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Clinical and financial impacts of Flexible Intramedullary Nailing in pediatric diaphyseal forearm fractures: a case-control study.

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préparée sous la direction du Docteur Nicolas Lutz

et présentée à la Faculté de biologie et de médecine de
l'Université de Lausanne pour l'obtention du grade de

DOCTEUR EN MEDECINE

par

Aline LEUBA

Médecin diplômé(e) de la Confédération Suisse
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***Clinical and financial impacts of Flexible Intramedullary Nailing
in pediatric diaphyseal forearm fractures: a case-control study***

Lausanne, le 12 mai 2022

*pour Le Doyen
de la Faculté de Biologie et de Médecine*


**Monsieur le Professeur John Prior
Vice-Directeur de l'Ecole doctorale**

Impact financier et clinique de l'ECMES dans les fractures de l'avant-bras en pédiatrie

Objectif

L'enclouage centromédullaire élastique stable (ECMES) est régulièrement utilisé pour les fractures instables déplacées de l'avant-bras en âge pédiatrique. Comparé à la réduction fermée et au plâtrage (traitement conservateur - TC), l'ECMES diminue l'angulation en fin de traitement, raccourcit la durée d'immobilisation et devrait réduire les contrôles de suivi. Une comparaison entre l'ECMES et le TC dans la gestion clinique, radiologique et financière de ces fractures a été réalisée.

Méthodes

Une étude rétrospective sur 5 ans de cas pédiatriques dans deux départements universitaires d'orthopédie pédiatrique a été réalisée. La méthode de traitement, l'évolution postopératoire et le suivi radiologique ont été examinés. Le nombre de radiographies, les contrôles de suivi, le type et la durée de l'immobilisation, l'angulation finale de l'os et les complications rapportées ont été comparés. Une analyse financière approfondie a été réalisée.

Résultats

Sur 73 filles et 168 garçons inclus dans l'étude, 150 ont été traités par ECMES et 91 par TC. Aucune différence n'a été notée en ce qui concerne le nombre total de radiographies (respectivement 7,3 contre 7,2). Le nombre total de suivis était de 6,4 (ECMES) et 5,5 (TC). Une angulation pathologique en fin de traitement est survenue chez 2 patients traités par ECMES contre 16 traités par TC. Le coût le moins élevé a été celui du TC ambulatoire.

Conclusions

Les enfants traités par ECMES avaient un nombre similaire de radiographies ou de consultations de suivi mais moins d'angulation pathologique en fin de traitement par rapport au TC. La gestion orthopédique était systématiquement moins chère que l'ECMES. À moins que des directives de gestion postopératoire diminuant le nombre de radiographies et de suivis ne soient mises en œuvre, l'ECMES restera une procédure coûteuse par rapport au traitement conservateur conventionnel.

Clinical and financial impacts of flexible intramedullary nailing in pediatric diaphyseal forearm fractures: A case–control study

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Abstract

Purpose: Flexible intramedullary nailing is regularly applied for pediatric displaced unstable forearm fractures. When compared to closed reduction and casting (orthopedic treatment), flexible intramedullary nailing decreases malalignment, shortens immobilization time, and should decrease follow-up controls. Comparing flexible intramedullary nailing and orthopedic treatment in the clinical, radiological, and financial managements of these fractures was performed.

Methods: Retrospective 5 years study of pediatric cases in two pediatric orthopedic university departments. Treatment method, post-operative course, and radiological follow-up were reviewed. Number of radiographs, follow-up controls, type and duration of immobilization, final bone angulation, and reported complications were compared. Extensive financial analysis was completed.

Results: Of 73 girls and 168 boys included in the study, 150 were treated by flexible intramedullary nailing and 91 by orthopedic treatment. No difference was noted with regard to total number of radiographs (7.3 vs 7.2, respectively). Total number of follow-ups was 6.4 and 5.5, respectively. Malalignment occurred in two flexible intramedullary nailing and sixteen orthopedic treatments. The least expensive cost was ambulatory orthopedic treatment.

Conclusion: Flexible intramedullary nailing treated children had similar numbers of radiographs or follow-up consultation, but less malunion when compared to orthopedic treatment. Orthopedic management was systematically cheaper than flexible intramedullary nailing. Unless post-operative management guidelines decreasing the number of radiographs and follow-ups are implemented, flexible intramedullary nailing will remain a costly procedure when compared to conventional orthopedic treatment.

Level of evidence: level III case–control retrospective study.

Keywords: Fracture, forearm, child, flexible intramedullary nailing, follow-up

Introduction

Forearm fracture is very common in children and represents 59% of all fractures encountered between 0 and 9 years of age.¹ For displaced and unstable diaphyseal forearm fractures, flexible intramedullary nailing (FIN) has gained popularity over the last 20 years and may be currently considered as the treatment of choice.^{2–5}

However, orthopedic treatment (OT) including closed reduction and casting still gives excellent results when performed accordingly. This non-invasive treatment method also ensures less skin and no hardware complications.^{6–9} Only children with clinically significant secondary displacements will require further manipulation and fixation

under anesthesia. Regular follow-up appointments with timely performed imaging studies are therefore necessary. A well-defined follow-up scheme plays a major role in the

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success of the OT management in children with displaced forearm fractures.

Compared to OT, FIN does not allow secondary displacement and decreases the risk of malalignment. This relative stability allows for early mobilization. Unless open reduction is required, the natural bone healing process is not affected. Moreover, the number of clinical and radiological follow-ups in these children should be minimized. These relevant FIN treatment principles and advantages should be similar whatever bone is treated.

Even though FIN has given excellent results with regard to anatomical reduction and stabilization, OT is still a widely performed in the management of pediatric upper extremity fractures. Only one study compared the clinical and radiological follow-up processes of these two means of treatment.¹⁰ Financial consequences of both treatments based on national billing processes were rarely evaluated.^{11–14} The impacts of FIN on the follow-up management scheme of children with forearm fractures is of major clinical and socio-economical interest. The progressive shift to FIN in the best practice management for this fracture makes it further interesting to investigate.^{2,3}

The hypothesis for this study was based on the feeling that the number of follow-ups appointments and radiological evaluations were paradoxically not reduced in patients treated with FIN. Similarly, the length of immobilization following FIN seemed to be more than necessary. The purposes of this study were to compare OT and FIN in terms of number of clinical and radiological follow-ups, length of immobilization, and overall costs, taking into account post-reduction complications.

Method

A 5 years retrospective study of all cases treated in two neighboring pediatric orthopedic university services was performed (January 2010 to December 2014, Lausanne and Geneva, Switzerland).

Displaced diaphyseal forearm fractures are uncommon in children less than 4 years old. They are treated mainly conservatively because of both remodeling potential and higher risks of complications if an operation is performed.^{15–17} Patients over 14 years old are adolescent whose closing growth plates have significant impact on the healing process.^{18,19} The selected patients were 4–14 years of age to increase the homogeneity of the studied population.

Using the AO Foundation classification,²⁰ only diaphyseal fracture (defined as exterior to the square long as ulnar and radial growth cartilage added) affecting both ulna and radius were included in the study. All cases had a reduction performed under general anesthesia. One group consisted of children treated by closed reduction and FIN. The second group included each child who benefited from closed reduction and long-arm cast immobilization (OT). This

reduction procedure was used as the baseline for data collection and follow-up assessment.

The exclusion criteria included children with closed growth plates, refracture defined as occurring within 1 year of a previous fracture, fractures treated by open reduction,^{12,21} patients with chronic diseases affecting the musculoskeletal system, or children with a psychiatric disorders. Patients lost to follow-up were also excluded. The patient's demographic data recorded included age, gender, time of reduction with respect to time of injury, fracture type, and intervention and time to hardware removal.

The recorded length of immobilization was the number of days between application and removal of any type of cast. The evaluation of immobilization did not include temporary post-operative splints and bandages. Institutional guidelines for the management of pediatric fractures in the two hospitals served as the basis for the evaluation of the length of immobilization.

Any pre-operative and perioperative studies such as fluoroscopy were counted. Post-operative radiographs included planned and unplanned studies, as well as the one ordered in cases of secondary displacement or other complication. Radiographs performed after hardware removal were also included.

Malunion was defined as an angulation >10 degrees measured on either the last radiograph of the ulna and/or radius. The number of consultations included all planned and unplanned patient encounter with a physician following the initial treatment of the fracture under general anesthesia until the final follow-up when the fracture was considered as healed without complications.

The complications included cast issues requiring modification, hardware infection, nerve, or tendon injury as well as secondary hardware bending. A refracture was defined as a fracture occurring within 1 year following the first fracture.²² Bone complications such as secondary displacement, delayed union, or pseudoarthrosis as well as any other noted complication were recorded.

Ambulatory treatment was defined as a fracture management which did not require one-night stay in hospital. The number of nights was calculated for each hospitalized child.

The level of training of the treating doctors was classified in three categories (specialist, in-training, or unspecialized). The specialist was a fully trained pediatric and/or orthopedic surgeon. The doctor in-training was a fellow with at least 5 years of post-graduate experience. The unspecialized doctor was a junior doctor rotating in the department with less than 5 years of post-graduate education. Both the surgeon at the time of initial management as well as the doctors supervising the follow-up appointments were assigned to one of these three categories.

The financial analysis focused on costs calculated according to the Swiss tariffication system (TARMED)²³

for ambulatory medicine and based on the Swiss Diagnosis Related Groups system (DRG)²⁴ for stationary management. Total costs were estimated for an uncomplicated case who benefited from standard OT or FIN management and regular out-patient follow-up appointments. Costs were expressed in Swiss francs (CHF).

Using the hospital financial database, every surgical intervention codes related to the management of uncomplicated displaced diaphyseal forearm fracture were identified in the Swiss Classification of Surgical Intervention Index (CHOP codes).²⁵ Various commonly used ambulatory billing positions were identified, such as the ones for a standard physical examination, 15 min discussion, radiographic analysis and review, upper arm cast application or removal, and so on.

Each CHOP code relevant to the study was used to identify eligible pediatric patients in the billing information system from the Lausanne Hospital financial database over a 1-year period. More the 5000 initial and 14,000 follow-up treatments TARMEED positions were used to estimate total costs on a patient basis, whether treated by OT or FIN. Financial billings concerning emergency (within 12h of unplanned admission) versus delayed (planned for the next day) management were incorporated in the estimates. The administrative in- or out-patient registrations were also used for the initial management final cost estimates. The costs of ambulatory hardware removal under general anesthesia were calculated and added, when appropriate.

Statistical analysis was descriptive and comparative, using R v.3.1.3 and his graphic interface RStudio. Comparison between FIN and OT groups was done with *t*-test of Student's non-paired for the continuous variables and with a χ^2 test for the dichotomic variables.

Results

Over the study period, 538 children sustained a forearm fracture of which 299 had a significantly displaced diaphyseal forearm fracture needing reduction. Fifty-eight children were excluded. The remaining 241 children were used as the basis for the study.

Table 1 summarizes the distribution of children in the two groups with regard to demographic data as well as outcome measures.

There were twice as many boys than girls (168 and 73, respectively). This 2.3 to 1 gender proportion was similar in both FIN and OT groups. One hundred fifty children benefited from FIN and 41 had an OT. The mean age was 9.9 years (standard deviation (SD)=2.8) in the FIN group and 7.4 years (SD=2.6) in the OT group.

Most fractures (73.7%) affecting the radius or/and ulna were complete simple transverse or oblique (AO types 22-D/4.1 or 5.1). Of the remaining fractures, 24.1% were green stick (AO type 22-D/2.1) and 2.3% buckle (AO type

22-D/1.1). A Gustilo I open fracture was noted in 23 cases (9.5%). The proportion of open fractures was twice as high in the FIN group when compared to the OT group (11.3% and 6.6%, respectively). In six children, one bone with a complete fracture was stabilized with FIN, while the other bone had a buckle fracture realigned. These six cases were included in the FIN group.

Overall, the length of immobilization was a mean 19.2 days (SD=13.6) in the FIN group and 58 days (SD=18.1) in the OT group. The total number of radiographs was similar in both groups (mean=7.3 in FIN group and 7.2 in OT group). The total number of follow-ups consultations was statistically significantly higher with a mean 6.4 (SD=2.2) in the FIN group compared to 5.8 (SD=2.1) in the OT group (95% CI=0.1 to 1.2, *P*=0.034). From the 241 patients, 38 suffered of a complication. Although higher in the OT group (17.6%) than in the FIN group (14.7%), the percentage of complications was not statistically different. Refracture occurred in three FIN cases and in five OT cases. Cast issues were noted in nine FIN cases and five OT cases. Infection occurred in four FIN cases. Bone complications (secondary displacement and/or pseudoarthrosis) occurred in one FIN and six OT cases. Five children with FIN suffered from nail issues. Other complications included wrist pain and persistent hand numbness occurred in three cases.

The final bone angulations were of a mean 4° (radius and ulna) in the FIN group and 6° (radius) and 7° (ulna) in the OT group. The difference was statistically significant only for the ulna. Malunion was measured in two children (one radius and two ulna) of the FIN group and in sixteen children (11 radius and 19 ulna) of the OT group. This difference was statistically significant. The length of stay in hospital was on average one night for the FIN group. In the OT group, half of the patients were hospitalized for one night. This difference was statistically significant.

The analysis of the 203 uncomplicated cases alleviating the complication bias was summarized in Table 2. One hundred forty-three were boys (70%) and 60 were girls (30%). The average age remained higher in the FIN group. The type of fracture was identical in both groups and the length of hospitalization remained longer in the FIN group.

None of the uncomplicated FIN cases had a final radius angulation over 10°, compared to 8% of the OT cases (*n*=6). With regard to the ulna, 1.5% (*n*=2) of FIN patients had a final angulation over 10°, while it was 16% (*n*=12) in the OT group. The difference was statistically significant. The mean length of time between FIN and hardware removal was 260.5 days (range=71–532 days).

With regard to the level of training of the treating doctors, the analysis was summarized in Table 3. In the FIN group, unspecialized doctors immobilized patients longer (24 days) compared to doctors in-training (15 days) and specialized surgeons (16 days). The more trained the doctor was, the more the child was hospitalized following

Table 1. Distribution of cases with regard to gender, age, fracture type, duration of immobilization, number of consultations, malunion, and complications.

	Total (n = 241)	FIN group (n = 150)	Conservative group (n = 91)	Comparison between FIN and conservative groups		
				P	95% CI	Effect size
Female, n (%)	73 (30.3%)	45 (30.0%)	28 (30.8%)	1.000	-13.5 to 12.0	<0.001
Age, mean (SD), years	8.9 (2.9)	9.9 (2.8)	7.4 (2.6)	<0.001*	1.8 to 3.2	0.930
Open fractures, n (%)	23 (9.5%)	17 (11.3%)	6 (6.6%)	0.323	-3.3 to 12.8	0.080
Time of hospitalization, mean (SD), days	0.83 (0.70)	1.05 (0.69)	0.47 (0.54)	<0.001*	0.42 to 0.73	0.903
Time of immobilization, mean (SD), days	33.9 (24.4)	19.2 (13.6)	58.0 (18.1)	<0.001*	-43.2 to -34.5	2.523
Total number of consultations, mean (SD), n	6.2 (2.2)	6.4 (2.2)	5.8 (2.1)	0.034*	0.1 to 1.2	0.280
Total number of radiographies, mean (SD), n	7.30 (2.23)	7.34 (2.24)	7.23 (2.21)	0.712	-0.47 to 0.69	0.049
Residual angle—radius >10°, n (%)	12 (5.0%)	1 (0.7%)	11 (12.1%)	<0.001*	-19.1 to -3.7	1.086
Residual angle—ulna >10°, n (%)	21 (8.7%)	2 (1.3%)	19 (20.9%)	<0.001*	-29.0 to -10.1	2.025
Patients with complications, n (%)	38 (15.8%)	22 (14.7%)	16 (17.6%)	0.675	-7.6 to 13.5	0.014

FIN: flexible intramedullary nailing; CI: confidence interval; SD: standard deviation.

Statistical tests used were un-paired Student's *t*-test when results are presented mean (SD), and two-sample χ^2 test when results are presented *n* (%).

*Significant differences between Groups 1 and 2 were considered at $P < 0.05$ level.

emergency treatment. In-training surgeons waited more before removing the hardware (mean 269 days). In the OT group, no significant difference was highlighted between the three levels of trainings.

Based on the Swiss billing systems (TARMED and DRG), an initial ambulatory FIN treatment was estimated to be billed CHF 2299, if the case was urgent and CHF 2207, if the case was planned with a minimum of 24h notice. In-patient urgent treatment was CHF 5825, and raised to CHF 6834, if the case could be planned for the next day.

An ambulatory urgent OT treatment was billed an estimated CHF 1430 and CHF 929, if performed on an elective basis. In-patient OT treatment was estimated at CHF 3865 for urgent cases and CHF 3286 for elective cases. The hardware removal was estimated at CHF 1572 and mostly performed on an ambulatory basis.

A follow-up consultation was billed an average CHF 84. A standard antero-posterior (AP) and lateral forearm radiograph was billed CHF 67. The average cost for the first emergency consultation was estimated at CHF 244.

In summary, following a displaced forearm fracture needing manipulation under general anesthesia, the costliest management was a non-urgent in-patient FIN treatment. The lowest billing was calculated for a planned ambulatory OT management.

Discussion

In the management of pediatric fracture, early mobilization without secondary fracture displacement has been one of the main benefits of nailing. It has been part of the success of FIN since its introduction in the early 80s. Surprisingly, this advantage was never assessed in the forearm, with regard to potential radio-clinical

follow-up benefits as well as costs saving. With close reduction and casting, forearm fracture needs regular follow-up radiographs, as up to 30% secondary displacements have been described. Luther et al.¹¹ have shown how regular check-up radiographs could be decreased in order to save costs. Intuitively, in non-baring bones such as the forearm, using a technique that allows sufficient stabilization without the need for immobilization should decrease both follow-up appointments and control radiographs, thus decreasing overall costs. Following through literature review, one recent study assessing the costs and effectiveness of FIN and OT in the treatment of forearm fractures in children was identified.¹⁰ Focusing on the emergency treatment costs, Adam et al. did not assess the follow-ups with regard to the clinical outcome, cast, and hardware management as well as radiological evaluations. These were specifically the aims of our original study.

The population of both groups was homogeneous with regard to gender distribution. Children in the FIN group were an average 2.5 years older than in the OT group. This trend for using nails in older children was most likely a direct consequence of the surgeon's choice at the time of injury, knowing that bone remodeling potential starts to decrease around 8–10 years of age.¹⁷ Of note, more post-operative complications are reported in children over 10 years of age treated by FIN, when compared to OT.^{15,26}

According to the internal guidelines of both University hospitals, forearm fractures treated orthopedically should have been immobilized a minimum of 42 days. FIN patients should have benefited from some kind of forearm protection for 15 days (cast, brace, or sling). In this study, a majority (85%) of injured children treated by OT were immobilized for a longer period (average 58 days). This

Table 2. Distribution of uncomplicated cases with regard to gender, age, fracture type, duration of immobilization, number of consultations, and malunion.

	Total (n=203)	FIN group (n=128)	Conservative group (n=75)	Comparison between FIN and conservative groups		
				P	95% CI	Effect size
Female, n (%)	60 (29.6%)	37 (28.9%)	23 (30.7%)	0.916	-15.0 to 12.4	<0.001
Age, mean (SD), years	8.9 (3.0)	9.8 (2.8)	7.3 (2.6)	<0.001*	1.7 to 3.2	0.913
Open fractures, n (%)	19 (9.4%)	14 (10.9%)	5 (6.7%)	0.448	-4.6 to 13.1	0.051
Time of hospitalization, mean (SD), days	0.88 (0.69)	1.07 (0.69)	0.55 (0.54)	<0.001*	0.43 to 0.70	0.350
Time to hardware removal, mean (SD), days	-	260.5 (196.9)	-	-	-	-
Time of immobilization, mean (SD), days	33.8 (25.6)	18.2 (13.5)	60.4 (18.2)	<0.001*	-47.0 to -37.4	2.752
Total number of consultations, mean (SD), n	5.7 (1.5)	5.9 (1.4)	5.3 (1.5)	0.003*	0.2 to 1.0	0.440
Total number of radiographies, mean (SD), n	7.0 (1.5)	7.1 (1.4)	6.9 (1.6)	0.422	-0.3 to 0.6	0.123
Post-op residual angle—radius >10°, n (%)	6 (3.0%)	0 (0.0%)	6 (8.0%)	0.005*	-15.2 to -0.8	0.702
Post-op residual angle—ulna >10°, n (%)	14 (6.9%)	2 (1.5%)	12 (16.0%)	<0.001*	-24.1 to -4.8	1.166

FIN: flexible intramedullary nailing; CI: confidence interval; SD: standard deviation.

Statistical tests used were un-paired Student's *t*-test when results are presented mean (SD), and two-sample χ^2 test when results are presented *n* (%).

*Significant differences between Groups 1 and 2 were considered at $P < 0.05$ level.

significant increase compared to than what is suggested in the guidelines may be secondary to a lack of awareness of the guidelines. Difficulties in finding the appropriate follow-up appointment may also have been secondary to agenda overload or low parents compliance.

In the FIN group, the average immobilization time was of 19 days, with 57 (45%) children having the forearm in a cast for more than 2 weeks. This increase may be explained with the same reasons as for the OT group. Theoretically, with the exception of pain management, there is no reason for immobilizing a fractured forearm following FIN. Clinical experience suggests that the use of a temporary brace to be removed as needed on an individual basis is sufficient. Prolonged closed forearm manipulation and post-operative swelling were not assessed in this study. They may also have influenced the decision to use a cast after nailing.

In both groups, two to three radiographs and three to four follow-up consultations were done in excess of the guidelines. These results from the uncomplicated cases outlined the necessity to acknowledge and respect guidelines more meticulously. Furthermore, an average seven radiographs in the FIN group revealed significant refrain for applying the benefits of bone stability following intramedullary nailing. If pre-treatment, immediate post-operative, 4–6 weeks, 3 months, and pre-removal radiographs were performed, two out-patient clinic appointments and two radiological evaluations could easily have been avoided.

These FIN treated children could have been less irradiated, have had less follow-ups while improving their mobility and quality of life without affecting their final outcome. Of note, post-hardware removal radiographs were suppressed from the Geneva Hospital guidelines soon after early review of the results of this study. No

study has proven that such late radiographs were useful in preventing refracture.

In the forearm, final bone angulation of both fractured ulna and radius gives a reliable indirect evaluation of the functional result. Above 10° angulation has an impact on the forearm's mobility.²¹ Only 2% of the FIN patients had a residual bone angulation over 10° on the ulna and/or radius, compared to 21% in the OT group. Bone complications such as malalignment or nonunion were statistically significantly less represented in the FIN group (95% CI=-11.9 to -0.2, $P < 0.024$). This comparison confirmed that children with a displaced forearm fracture needing manipulation had a better functional result when treated with FIN.

The complication rate was 14.7% in the FIN group and 17.6% in the OT group. Overall, this difference was not statistically significant and equivalent to what was found in the literature.⁵ 6.6% ($n=6$) of the children treated with OT required a second intervention, mainly FIN, compared to 1.3% of the children in the FIN group (one refracture and one pseudoarthrosis). In terms of cost analysis, this study estimated that the cheapest treatment modality was closed reduction and cast immobilization (OT) performed on an ambulatory basis. The most expensive treatment was intramedullary nailing (FIN) performed on a stationary basis. Knowing the costs of the material and the facilities (operating room time, bed, and room overnight), this was of no surprise. Delayed or urgent OT treatment costs varied significantly if performed on an out-patient basis. This was not the case with FIN, possibly because of the need for temporary casting and other extra costs. In both groups, keeping a patient overnight increased the costs about one- to three-folds.

In a completely different socio-economical (Romania, EU), Adam et al.¹⁰ estimated FIN to be 28%

Table 3. Distribution of descriptive outcome values related to the level of training of the treating doctor.

	FIN group (n = 128)				Conservative group (n = 75)			
	Specialist (n = 43)	In specialization (n = 48)	Un-specialized (n = 37)	Post hoc	Specialist (n = 12)	In specialization (n = 8)	Un-specialized (n = 55)	Post hoc
Ambulatory intervention, n (%)	3 (6.98%)	5 (10.42%)	12 (32.43%)	a,b	4 (33.33%)	3 (37.50%)	29 (52.73%)	0.391
Time before AMO, mean (SD), days	238.28 (76.33)	268.79 (79.78)	221.51 (76.92)	b	—	—	—	—
Immobilization time, mean (SD), days	16.47 (11.95)	15.17 (11.58)	24.08 (15.81)	a,b	58.25 (22.36)	69.00 (18.75)	59.60 (17.18)	0.883
Nb of control consult., mean (SD), n	6.16 (1.34)	5.88 (1.47)	5.81 (1.41)	—	5.17 (1.75)	4.88 (1.00)	5.44 (1.48)	0.428
Nb of RX, mean (SD), n	7.19 (1.44)	7.02 (1.39)	6.97 (1.42)	—	7.00 (1.54)	6.63 (1.41)	6.89 (1.72)	0.938
Post-op RA (°)—radius > 10°, n (%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	—	0 (0.00%)	2 (25.00%)	4 (7.23%)	0.121
Post-op RA (°)—ulna > 10°, n (%)	0 (0.00%)	0 (0.00%)	2 (5.41%)	—	1 (8.33%)	2 (25.00%)	9 (16.36%)	.603

FIN: flexible intramedullary nailing; SD: standard deviation.

Statistical tests used were ANOVA when results are presented mean (SD), and multiple two-sample χ^2 test when results are presented n (%).

RA (°) is residual angle in degrees. Post hoc analysis were, respectively, pairwise un-paired Student's t-test when results are presented mean (SD), and pairwise two-sample χ^2 test when results are presented n (%). Significant differences are presented with a between "Specialist" and "Un-specialized," and b between "In specialization" and "Un-specialized." There was no significant differences between "Specialist" and "In-specialization".

*Significant differences between Groups 1 and 2 were considered at $P < 0.05$ level.

more expensive than OT. They did not elaborate on the difference between urgent and delayed management. In the Swiss setting, urgent FIN was, respectively, 33% and 38 % more expensive than OT, whether the child was treated on an ambulatory or in-patient basis. But, when the fracture management was planned in advance on an out-patient basis, the estimated cost was reduced by 51% only in the OT group. Of note, hardware removal was around 82% more expensive than cast removal.

This study had some limitations. The functional result was based on measurements of bone angulations while reviewing all radiographs. The clinical pro-supination evaluation and functional outcome of the injured forearm were not systematically retrieved from charts and medical notes. Nevertheless, this was sufficient to compare both groups in terms of final bone angulations and give objective reliable measures to compare both groups. This retrospective study did not assess the fractured arm side and the dominant hand. Neither the mechanism of injury nor the size of nails used for fixation was taken into account when analyzing the data. This missing information may have limited further refinement in the evaluation of the results. Too thin of a nail may increase the risk of malalignment or refracture.²³

The results of this study could easily influence clinical practice guidelines. Surgeons should aim for less immobilization, less radiographs, and follow-up consultations when treating children's forearm fractures with FIN. Not only would these measures directly improve the child's wellbeing, but it would also substantially decrease costs of a procedure which were between 30% and 50% more expensive, when compared to the conventional orthopedic treatment.

This study confirmed that a displaced forearm fracture in a child could be treated adequately with FIN, but at increased costs when compared to OT. This allowed reduced length of immobilization, less malunion with no more complications. It did not reduce the number of radiographs and follow-up consultations. FIN should be promoted in conjunction with an appropriate follow-up plan sparing radiograph, for the child to benefit from all the advantages of the technique. Diaphyseal forearm fractures in children should be based on child-oriented and technique-related management guidelines, with realistic financial sparing consequences.

Compliance with ethical standards

The research does not involve human participants and/or animals. The ethical committees of the cantons of Vaud and Geneva approved the study protocol.


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References

- Joeris A, Lutz N, Wicki B, et al. An epidemiological evaluation of pediatric long bone fractures—a retrospective cohort study of 2716 patients from two Swiss tertiary pediatric hospitals. *BMC Pediatr* 2014; 14(1): 314.
- Cumming D, Mfula N and Jones JW. Paediatric forearm fractures: the increasing use of elastic stable intra-medullary nails. *Int Orthop* 2008; 32(3): 421–423.
- Sinikumpu JJ, Pokka T and Serlo W. The changing pattern of pediatric both-bone forearm shaft fractures among 86,000 children from 1997 to 2009. *Eur J Pediatr Surg* 2013; 23(4): 289–296.
- Lutz N. To fix or not to fix? *J Musculoskelet Surg Res* 2019; 3(4): 317–318.
- Poutoglidou F, Metaxiotis D, Kazas C, et al. Flexible intramedullary nailing in the treatment of forearm fractures in children and adolescents, a systematic review. *J Orthop* 2020; 20: 125–130.
- Van Egmond PW, Schipper IB and van Luijt PA. Displaced distal forearm fractures in children with an indication for reduction under general anesthesia should be percutaneously fixated. *Eur J Orthop Surg Traumatol* 2012; 22(3): 201–207.
- Schneider J, Staubli G, Kubat S, et al. Treating displaced distal forearm fractures in children. *Eur J Trauma Emerg Surg* 2007; 33(6): 619–625.
- Schmittenebecher PP. State-of-the-art treatment of forearm shaft fractures. *Injury* 2005; 36(Suppl. 1): A25–A34.
- Lascombes P, Haumont T and Journeau P. Use and abuse of flexible intramedullary nailing in children and adolescents. *J Pediatr Orthop* 2006; 26(6): 827–834.
- Adam O, David VL, Horhat FG, et al. Cost-effectiveness of titanium elastic nail (TEN) in the treatment of forearm fractures in children. *Medicina* 2020; 56(2): 79.
- Luther G, Miller P, Waters PM, et al. Radiographic evaluation during treatment of pediatric forearm fractures: implications on clinical care and cost. *J Pediatr Orthop* 2016; 36(5): 465–471.
- Smith VA, Goodman HJ, Strongwater A, et al. Treatment of pediatric both-bone forearm fractures: a comparison of operative techniques. *J Pediatr Orthop* 2005; 25(3): 309–313.
- Heare A, Goral D, Belton M, et al. Intramedullary implant choice and cost in the treatment of pediatric diaphyseal forearm fractures. *J Orthop Trauma* 2017; 31(10): e334–e338.
- Rijal L, Ansari T and Gupta V. Management of pediatric both bone forearm fractures with titanium elastic nails: a cost cutting measure. *Tech Orthop* 2017; 32(3): 173–174.
- Martus JE, Preston RK, Schoenecker JG, et al. Complications and outcomes of diaphyseal forearm fracture intramedullary nailing: a comparison of pediatric and adolescent age groups. *J Pediatr Orthop* 2013; 33(6): 598–607.
- Kraus R, Reyers J, Alt V, et al. Physiological closure of the physal plate of the distal radius: an MRI analysis. *Clin Anat* 2011; 24(8): 1010–1015.
- Bowman EN, Mehlman CT, Lindsell CJ, et al. Non-operative treatment of both-bone forearm shaft fractures in children: predictors of early radiographic failure. *J Pediatr Orthop* 2011; 31(1): 23–32.
- De la Roza G and Damron TA. Histology of bone, 2019, <https://emedicine.medscape.com/article/1254517-overview>
- Poduval M. Skeletal system anatomy in children and toddlers, 2015, <https://emedicine.medscape.com/article/1899256-overview>
- Slongo T and Audigé L. *AO pediatric comprehensive classification of long-bone fractures (PCCF)*. Davos: AO Foundation, 2007.
- Pace JL. Pediatric and adolescent forearm fractures: current controversies and treatment recommendations. *J Am Acad Orthop Surg* 2016; 24(11): 780–788.
- Baitner AC, Perry A, Lalonde FD, et al. The healing forearm fracture: a matched comparison of forearm refractures. *J Pediatr Orthop* 2007; 27(7): 743–747.
- TARMED, <https://www.tarmed-browser.ch/fr>
- SwissDRG, <https://www.swissdrg.org/fr/somatique-aigue/swissdrg>
- Bundesamt für Statistik (BFS). Classification suisse des interventions chirurgicales (CHOP), 2018, <https://www.bfs.admin.ch/hub/api/dam/assets/5808564/bibtex>
- Whitaker JJ, Tauberg BM, Kwon MS, et al. Forearm fractures. *Peiatr Exterm* 2015; 2015: 1069–1094.

