ORIGINAL ARTICLE

Goniometric Estimation of Treatment Efficiency in Pediatric Midshaft Forearm Fracture Patients

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Summary.

Introduction. The overall forearm fracture rate is extremely high in pediatric population, significantly being composed of forearm midshaft fractures. Conservative vs. operative treatment are the two competing approaches being introduced for treatment of these fractures depending on the type and localization of the fracture as well as on the age of children. Objective measurements of ROM and correct interpretation of the results can have a substantial impact on the development of the scientific basis of therapeutic interventions.

Aim of the study. 1) to evaluate ROM in elbow and wrist joints using goniometry, comparing conservatively and operatively treated forearm fracture patients with healthy controls; 2) to estimate limitation of ROM that causes subjective complaints; 3) to determine if potential limitations of ROM can be the main argument for choice of treatment method despite the age and gender of the child.

Materials and methods. Stratified randomized controlled prospective clinical trial from 2010 to 2012 was performed including comparable groups of conservatively and operatively treated boys and girls (age 7-15 years), 6 months after forearm midshaft fracture, compared to similar groups of children without fractures. Total number of respondents was 180 children (30 in each group). Length of immobilization for all treated children was 4 weeks (28 ± 2 days). None of the included patients was administered to special rehabilitation course. During follow-up active ROM of elbow (flexion, extension, pronation, supination) and wrist (flexion, extension, abduction and adduction) joint was assessed using standard plastic goniometer. All measurements were performed by one person, the same tool, twice for each patient. All children together with parents filled questionnaires about self-estimation of functional status (PedsQL v3.0) before (all groups) and after trauma (treated patients only). Each parent signed informed consent of the participation in the research, hospital's ethical committee gave the approval for the study.

Results. All fractures consolidated. Statistically significant differences were detected comparing both non-operated and operated patients to controls. Both – conservative and operative treatment predicted higher level of ROM limitation rate, compared to controls. Conservative treatment predisposes patients to significantly higher ROM limitation – 75.0 %, compared to operated patients – 31.7%. Most of limitations in all four treated groups were asymptomatic: 77.8 % in conservative groups; 63.2 % in operated groups; and 100 % in controls groups. Subjective complaints of ROM limitations in conservatively treated children were about elbow flexion, elbow pronation and supination and wrist extension. Operated children complained of limited elbow flexion, elbow supination and wrist extension. There were no gender differences among conservatively and operatively treated groups, both girls and boys had 53.3 % limitation rate. Dominant hand was injured more often (ratio = 1.14:1). No statistically significant differences were found in all three age groups (7-9 years, 10-12 years and 13-15 years) in both genders, comparing to other age groups of the same gender.

Conclusions. The results of this study indicate superior effectiveness of elastic stable intramedullary nailing over conservative approach. Frequency of ROM limitations performing surgical stabilization is more than twice lower than that of conservatively treated children. Only moderate ($>20^\circ$) limitations of ROM cause subjective complaints. Although compensatory capacities of a growing child are high and therefore most limitations of ROM are asymptomatic and do not reduce quality of life, it advocates surgical treatment to become the golden standard for midshaft forearm fracture treatment in pediatric population. The age and gender of a child does not influence frequency and severity of ROM limitations therefore should not be considered as the main arguments while choosing treatment method.

Keywords: Forearm fractures, children, treatment options, goniometry.

INTRODUCTION

The total fracture rate in pediatric population significantly is being composed of these affecting forearm bone fractures, especially in 7-15 years old children; some authors mention even 40-50% (22,26). Pediatric diaphyseal forearm fractures are ranked in 3rd position after distal forearm and supracondylar fractures (8). Conservative vs. operative treatment are the two competing approaches being introduced for

treatment of these fractures depending on the type and localization of the fracture as well as on the age of children. Objective evaluation of functional outcome is performed rarely, especially when children show no complaints of functional limitations. Therefore it is hard to compare functional outcomes from objective (doctor's view) and subjective (patient's view) perspectives after application of different treatment methods. Objective measurements of ROM and correct

interpretation of the results can have a substantial impact on the development of the scientific basis of therapeutic interventions.

AIM OF THE STUDY

The aim of our study is 1) to evaluate ROM in elbow and wrist joints using goniometry, comparing conservatively and operatively treated forearm fracture patients with healthy controls; 2) to estimate limitation of ROM that causes subjective complaints; 3) to determine if potential limitations of ROM can be the main argument for choice of treatment method despite the age and gender of the child.

MATERIALS AND METHODS

The design of study was stratified randomized controlled prospective clinical trial from 2010 to 2012. Six groups of 7-15 years old patients were included (30 children each: 7-9 years (n=10), 10-12 years (n=10) and 13-15 years (n=10)). Group I and II were girls and boys, respectively, 6±1 months after both bone forearm midshaft fractures, treated conservatively by closed reduction and plaster immobilization. Group III and IV were girls and boys, respectively, with the same trauma localization and duration, but treated surgically by intramedullary nailing (ESIN) followed by plaster. Group V and VI were girls and boys, respectively, without forearm fractures, admitted to the hospital due to other conditions.

Conservative group patients were admitted to hospital, closed reduction under general anesthesia using fluoroscopy control was performed, followed by over-the-elbow immobilization in plaster of Paris. Operative treatment group patients were admitted to hospital, operation was performed under general anesthesia, using fluoroscopy control. After closed reduction of fracture two 2.0, 2.5 or 3.0 mm elastic Nancy nails were introduced: retrograde in radius (perforation level – distal metaphysis, anteromedial surface) and antegrade in ulna (perforation level – olecranon ulnae, posterolateral surface). Nail diameter (d) was chosen according to medullary canal diameter at fracture site (D), using formula:

$$d = 0.4D; (1)$$

Nail length (l) was chosen according to bone length (L), in order not to cross growth plates, using formula: $l = L - 4$ (2)

Nails were buried under the skin; over-the-elbow plaster of Paris was applied.

Both conservative and operated patients were discharged next day after X-ray control for further follow-up on out-patient basis. Length of immobilization for all treated children was 4 weeks (28 ± 2 days), then plaster was removed, control X-rays were performed and patients were allowed to use their arms in everyday activities. None of the included patients was administered to special rehabilitation course. Control group patients underwent investigation and questionnaire during their stay at hospital due to other conditions. During

follow-up active ROM of elbow (flexion, extension, pronation, supination) and wrist (flexion, extension, abduction and adduction) joint was assessed using standard plastic goniometer. All measurements were performed by one person, the same tool, twice for each patient, to avoid intertester, intertool and intratester errors.

Limitations of ROM less than 10° were considered to be either measurement errors or interside differences. Limitations $10-19^\circ$ were considered to be mild, $20-29^\circ$ – moderate and $>30^\circ$ – severe. Patients, who met the criteria for exclusion, were replaced by appropriate respondents. Exclusion criteria were: 1) patients who refused or failed to attend follow-up session due to compliance problems; 2) patients with single bone surgical stabilization using one elastic nail; 3) patients with „complicated” fractures in terms of refracture, open fracture, secondary dislocation and wound infection; 4) patients who had their nails removed prior to follow-up term.

All children together with parents filled questionnaires about self-estimation of functional status (PedsQL v3.0) before (all groups) and after trauma (groups I-IV). Each parent signed informed consent of the participation in the research, hospital's ethical committee gave the approval for the study.

Raw data was processed using the software package SPSS v20.0. In data analysis descriptive statistical methods were used. To determine the statistical reliability χ^2 test was employed. The statistical significance for all tests was set at $p < .05$. Characteristics of data used crosstabs and 95% confidence interval set for comparison.

RESULTS

All fractures consolidated, no healing disturbances in terms of malunion or nonunion were documented. 19 respondents of treated patients were withdrawn, as they met exclusion criteria mentioned above, and substituted by respondents of the same age group (see Table 1).

Table 1. Overview of excluded and substituted respondents

Group	Age of respondent	Cause	Age of substitute
I	7	Malalignment	8
	10	Malalignment	10
	11	Malalignment	12
	12	Refused follow-up	12
II	8	Malalignment	7
	12	Malalignment	11
	8	Malalignment	8
	9	Malalignment	8
	15	Refused follow-up	14
	13	Failed to follow-up	13
III	12	Refused follow-up	11
	14	Refused follow-up	13
	8	Refused follow-up	8
	10	Removed prior follow-up	10
IV	15	Refused follow-up	14
	9	Failed to follow-up	8
	14	Failed to follow-up	15
	11	Wound infection	10
	11	Removed prior follow-up	12

Statistically significant differences were detected comparing both non-operated Groups I and II) and operated (Groups III and IV) patients to controls (Groups V and VI): $p < .001$ ($\chi^2 = 64.669$; $df = 1$) and $p < .001$ ($\chi^2 = 16.681$; $df = 1$), respectively.

Both – conservative and operative treatment predicted higher level of ROM limitation rate, compared to controls $p < .001$ ($\chi^2 = 43.062$; $df = 1$), i.e. 53.3% of cases ($n = 64$; 95% CI 44.4-62.0%) manifest limitations, while control groups had only 3.3 % ($n = 2$; 95% CI .9-11.4%).

Conservative treatment predisposes patients to significantly higher ROM limitation - 75.0 % ($n = 45$; 95% CI 62.8-84.2%) compared to operated patients – 31.7% ($n = 19$; 95% CI 21.3-44.2%), $p < .001$; $\chi^2 = 20.886$; $df = 1$.

Most of limitations in all four treated groups were asymptomatic: 77.8 % (35 of 45) in Group I and II; 63.2 % (12 of 19) in Group III and IV, and 100 % (2 of 2) in controls Group V and VI. Subjective complaints of ROM limitations in Group I were seen mainly due to elbow flexion (3 of 6), elbow pronation (1 of 1) and wrist extension (1 of 6). Group II showed symptoms of limited elbow flexion (1 of 5), elbow supination (2 of 3) and wrist extension (2 of 7). Group III manifested elbow flexion (2 of 4) and wrist extension (2 of 4). Symptomatic patients in Group IV complained of limited elbow flexion (1 of 3), elbow supination (1 of 1) and wrist extension (1 of 3). Group V and VI had one case of limited elbow flexion and wrist flexion, respectively, both patients were asymptomatic. Overview of all patient groups, included in this research is depicted in table 2.

Table 2. Distribution of limitations in ROM and subjective complaints.

	Joint	Elbow	Wrist	Total							
	Limitation	Flexion	Extension	Pronation	Supination	Flexion	Extension	Abduction	Adduction	(% of group)	(% of all)
	Plane	Sagittal	Transverse	Sagittal	Frontal						
	Axis	Frontal	Vertical	Frontal	Sagittal						
Group I	W/o	3 (10.0)	3 (10.0)	0 (0)	2 (6.6)	2 (6.6)	5 (16.6)	1 (3.3)	1 (3.3)	17 (56.6)	17 (9.4)
	W	3 (10.0)	0 (0)	1 (3.3)	0 (0)	0 (0)	1 (3.3)	0 (0)	0 (0)	5 (16.6)	5 (2.8)
	T	6 (20.0)	3 (10.0)	1 (3.3)	2 (6.6)	2 (6.6)	6 (20.0)	1 (3.3)	1 (3.3)	22 (73.3)	22 (12.2)
Group II	W/o	4 (13.3)	3 (10.0)	2 (6.6)	1 (3.3)	2 (6.6)	5 (16.6)	1 (3.3)	0 (0)	18 (60.0)	18 (10.0)
	W	1 (3.3)	0 (0)	0 (0)	2 (6.6)	0 (0)	2 (6.6)	0 (0)	0 (0)	5 (16.6)	5 (2.8)
	T	5 (16.6)	3 (10.0)	2 (6.6)	3 (10.0)	2 (6.6)	7 (23.3)	1 (3.3)	0 (0)	23 (76.6)	23 (12.8)
Group III	W/o	2 (6.6)	1 (3.3)	0 (0)	0 (0)	1 (3.3)	2 (6.6)	0 (0)	0 (0)	6 (20.0)	6 (3.3)
	W	2 (6.6)	0 (0)	0 (0)	0 (0)	0 (0)	2 (6.6)	0 (0)	0 (0)	4 (13.3)	4 (2.2)
	T	4 (13.3)	1 (3.3)	0 (0)	0 (0)	1 (3.3)	4 (13.3)	0 (0)	0 (0)	10 (33.3)	10 (5.5)
Group IV	W/o	2 (6.6)	1 (3.3)	0 (0)	0 (0)	1 (3.3)	2 (6.6)	0 (0)	0 (0)	6 (20.0)	6 (3.3)
	W	1 (3.3)	0 (0)	0 (0)	1 (3.3)	0 (0)	1 (3.3)	0 (0)	0 (0)	3 (10.0)	3 (1.7)
	T	3 (10.0)	1 (3.3)	0 (0)	1 (3.3)	1 (3.3)	3 (10.0)	0 (0)	0 (0)	9 (30.0)	9 (5.0)
Group V	W/o	1 (3.3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.3)	1 (.6)
	W	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	T	1 (3.3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.3)	1 (.6)
Group VI	W/o	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.3)	0 (0)	0 (0)	0 (0)	1 (3.3)	1 (.6)
	W	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	T	0 (0)	0 (0)	0 (0)	0 (0)	1 (3.3)	0 (0)	0 (0)	0 (0)	1 (3.3)	1 (.6)
Total (% of all)	19 (10.6)	8 (4.4)	3 (1.7)	6 (3.3)	7 (3.9)	20 (11.1)	2 (1.1)	1 (.6)	66 (36.7)		

* W/o - patients with limitations without complaints, in absolute numbers and (per cent)

** W – patients with limitations and complaints, in absolute numbers and (per cent)

*** T - patients with limitations, in absolute numbers and (per cent)

There were no gender differences detected among conservatively and operatively treated groups ($p=1.000$, $\chi^2=.000$; $df=1$), both girls and boys had 53.3 % limitation rate ($n=32$; 95% CI 40.9-65.4). Analyzing injured side in aspect of hand dominance, it became clear that dominant hand was injured more

often (ratio = 1.14:1). Analyzing age structure, no statistically significant differences were found in all three age groups (7-9 years, $p=.196$ $\chi^2=1.674$; $df=1$; 10-12 years $p=.155$; $\chi^2=2.026$; $df=1$; and 13-15 years $p=.897$; $\chi^2=.017$; $df=1$) in both genders, comparing to other age groups of the same gender (see Table 3).

Table 3. Distribution of injuries and limitations of ROM by age and hand dominance, including range of limitations causing subjective complaints

	Age, years	Dominant (D)	Injured (I)	D-I	Limitations	Complaints			
		Dx	Sin	Dx	Sin			n	Degrees
Group I	7-9	8	2	5	5	7	7	0	
	10-12	10	0	7	3	6	8	1	20
	13-15	8	2	5	5	8	7	4	22/23/25/22
Group II	7-9	9	1	6	4	7	8	1	25
	10-12	7	3	5	5	2	7	1	24
	13-15	8	2	5	5	5	8	3	22/22/25
Group III	7-9	9	1	5	5	4	2	1	21
	10-12	7	3	6	4	5	5	2	24/25
	13-15	9	1	5	5	6	3	1	22
Group IV	7-9	8	2	5	5	5	1	0	
	10-12	8	2	8	2	6	5	1	20
	13-15	10	0	4	6	4	3	2	23/20
Group V	7-9	9	1	N/A	N/A	N/A	0	N/A	N/A
	10-12	9	1	N/A	N/A	N/A	0	N/A	N/A
	13-15	7	3	N/A	N/A	N/A	1	N/A	N/A
Group VI	7-9	8	2	N/A	N/A	N/A	0	N/A	N/A
	10-12	8	2	N/A	N/A	N/A	0	N/A	N/A
	13-15	8	2	N/A	N/A	N/A	1	N/A	N/A
Total		150	30			65	66		

DISCUSSION

The main question of our study was „Does operative treatment of forearm midshaft fractures in children provide better results than conservative approach?“ Stratified randomization of patients along with objective (ROM assessment) and subjective (PedsQL questionnaires) parameter analysis provided us reliable and reproducible data.

Overall results of our study pointed out that surgical treatment is a more effective method compared to conservative treatment. Modern intramedullary nailing techniques allow optimization of treatment parameters (intervention breadth, duration of admittance, treatment expenses, functional outcomes and quality of life, due to increased stability of bone fractures, reduced immobilization period and complications associated with prolonged plaster wearing - joint stiffness and reduction in ROM (33). Assessment of bone healing revealed normal healing process both in conservatively and operatively treated

patients, avoiding complications as malunion and nonunion. 3 patients of group I and 4 patients of group II were expelled due to malalignment, requesting additional manipulation and intramedullary fixation due to unacceptable secondary dislocation. No malalignment was documented in both surgically treated groups III and IV that advocates for better bone stability in these children. Other causes of exclusion were poor compliance - refusal or defiance of recommended follow-up, one case of deep wound infection and two cases when respondents chose to remove the nails before the appointed follow-up term. Controversial opinions about acceptable displacement, rotation and angulation exist. It is considered that patients under 10 years of age can tolerate increased level of displacement (even complete), rotation (up to 45°) and angulation (up to 15°) (9,12,13,23). Children over 10 years of age are supposed to tolerate up to 10° of angulation and 50% displacement;

greater deviations and malrotation request operative intervention (9,12,24).

Analyzing both conservatively and surgically treated groups we found that they differed from controls group, it suggests correct respondent selection. Limitations of ROM were significantly higher in both conservatively treated groups, regardless of age subgroups, suggesting that operative treatment using ESIN should not be limited as golden standard for treatment of adolescents with forearm midshaft fractures only, but implemented in younger age groups as well.

Most of the limitations were asymptomatic that depicts the high level of compensatory and adaptive capacities of a growing child. Some authors suggest that the functional ROM of the wrist utilized in most daily tasks is smaller than the actual ROM available for the wrist (3,16). Assessment of ROM in aspect of subjective complaints revealed that no severe limitations were detected in this study, only mild or moderate limitations were identified and only the latter caused subjective complaints. This can be an explanation why children have seldom complaints and potential ROM limitation has not been included in argument list while choosing the proper treatment method.

Analysis of anatomical aspects of ROM limitations revealed that most of the limitations affected flexion-extension movements in sagittal plane around frontal axis. Forearm shaft fractures usually impact rotation movements – pronation and supination (20), but we identified just some cases of this limitation type in our study. Some authors believe that 60% of patients after these fractures have > 20° limitations of rotation (9). Still subjective results are good and limited ROM can be identified only performing goniometry (37). Functionally shoulder compensates loss of pronation by abduction and internal rotation, but loss of supination is compensated by adduction and external rotation (9).

The two respondents with mild limitations of ROM in control groups were asymptomatic and should be considered as incidental finding.

Limitations of ROM showed no significant differences between boys and girls neither from the aspect of incidence nor frequency of subjective complaints. According to this study we do not recommend to use gender as an argument choosing the treatment. Rather similar is the aspect of patient age. We could not establish statistically significant correlation, proving that limitations are found more often in younger or older children, but what we found is the difference of treatment efficiency in favor of surgical approach. We have used to consider that surgery is used more for older children, while younger children usually undergo conservative treatment, they have faster healing and thus – better functional outcome [29,33,37]. Our results with patient randomization showed that there are no differences among age groups treated by the same method. This means that

the chosen method of treatment per se has the main influence on the incidence of ROM limitations.

Analyzing influence of the dominating hand, we found that it was injured more often (1.14:1). This is an interesting finding, because usually dominant hand is considered to be „stronger”, as it is more used, has increased muscle mass and better tolerance to similar impact (11,33).

Despite the wide use of goniometry in physical therapy for objective assessment of ROM, the reliability of using it under clinical settings is variable, and depends significantly on experience of tester and performance of the assessment (intratester errors), number of persons performing the same study (intratester errors), and tool used (intertool errors) (15,17,27). In most cases assessing arm motion range by the same person and the same tool (like it was in our study), the reliability is high (5,14). Publications also suggest that expensive electronic devices do not guarantee higher precision of measurement compared to simple plastic goniometer (used in our study), and taking single measurement is enough (2,21). Still we performed so called „test-retest” assessment model with two consequent measurements, separated by short time interval which is supposed to be the most accurate performance of measurement.

Validity of goniometry means the goniometer and measurement procedures are accurate and we understand the meaning of the measurement results. Although insignificant errors in the construction of goniometers may exist, the instruments generally are accepted as valid clinical tools (5,15,32).

The reliability and the validity of even simple measurements, however, may be decreased because of patient differences that we cannot control. Obesity and variations in bony structures can make accurate visual inspection and bony palpation very difficult (2,14,17).

Many authors suggest that it is more difficult to measure reliably passive ROM than active ROM. Amis and Miller stated this problem as follows: “Passive movements are extremely difficult to reproduce, because the stretching of soft tissues at the limits of motion depends on the force applied to the limb, which must, therefore, be carefully controlled” (1). Bird indicated that measurement error in the wrist joint was higher in passive movements, compared to active (4). Wagner suggested that variability of passive flexibility was higher than that of active variability (36).

Some authors have questioned the necessity of surgical treatment, because in their opinion conservative treatment provides acceptable results without any surgical intervention, especially in younger children (10,19,28,31,34). Others advocate for elastic stable intramedullary nailing, but set lower age limits of the method to 8-10 years (6,7). Some enthusiasts of ESIN point out the lack of necessity in postoperative immobilization and consider early mobilization to be the main argument for surgery (29). Relatively

low compliance of children and the ultimate level of activity, may endanger treatment results, besides the overall level of children activity is more than enough to mobilize arm after removal of plaster without special rehabilitation program. Therefore we do not recommend avoidance of postoperative immobilization.

Only few surgical alternatives are provided to ESIN for treatment of diaphyseal forearm fractures – *K-wire* osteosynthesis (18,30), *Steinmann pin* implantation (25), along with use of semitubular plates (35) and *ExFix* (29), but none of them has proved to be superior in pediatric population due to debatable anatomic, functional or cosmetic considerations.

Another question that remains unanswered is whether surgical treatment could be superior upon conservative treatment followed by rehabilitation in aspect of functional outcome. In this study we compared only children without post-treatment rehabilitation course, in order to make groups comparable, still this issue can be a good clinical question for the further research.

CONCLUSIONS

The results of this study indicate superior effectiveness of elastic stable intramedullary nailing over conservative approach. Frequency of ROM limitations performing surgical stabilization is more than twice lower than that of conservatively treated children. Only moderate (>20°) limitations of ROM cause subjective complaints. Although compensatory capacities of a growing child are high and therefore most limitations of ROM are asymptomatic and do not reduce quality of life, it advocates surgical treatment to become the golden standard for midshaft forearm fracture treatment in pediatric population. The age and gender of a child does not influence frequency and severity of ROM limitations therefore should not be considered as the main arguments while choosing treatment method.

Conflict of interest: None

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