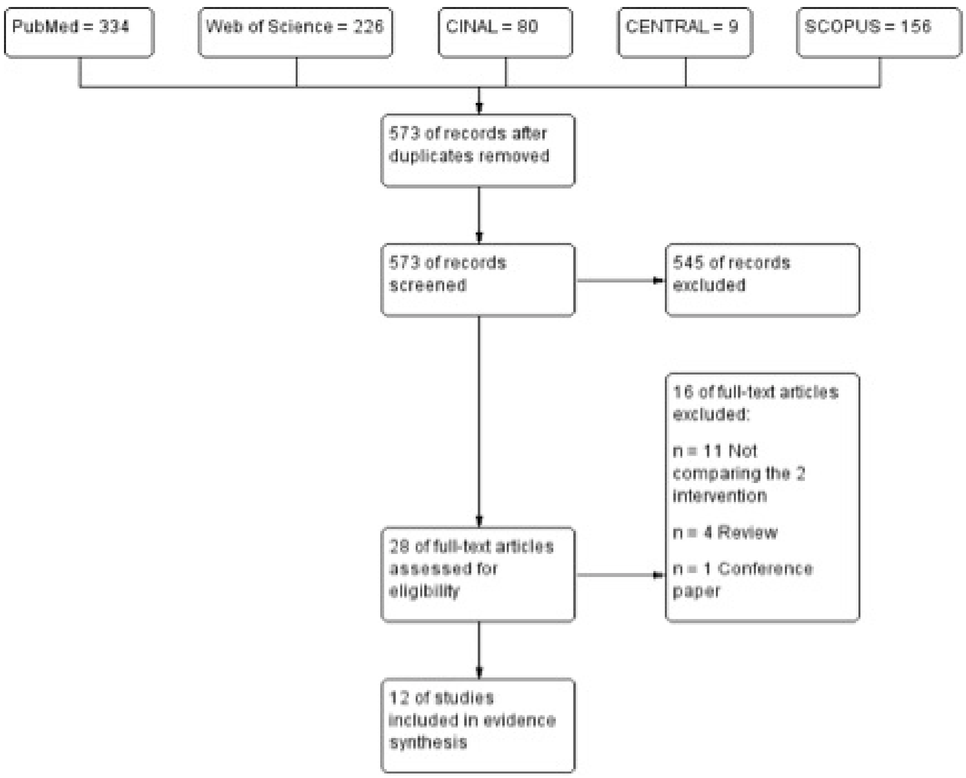

Figure 1. Shows PRISMA flow diagram for study selection.

included studies and their main results are shown in [Table 1].

Quality of included studies

The quality of the included studies was from moderate to high quality according to the Cochrane risk of bias assessment tool and the NOS. Therefore; included studies have acceptable quality for inclusion in our review. The summary of quality assessment domains of included studies is shown in supplementary file.

Table 1. Summary of included studies

Study ID	Design	Population	Sample size	Main finding
Heffernan, et al 2015 (39)	Retrospective observational study	Young Children Aged 2 to 6 Years with femur fractures	215	TENS is a reasonable option for treatment of femur fractures in young children when compared with spica casting with shorter time to independent ambulation and full activities. Fractures associated with a high-energy mechanism are especially appropriate for consideration of treatment with TEN.
Assaghir et al. 2013 (40)	Retrospective observational study	preschool children up to 6 years with femur fracture	104	TENS in preschool children is a safe choice but involves a scar, risk of infection, and the need for a second operation
Nascimento et al. 2013 (41)	Retrospective observational study	Children between the ages of 5 and 14 with femoral shaft fractures	60	The surgical method presented better results for children.
Sela et al. 2013 (42)	Retrospective observational study	Children with femur fractures	212	TENS treatment was superior to spica casting for children who had reached an average age of 4 years.
Say et al. 2013 (43)	Retrospective observational study	Children 6 to 16 years of age, with femur fractures	42	Both treatment options were similar with regard to complications and results. Although the complications are similar in two treatment methods, complications of elastic nail are more challenging and may require new surgical procedure. If the elastic nail is selected, surgical complications should not be underestimated
Buechsenschuetz et al. 2002 (44)	Retrospective observational study	Children admitted with femur fractures	68	Less cost and comparable clinical outcome make TENS a better option than traditional CRSC for femoral fracture care in the skeletally immature patient.
Flynn et al. 2004 (35)	Prospective observational study	Children 6 to 16 years of age, with femur fractures	83	The results of this prospective study support that a child in whom a femoral fracture is treated with titanium elastic nails achieves recovery milestones significantly faster than a child treated with traction and a spica cast. Hospital charges for the two treatment methods are similar. The complication rate associated with nailing compares favorably with that associated with traction and application of a spica cast.
Hsu et al. 2009 (45)	Prospective observational study	Children, five to twelve years of age, with femoral fractures	51	In resource-limited healthcare settings, Spica is an effective alternative to TENS with comparable post-op radiographic angulations, decreased hospital stays, and lower cost.
Kaiser et al. 2014 (31)	Prospective observational study	Patients ages 3–14 years	84	The initial experience of operative treatment of femoral shaft fractures in children using TENS was positive, with improved rates of treatment success and no surgical complications. Because of the high cost of implants, direct costs of treatment remained higher with ESIN despite reductions in length of hospital stay.
Saseendar et al. 2010 (46)	Prospective observational study	Children 5–15 years with femure fractures	17	Titanium elastic nailing led to better outcomes compared to hip spica casting in terms of earlier union, lower rates of malunion, shorter rehabilitation milestones, and better functional outcome scores.
Soleimanpour et al. 2013 (47)	Randomized controlled trial	Children, 6–12 years old, with one-sided femoral-shaft fractures	30	The results indicated that a child in whom a femoral fracture is treated with TENS achieves recovery milestones significantly faster than a child treated with traction and spica cast.
Shemshaki et al. 2011 (48)	Randomized controlled trial	Children, 6–12 years old, with simple femoral-shaft fractures	46	The results showed significant benefits of TENS compared with traction and hip spica cast in the treatment of femoral-shaft fractures in children. Further trials with longer follow-ups and comparison of TEN with other methods, such as external fixation, in children's femoral fractures are warranted.

Primary Outcomes

Duration to Union (in weeks)

In terms of duration till union (in weeks), reported effect sizes were heterogeneous and were not reliable for pooling in a meta-analysis model to give an overall effect estimate [Figure 2]. The duration till union was significantly less in the TEN group than the control group in two studies; while in the third study of (42-44).

Malunion

The pooled risk ratio of malunion showed less rate of malunioin in the TEN group compared with the Spica group (RR 0.43, 95% CI [0.26, 0.71], *P<0.001*, [Figure 3]. Pooled studies were homogenous (*P>0.1*; I-square=0%).

Sagittal Angulations

The overall standardized mean difference in sagittal angulations favored TEN group than the control group (SMD -0.48, 95% CI [-0.70 to -0.26], *P<0.001*, [Figure 4]. Pooled studies were not heterogeneous (Chi square *P=0.90*; I-square=0%).

	TEN			Spica cast			Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	IV, Random, 95% CI
Assaghir et al. 2013	6.1	1.3	52	7.5	1.8	52	-0.89 [-1.29, -0.48]
Heffernan, et al 2015	6.3	1.971429	74	6.442857	1.842857	141	-0.08 [-0.36, 0.21]
Saseendar et al. 2010	6.47	0.99	16	8.25	1.483	16	-1.38 [-2.16, -0.60]

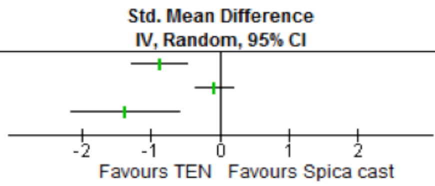

Figure 2. Shows the standardized mean difference between the two groups in the rate of union (in weeks) with 95% confidence intervals. IV=Inverse variance.

	TEN		Spica cast			Risk Ratio
Study or Subgroup	Events	Total	Events	Total	Weight	M-H, Random, 95% CI
Assaghir et al. 2013	5	52	12	52	27.1%	0.42 [0.16, 1.10]
Buechsenschuetz et al. 2002	9	42	8	26	38.2%	0.70 [0.31, 1.58]
Flynn et al. 2014	0	48	3	35	3.0%	0.10 [0.01, 1.97]
Heffernan, et al 2015	0	74	0	141		Not estimable
Kaiser et al. 2014	3	39	13	39	18.5%	0.23 [0.07, 0.75]
Say et al. 2013	2	22	4	20	10.2%	0.45 [0.09, 2.22]
Sela et al. 2013	0	21	0	151		Not estimable
Shemshaki et al. 2011	0	23	3	23	3.0%	0.14 [0.01, 2.62]
Total (95% CI)		**321**		**487**	**100.0%**	**0.43 [0.26, 0.71]**
Total events	19		43			

Heterogeneity: Tau² = 0.00; Chi² = 4.06, df = 5 (P = 0.54); I² = 0%
Test for overall effect: Z = 3.31 (P = 0.0009)

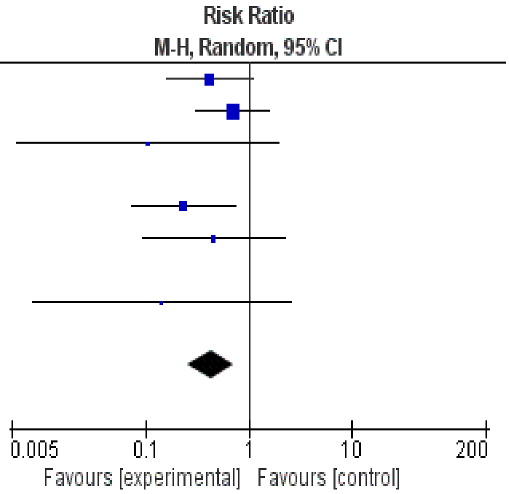

Figure 3. Shows the risk ratio of malunion between the two groups with 95% confidence intervals. M-H=mantel Haenzel.

	TEN			Spica cast				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Assaghir et al. 2013	0.3	0.1	52	1.5	3.2	52	31.3%	-0.53 [-0.92, -0.13]
Heffernan, et al 2015	4.9	4.1	74	7.7	6.5	141	58.9%	-0.48 [-0.77, -0.20]
Saseendar et al. 2010	5.75	6.137	16	7.79	5.466	16	9.8%	-0.34 [-1.04, 0.36]
Total (95% CI)			**142**			**209**	**100.0%**	**-0.48 [-0.70, -0.26]**

Heterogeneity: Tau² = 0.00; Chi² = 0.20, df = 2 (P = 0.90); I² = 0%
Test for overall effect: Z = 4.32 (P < 0.0001)

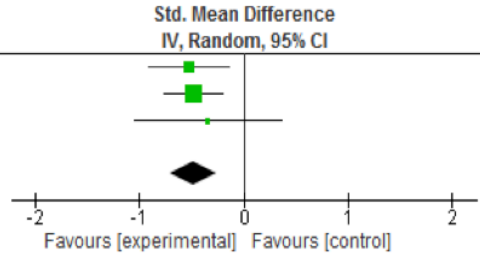

Figure 4. Shows the standardized mean difference between the two groups in the sagittal angulations with 95% confidence intervals.

Coronal Angulations

The overall standardized mean difference in coronal angulations favored TEN group than the control group (SMD -0.66, 95% CI [-1.00 to -0.31], *P<0.001*, [Figure 5]. Pooled studies were not heterogeneous (Chi square *P=0.14*; I-square=48%).

Hospital stay (days)

Three retrospective studies favored the CRSC group over the TEN group. The remaining retrospective study did not favor either of the two groups. The two RCTs, reported a statistically significant difference favoring shorter hospital stay in the case of TEN than the CRSC group (Mean Difference = -13.60 days, 95% CI [-16.25 to -10.95], and Mean Difference = -12.28 days, 95% CI [-13.26 to -11.30], respectively) (42, 43). The overall effect estimates did not support superiority of any of the two groups (Mean Difference = -3.13, 95% CI [-7.44, 1.18], *P=0.15*, [Figure 6]); the pooled effect estimate was highly heterogeneous (Chi square *P<0.001*; I-square=99%).

Malalignment

The overall risk ratio of malalignment favored TEN group than control group (RR=0.39, 95% CI [0.27 to 0.57], *P<0.001*, [Figure 7]). Pooled studies were not

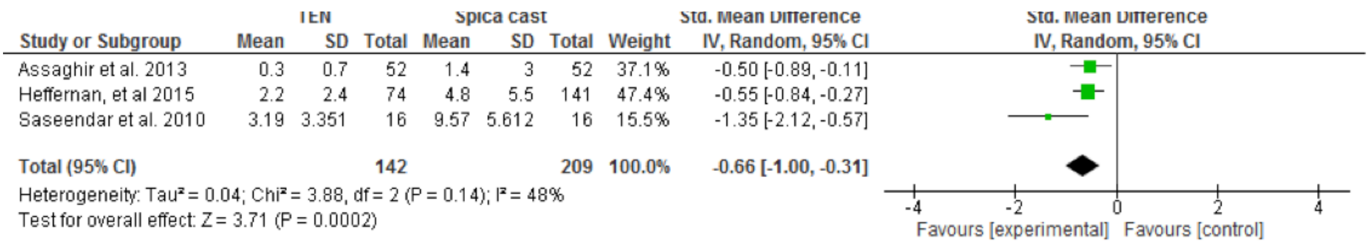

Figure 5. Shows the standardized mean difference between the two groups in the coronal angulations with 95% confidence intervals.

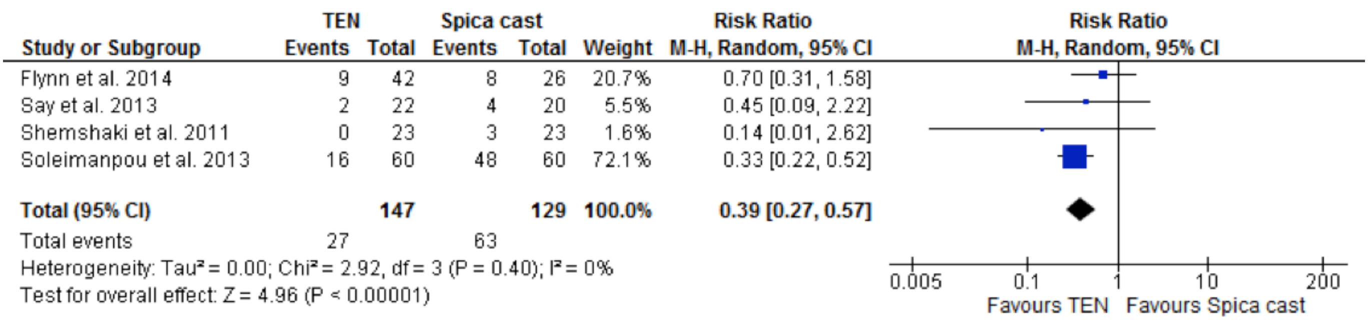

Figure 6. Shows the mean difference between the two groups in the length of hospital stay with 95% confidence intervals. IV=Inverse variance.

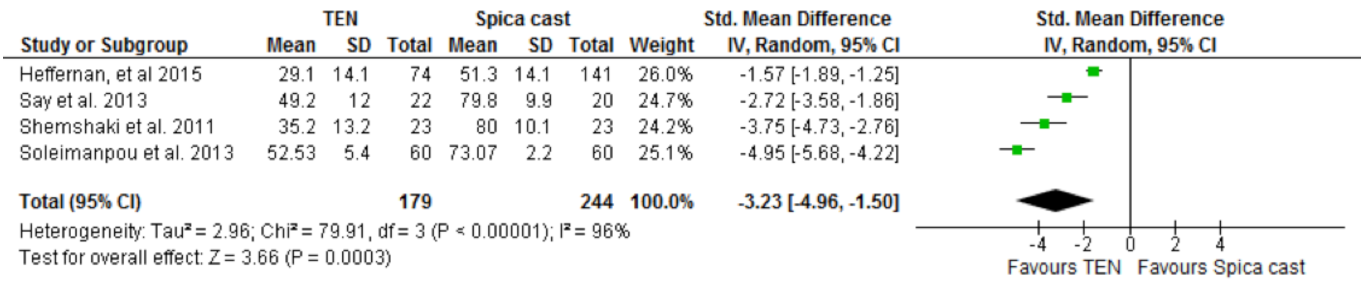

Figure 7. Shows the risk ratio between the two groups in the rate malalignment with 95% confidence intervals.

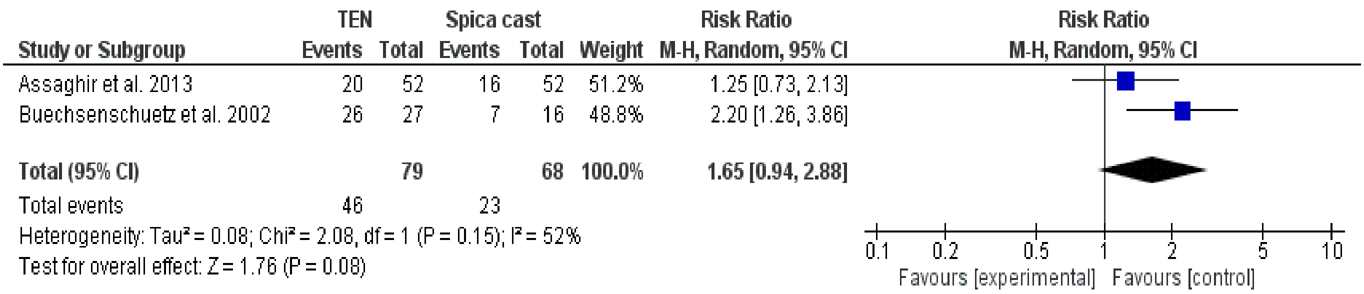

Figure 8. Shows the standardized mean difference between the two groups in the walking independently with 95% confidence intervals. IV=Inverse variance.

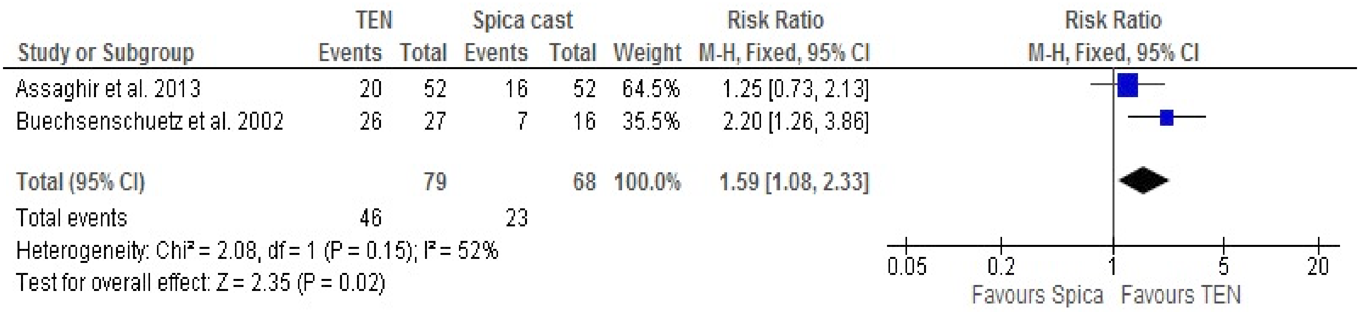

Figure 9. Shows the risk ratio between the two groups in the parent satisfaction with 95% confidence intervals.

Table 2. Complications for the TEN group			
Painful nail end	studies 8	20/279	7.1%
Pin migration through the skin	studies 4	8/177	4.5%
Superficial infection	studies 7	8/273	2.9%
Painful scar of open reduction	One study	2/52	3.8%
Painless limp	One study	1/52	1.9%

heterogeneous (Chi-square *P=0.40* and I-square=0%).

Walking independently

Four studies (two retrospective studies and two RCTs) investigated the ability of patients to walk independently. All the four studies reported a statistically significant difference in walking independently favoring the TEN group than the control group [Figure 8].

Secondary Outcomes

Parent Satisfaction

Two studies reported parent satisfaction; both studies showed higher satisfaction rate following TEN than Spica. The pooled RR of parent satisfaction did not significantly favored the TEN group than the Spica group (RR 1.65, 95% CI [0.94, 2.88], *P =0.08*, [Figure 9].

Complications

The complications of each procedure are mutually independent. Therefore, we cannot compare both procedures for the same complications. Therefore, the percentages could not be expressed as Risk Ratio between the two groups. Summary of complications is summarized in [Table 2] and [Table 3].

Table 3. Complications for the Cast Group			
Sores	studies 3	11/248	4.4%
Ulcer	studies 4	3/199	2.5%
infected traction pin	studies 7	7/299	2.3%
Wedging of the spica	studies 2	17/81	20.9%
Removal and reinsertion of a traction pin	One study	3/29	10.3%
Substantial loss of reduction	studies 4	20/222	9%
Revision under anesthesia once	One study	5/52	9.6%
Revision under anesthesia twice	One study	2/52	3.8%
Painless limp	One study	4/52	7.6%

Discussion

Our analysis showed a statistically significant difference favoring the TEN group in the duration of union when compared with CRSC - as well as malunion, sagittal and coronal angulations in the management of femoral fractures in patients younger than 16 years old. We report a statistically significant difference favoring shorter hospital stay in the case of TEN when compared to the CRSC group. Likewise, the overall risk ratio of malalignment favored TEN group than CRSC. Similarly, we have observed a statistically significant difference in independent walking and parents' satisfaction favoring the TEN group than the CRSC group. Subsequently, based on our observations, the results showed significant benefits of TEN compared to CRSC in the treatment of femoral-shaft fractures in children younger than 16 years old.

Traditionally, conservative treatment was the method of choice for diaphyseal fractures in children and adolescents, because it avoided surgical risks. However, spica use requires lengthy immobilisation and a higher risk for limb length discrepancy (LLD). TEN fixation subsequently replaced other surgical options in children, as it is an effective reproducible and minimally invasive option. It permits: a stable fixation, rapid healing and a prompt return to normal activity (35, 40, 44, 51).

Overall completeness of evidence

Shemshaki et al. compared spica cast with TEN in management of peadiatric femoral fractures and reported superior results in the TEN group with earlier discharge from hospital (*P<0.001*), return to independent walking (*P<0.001*), return to school (*P<0.001*) and better parent satisfaction (*P=0.003*); the two groups were similar in baseline characteristics (45). The Range of knee motion was 138.7 ± 3.4 and 133.5 ± 13.4 degrees in the CRSC and the TEN groups respectively (*P=0.078*). Malunion was observed three patients (13.0%) in the CRSC group compared with none in the TEN group (*P=0.117*). The occurrence of infection was reported in three patients (13.0%) in the TEN group, after surgery.

Similarly, Soleimanpour et al. reported superior results in the TEN group in regards to the absence time from school, duration of hospitalization, time required for return to normal walking and varus or valgus angular deviation were when compared with the CRSC group (46). They observed no statistically significant differences between the two groups in relation to malunion, wound complications and hospital charges.

Union

Heffernan et al. showed no statistical significant difference between the two groups in regards to the time to union (42). However, Sasseendar et al. and Flynn et al. showed a statistically significant difference favoring the TEN group than the control group (35, 44).

Sela et al. reported 100% union rate, less than 8% rate of LLD and a complication rate of less than 5% with CRSC (47). Only one of the 151 patients treated with CRSC needed a re-operation. Assaghir et al. retrospectively evaluated 104 pediatric femoral fracture in children with a mean age of 4.5 years managed with wither TEN or spica cast followed up for a minimum of 3 years (43). TEN was statistically better in terms of union (*P<0.001*), and shortening (*P=0.016*) subsequently leading to earlier weight bearing (*P<0.001*). Saseendar et al. demonstrated that fracture union happens earlier in the TEN group (6 weeks) than in the spica group (8 weeks) (*P=0.001*) (44).

Heffernan et al. performed a multicenter retrospective analysis of 215 patients aged 2 to 6 Years (42). Although there was no significant difference in healing times between TEN and the spica groups (*P=0.652*), they recommended that TEN is a sensible option for management of femur fractures in young children when compared with CRSC with shorter time to independent ambulation and full activities (*P=0.023*). They strongly recommended the utilization of TEN in high-energy mechanism fractures.

Complications

In our analysis, reported complications in TEN group included: painful nail ends, pin migration, superficial infection, painful scar and painless limb. On the other hand, complications in CRSC group ranged from: sores, ulcers, infected pin, wedging of the spica, revision and limbing.

Sela et al. reported that CRSC were associated with increased risks of adverse events- mainly contact dermatitis (47). The main complication was the risk of revision of manipulation when the reduction is lost. Additionally, they also had 10.5% more LLDs (>2 cm shortening or <1 cm lengthening). Similarly, Flynn et al. published complications associated with TEN compared favorably with that associated with CRSC (32). In their cohort, none of the children treated with TEN had more that one cm of LLD compared to 2/35 (4%).

Say et al. detected no significant differences in the rate of occurrence of complications (48). Although the complications are statistically alike in both procedures, they highlighted that the complications of TEN are more challenging.

Malunion, sagittal, and coronal angulation

Our analysis showed lower rate of malunion in the TEN group compared with the CRSC group. Similarly, the overall standardized mean difference in sagittal angulation (*P<0.0001*) and coronal angulation (*P=0.0002*) favored TEN group than the CRSC group. Satisfactory angulation in femoral shaft fractures in children has been established by Kasser (53): angulation of 30° in sagittal and coronal planes in children below 2 years of age, 20° (sagittal plane) and 15° (coronal plane) in children aged 2 and 5 years and 10° (coronal plane) and 15° (sagittal plane) in children aged between 5 and 10 years. When angulations during spica cast treatment occur beyond these ranges, different strategies must be considered - such as cast wedging (3). Loss of acceptable angulation after reduction of femoral fracture in children treated with spica casting has been reported (31, 35, 44). Assaghir et al. reported statistically significant differences in favor of TEN over CRSC in regards to shortening (*P=0.016*); sagittal angulation (*P=0.018*); coronal angulation (*P=0.022*); rotation (*P=0.014*) (43).

Heffernan et al. reported lingering angulation was higher in the CRSC vs (42). TEN group in both the sagittal plane (*P=0.002*) and coronal plane (*P=0.006*). Similarly, outcome success represented by coronal and sagittal angulation less than 10° and shortening less than 15 mm was attained in 92 % of the TEN group compared to 67% in the CRSC group (odds ratio for TEN group 9.28 (1.6–54.7); *P= 0.0138*) (31). Saseendar et al. demonstrated that Spica casting was associated with more coronal plane angulation (*P=0.001*), increased rotational malalignment (*P=0.001*), increased limb length discrepancy at one year post surgery (*P<0.001*) when compared with the TEN group (44).

Shemshaki et al. reported a 13.0% of nonunion in the CRSC group whereas none occurred in the TEN group in their randomized controlled trial (*P=0.117*) (45). In the younger age groups. Assaghir et al. retrospectively evaluated femoral fracture in children with a mean age of 4.5 years (43). TEN was statistically better in terms of sagittal angulation (*P=0.018*), coronal angulation (*P=0.022*), rotation (*P=0.014*).

Cost effectiveness

Buechsenschuetz et al. retrospectively undertook a cost analysis comparing both modalities (49). They looked at different aspects including hospital, physicians, physiotherapy and facility costs. Hospital costs were higher in the TEN group including the overall surgeon's and physiotherapy costs paid (*P<0.001*). The metalwork removal procedure was included as well in the TEN group. Nevertheless, hospitalization costs, were higher in the spica group (*P<0.015*). Subsequently, there is a slight difference in overall inpatient expenses between the two groups (*P<0.047*). Finally, they reported that the total overall costs of femoral shaft fractures with TEN was significantly less expensive (average, $11,077) than traditional CRSC approach (average, $13,490), with a value of *P<0.04*. On the other hand, Clinkscales and Peterson demonstrated that the costs for patients in the traction group were equal to the TEN group (51). Similarly, Flynn et al. and Soleimanpour et al. reported that costs for the two treatment options were similar (35, 46). Flynn et al. demonstrated that although the surgical costs is significantly higher in the TEN group (*P<0.0001*), the hospitalization cost was significantly higher in the CRSC group (*P<0.001*), yielding to insignificant total costs' differences between both groups (35).

Parent satisfaction

Two studies reported parent satisfaction (43, 49). Both studies showed higher satisfaction rate following TEN than Spica. Also comparable to our results, there was reduced parent satisfaction in the CRSC group, with superior parental acceptance of the TEN treatment. This was also reported by Clinkscales and Peterson (51). This observation could be attributed to the various community and psychological aspects of treating femoral fractures with spica casts that was highlighted by different studies (54-56).

Buechsenschuetz et al. reported that most children in the TEN group were reintegrated with their social environment quicker than their CRSC equivalents (49). Patients in the TEN group were capable to rejoin school within 2 to 3 weeks of their surgery, and in certain cases even before the CRSC group patients were discharged from hospital. They showed that two children in the CRSC group had to repeat a school grade. This led to parental dissatisfaction and had adverse implications on the child. One parent reported that their child was "emotionally scarred" during the cast period, and another patient ultimately needed psychiatric consultation after removal of the cast. Though these observations cannot be generalized, this is inferred as a direct consequence of the CRSC procedure, as was previously reported by Streissguth and Streissguth (57).

Length of hospital stay

Two RCTs reported a statistically significant difference favoring shorter hospital stay in the case of TEN than the CRSC group (45, 46). Shemshaki et al. reported a short length of stay in the TEN group when compared with the CRSC group with a mean of 6.9 ± 2.9 days in the TEN group to 20.5 ± 5.8 days in the CRSC group (*P<0.001*) (45). Likewise, Soleimanpour et al. and Flynn et al. reported a shorter hospitalization in the TEN group, when compared with CRSC group (*P<0.05*) and (*P<0.0001*) respectively (35, 46). Flynn et al. reported a mean of 5 days of hospitalization in the TEN group compared to 24 days in the CRSC group. Nonetheless, the reminder of the included studies demonstrated different results with reduced hospital stay in the CRSC group. Our pooled effect estimate did not favor any of the two group.

Independent walking and return to school

Similar to our findings, Shemshaki et al. reported a short time interval to independent walking in the TEN group when compared with the CRSC group (45). They reported a mean 17.6 ±10.2 days to supported walking in the TEN group compared to 65.6 ± 10.7 in the CRSC group (*P<0.001*). Additionally, they demonstrated that the children in the TEN group took a shorter time to return to school sooner. It took the patients in the TEN group a mean of 31.5 ± 13.4 to return back to school compared to 64.3 ±19.6 days in the CRSC group (*P<0.001*). Similarly, Flynn et al. reported an earlier return to supported walking and independant walking in children in the TEN group, and a quicker return to school and these differences were significant when compared with CRSC group (48 days in the TEN compared to 103 days in the CRSC group (*P<0.0001*)) (35). The same observations were reported by Soleimanpour et al.; they demonstrated that mean non-attendance time from school, time needed for walking with and without help were significantly lower in the group treated by TEN (*P<0.05*) (46). Assaghir et al. demonstrated TEN was statistically better in terms of earlier weight bearing (*P<0.001*), and earlier return to nursery (*P=0.000*) in children less than 6 years old (43).

Quality of the evidence

The quality of this evidence is reliable as it is based on high-quality investigations as shown by the quality assessment. Search designs and eligibility criteria were well established. We used the PRISMA checklist to plan this study and we completed all the steps following the guidance by the Cochrane Handbook for Systematic Reviews of Interventions. We should state that in our study, we mixed data from Randomised Controlled Trials and observational studies. Notwithstanding, most effect estimates were pooled without significant heterogeneity. Moreover, the effect estimates of Randomised Controlled Trials were not significantly different from those of observational studies except in terms of hospital stay. Accordingly, we conclude that evidence obtained from our analysis is robust.

Based on our analysis we recommend the use of TEN fixation in management of pediatric femoral fractures in patients younger than 16 years old. The results imply that a child with a femoral fracture when treated with a TEN, achieves recovery milestones significantly faster than a child treated with traction and spica cast. Further studies with longer follow-ups and comparison of TEN with other surgical methods, such as external fixation, in children's femoral fractures are required.

All authors confirm no financial or personal relationship with a third party whose interests could be positively or negatively influenced by the article's content.

Limitations

This meta-analysis included retrospective and observational studies together with two RCTs. It is well established that RCTs are the gold standard comparative studies providing class one evidence. Given this, we recommend further RCTs comparing the TEN with Spica hip. Additionally, the included studies did not study comprehensively different aspects of femoral shaft fractures and subsequently, this has been under-reported in our meta-analysis. These include factors like fracture type, patients' skeletal maturity and associated co-morbidities in those children. As these are important factors that should be considered when choosing the preferred treatment method.

Acknowledgements

We would like to thank Ali M. Hammad for his help in the literature search and selection of studies.

Mohamed A. Imam MD PhD FRCS
Department of Trauma and Orthopaedics, Faculty of Medicine, Suez Canal University, Egypt
Ashford and St Peters NHS Trust, Chertsey, UK

Ahmed S. Negida MBBC
Faculty of Medicine, Zagazig University, El-Sharkia, Egypt

Ahmed Elgebaly MBBCH
Faculty of Medicine, Al Azhar University, Cairo, Egypt

Amr Samy Hussain MRCS MSc
Warwick University Hospitals, Warwick, UK

Lukas Ernstbrunner MD
Department of Orthopaedics, Balgrist University Hospital, University of Zurich, Forchstrasse, Zurich, Switzerland
Department of Orthopaedics and Traumatology, Paracelsus Medical University, Muellner Hauptstrasse, Salzburg, Austria

Saqib Javed MD FRCS
Wrightington Hospital Appley Bridge, UK

Joshua Jacob FRCS
Paul Trikha FRCS
Kevin Newman FRCS
David Elliott FRCS
Arshad Khaleel FRCS
Ashford and St Peters NHS Trust, Chertsey, UK

Mark Churchill FRCS
Epsom and St Helier NHS Trust, Carshalton, UK

References

1. Bahuaud C, Beneteau M, Dorr MF. [Treatment of fractures of the femoral diaphysis in children]. Soins Chir. 1993(150-151):36-42.
2. Rewers A, Hedegaard H, Lezotte D, Meng K, Battan FK, Emery K, et al. Childhood femur fractures, associated injuries, and sociodemographic risk factors: a population-based study. Pediatrics. 2005;115(5):e543-52.
3. Sanzarello I, Calamoneri E, D'Andrea L, Rosa MA. Algorithm for the management of femoral shaft fractures in children. Musculoskeletal surgery. 2014;98(1):53-60.
4. Rodriguez-Merchan EC, Moraleda L, Gomez-Cardero P. Injuries associated with femoral shaft fractures with special emphasis on occult injuries. Arch Bone Jt Surg. 2013; 1(2):59-63.
5. Dalton HJ, Slovis T, Helfer RE, Comstock J, Scheurer S, Riolo S. Undiagnosed abuse in children younger than 3 years with femoral fracture. American journal of diseases of children (1960). 1990;144(8): 875-8.
6. Hinton RY, Lincoln A, Crockett MM, Sponseller P, Smith G. Fractures of the femoral shaft in children. Incidence, mechanisms, and sociodemographic risk factors. The Journal of bone and joint surgery American volume. 1999;81(4):500-9.
7. Flynn JM, Schwend RM. Management of pediatric femoral shaft fractures. The Journal of the American Academy of Orthopaedic Surgeons. 2004;12(5):347-59.
8. Sanders JO, Browne RH, Mooney JF, Raney EM, Horn BD, Anderson DJ, et al. Treatment of femoral fractures in children by pediatric orthopedists: results of a 1998 survey. Journal of pediatric orthopedics. 2001;21(4):436-41.
9. Aslani H, Tabrizi A, Sadighi A, Mirbolook AR. Treatment of pediatric open femoral fractures with external fixator versus flexible intramedullary nails. Arch Bone Jt Surg. 2013; 1(2):64-7.
10. Andalib A, Sheikhbahaei E, Andalib Z, Tahririan MA. Effectiveness of minimally invasive plate osteosynthesis (MIPO) on comminuted tibial or femoral fractures. Arch Bone Jt Surg. 2017; 5(5):290-5.
11. Buckley SL. Current trends in the treatment of femoral shaft fractures in children and adolescents. Clinical orthopaedics and related research. 1997(338):60-73.
12. Buehler KC, Thompson JD, Sponseller PD, Black BE, Buckley SL, Griffin PP. A prospective study of early spica casting outcomes in the treatment of femoral shaft fractures in children. Journal of pediatric orthopedics. 1995;15(1):30-5.
13. Curtis JF, Killian JT, Alonso JE. Improved treatment of femoral shaft fractures in children utilizing the pontoon spica cast: a long-term follow-up. Journal of pediatric orthopedics. 1995;15(1):36-40.
14. Miller ME, Bramlett KW, Kissell EU, Niemann KM. Improved treatment of femoral shaft fractures in children. The "pontoon" 90-90 spica cast. Clinical orthopaedics and related research. 1987(219): 140-6.
15. Rasool MN, Govender S, Naidoo KS. Treatment of femoral shaft fractures in children by early spica casting. S Afr Med J. 1989;76(3):96-9.
16. Al-Habdan I. Diaphyseal femoral fractures in children: should we change the present mode of treatment? Int Surg. 2004;89(4):236-9.
17. Krettek C, Haas N, Walker J, Tscherne H. Treatment of femoral shaft fractures in children by external fixation. Injury. 1991;22(4):263-6.
18. Aronson J, Tursky EA. External fixation of femur fractures in children. Journal of pediatric orthopedics. 1992;12(2):157-63.
19. Kirschenbaum D, Albert MC, Robertson WW, Jr., Davidson RS. Complex femur fractures in children: treatment with external fixation. Journal of pediatric orthopedics. 1990;10(5):588-91.
20. Mostafa MM, Hassan MG, Gaballa MA. Treatment of femoral shaft fractures in children and adolescents. The Journal of trauma. 2001;51(6):1182-8.
21. Kregor PJ, Song KM, Routt ML, Jr., Sangeorzan BJ, Liddell RM, Hansen ST, Jr. Plate fixation of femoral shaft fractures in multiply injured children. The Journal of bone and joint surgery American volume. 1993;75(12):1774-80.
22. Beaty JH, Austin SM, Warner WC, Canale ST, Nichols L. Interlocking intramedullary nailing of femoral-shaft fractures in adolescents: preliminary results and complications. Journal of pediatric orthopedics. 1994;14(2):178-83.
23. Beaty JH. Operative treatment of femoral shaft fractures in children and adolescents. Clinical orthopaedics and related research. 2005(434):114-22.
24. Buford D, Jr., Christensen K, Weatherall P. Intramedullary nailing of femoral fractures in adolescents. Clinical orthopaedics and related research. 1998(350):85-9.
25. Momberger N, Stevens P, Smith J, Santora S, Scott S, Anderson J. Intramedullary nailing of femoral fractures in adolescents. Journal of pediatric orthopedics. 2000;20(4):482-4.
26. Galpin RD, Willis RB, Sabano N. Intramedullary nailing of pediatric femoral fractures. Journal of pediatric orthopedics. 1994;14(2):184-9.
27. Keeler KA, Dart B, Luhmann SJ, Schoenecker PL, Ortman MR, Dobbs MB, et al. Antegrade intramedullary nailing of pediatric femoral fractures using an interlocking pediatric femoral nail and a

lateral trochanteric entry point. Journal of pediatric orthopedics. 2009;29(4):345-51.
28. Lee MC. Luau Limbo and the Age for Rigid Nailing of Pediatric Femoral Fractures: How Low Can You Go? Commentary on an article by Samuel N. Crosby Jr., MD, et al.: "Twenty-Year Experience with Rigid Intramedullary Nailing of Femoral Shaft Fractures in Skeletally Immature Patients". The Journal of bone and joint surgery American volume. 2014;96(13):e116.
29. Allar BG, Hedequist DJ, Miller PE, Glotzbecker MP, Spencer SA, Shore BJ. Treatment outcomes after insufficiency femoral diaphyseal fractures in nonambulatory children. J Pediatr Orthop B. 2016.
30. Cosma D, Vasilescu DE. Elastic Stable Intramedullary Nailing for Fractures in Children - Specific Applications. Clujul Med. 2014;87(3):147-51.
31. Kaiser SP, Holland T, Baidoo PK, Coughlin RC, Konadu P, Awariyah D, et al. An observational cohort study of the adoption of elastic stable intramedullary nailing for the treatment of pediatric femur fractures in Kumasi, Ghana. World J Surg. 2014;38(11):2818-24.
32. Till H, Huttl B, Knorr P, Dietz HG. Elastic stable intramedullary nailing (ESIN) provides good long-term results in pediatric long-bone fractures. Eur J Pediatr Surg. 2000;10(5):319-22.
33. Ligier JN, Metaizeau JP, Prevot J, Lascombes P. Elastic stable intramedullary nailing of femoral shaft fractures in children. The Journal of bone and joint surgery British volume. 1988;70(1):74-7.
34. Heinrich SD, Drvaric DM, Darr K, MacEwen GD. The operative stabilization of pediatric diaphyseal femur fractures with flexible intramedullary nails: a prospective analysis. Journal of pediatric orthopedics. 1994;14(4):501-7.
35. Flynn JM, Luedtke LM, Ganley TJ, Dawson J, Davidson RS, Dormans JP, et al. Comparison of titanium elastic nails with traction and a spica cast to treat femoral fractures in children. J Bone Joint Surg Am. 2004;86-A(4):770-7.
36. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. Eur J Epidemiol. 2010;25(9):603-5.
37. Altman DG, Bland JM. Standard deviations and standard errors. Bmj. 2005;331(7521):903.
38. DerSimonian R, Laird N. Meta-analysis in clinical trials revisited. Contemporary clinical trials. 2015;45(Pt A):139-45.
39. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. Statistics in medicine. 2002;21(11):1539-58.
40. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. Bmj. 2003;327(7414):557-60.
41. Terrin N, Schmid CH, Lau J, Olkin I. Adjusting for publication bias in the presence of heterogeneity. Stat Med. 2003;22(13):2113-26.
42. Heffernan MJ, Gordon JE, Sabatini CS, Keeler KA, Lehmann CL, O'Donnell JC, et al. Treatment of femur fractures in young children: a multicenter comparison of flexible intramedullary nails to spica casting in young children aged 2 to 6 years. Journal of pediatric orthopedics. 2015;35(2):126-9.
43. Assaghir Y. The safety of titanium elastic nailing in preschool femur fractures: a retrospective comparative study with spica cast. J Pediatr Orthop B. 2013;22(4):289-95.
44. Saseendar S, Menon J, Patro DK. Treatment of femoral fractures in children: is titanium elastic nailing an improvement over hip spica casting? J Child Orthop. 2010;4(3):245-51.
45. Shemshaki HR, Mousavi H, Salehi G, Eshaghi MA. Titanium elastic nailing versus hip spica cast in treatment of femoral-shaft fractures in children. J Orthop Traumatol. 2011;12(1):45-8.
46. Soleimanpour J, Ganjpour J, Rouhani S, Goldust M. Comparison of titanium elastic nails with traction and spica cast in treatment of children's femoral shaft fractures. Pakistan journal of biological sciences : PJBS. 2013;16(8):391-5.
47. Sela Y, Hershkovich O, Sher-Lurie N, Schindler A, Givon U. Pediatric femoral shaft fractures: treatment strategies according to age--13 years of experience in one medical center. J Orthop Surg Res. 2013;8:23.
48. Say F, Gurler D, Inkaya E, Yener K, Bulbul M. Which treatment option for paediatric femoral fractures in school-aged children: elastic nail or spica casting? European journal of orthopaedic surgery & traumatology : orthopedie traumatologie. 2014;24(4):593-8.
49. Buechsenschuetz KE, Mehlman CT, Shaw KJ, Crawford AH, Immerman EB. Femoral shaft fractures in children: traction and casting versus elastic stable intramedullary nailing. The Journal of trauma. 2002;53(5):914-21.
50. Nascimento FP, Santili C, Akkari M, Waisberg G, Braga Sdos R, Fucs PM. Flexible intramedullary nails with traction versus plaster cast for treating femoral shaft fractures in children: comparative retrospective study. Sao Paulo Med J. 2013;131(1):5-12.
51. Clinkscales CM, Peterson HA. Isolated closed diaphyseal fractures of the femur in children: comparison of effectiveness and cost of several treatment methods. Orthopedics. 1997; 20(12):1131-6.
52. Hsu AR, Diaz HM, Penaranda NR, Cui HD, Evangelista RH, Rinsky L, et al. Dynamic skeletal traction spica casts for paediatric femoral fractures in a resource-limited setting. Int Orthop. 2009;33(3):765-71.
53. Kasser JR. Femur fractures in children. Instructional course lectures. 1992;41:403-8.
54. Benum P, Ertresvag K, Hoiseth K. Torsion deformities after traction treatment of femoral fractures in children. Acta orthopaedica Scandinavica. 1979;50(1):87-91.
55. Karn MA, Ragiel CA. The psychologic effects of immobilization on the pediatric orthopaedic patient (continuing education credit). Orthop Nurs. 1986;5(6):12-7.

56. Streissguth AP, Streissguth DM. Planning for the psychological needs of a young child in a double spica cast. Including a plan for construction of a scooter. Clin Pediatr (Phila). 1978;17(3):277-83.

57. Osteogenic protein-1 for long bone nonunion: an evidence-based analysis. Ontario health technology assessment series. 2005;5(6):1-57.