Original Articles

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Comparative analysis of bone fixation in patients with uncomplicated multiple fractures and fracture-dislocations of the forearm

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Introduction The functional anatomy of the forearm sets up requirements for the choice of fixation constructs and medical technologies of osteosynthesis to be used for particular localization and pattern of injury. **Objective** was to evaluate the effectiveness of intramedullary nailing, plating, external fixation and combined techniques used to repair forearm shaft fractures of different severity based on comparative analysis of outcomes. **Material and methods** Outcomes of 153 patients with forearm shaft fractures treated with IM nailing, plating, external fixation (controls, n = 78; 51.0 %) and combined osteosynthesis with shape memory devices (index group, n = 75; 49.0 %) were comparatively analyzed using criteria offered by Anderson L.D. (consolidation time) and Grace T.G., Eversman W.W. (functional results) and statistical methods. Patients sustained either an isolated fracture of one bone (n = 62; 40.5 %) or combined both bones forearm injuries (n = 44; 28.8 %). A subgroup of complicated injuries included 25 (16.3 %) patients with fracture-dislocations and 22 (14.4 %) patients with multiple fractures (bifocal, comminuted, bone loss of at least 5.0 cm). **Results** Plating of isolated and combined forearm injuries showed significant advantages over intramedullary nailing with square nail (χ^2 = 5.329, p = 0.021). Intramedullary nailing appeared to be more efficacious when supported by thermomechanical memory devices and could be comparable with the results achieved with plating (χ^2 = 0.070, p = 0.792). Combined techniques with thermomechanical memory devices were practical for multiple fractures and fracture-dislocations (χ^2 = 6.649, p = 0.010). **Conclusions** Intramedullary nailing with square nails was shown to be efficient in 50.0 % of patients with transverse, oblique fractures of one or both forearm bones and in 20.0 % of fracture-dislocations. The bone consolidated and function recovered in 85.3 to 95.2 % of the patients with of one or both forearm bones fractures repaired either with plating or combined methods with the use of shape memory constructs. Patients with fracture-dislocations, comminuted and segmental fractures showed good results in 75.0 % of the cases addressed with external fixation and external fixation combined with shape memory devices, and in 42.9 % of cases repaired with plating.

Keyword: forearm, fracture, comminution, segmental fracture, external fixation, intramedullary nailing, plating, shape memory device, outcome

INTRODUCTION

Diaphyseal fractures of the forearm account for 12.0 to17.5 % of all skeletal injuries with 35 % of the comminuted and multi-fragment cases [1, 2]. The forearm and its adjacent joints are considered as a complex functional unit due to the important role of upper limb functioning. A technique to be used to manage this demanding condition is supposed to address all types of bone displacement, retention of bone length, topography of interosseous membrane, relationships in the distal and proximal radioulnar articulations [3, 4, 5]. Plating is recognized as an optimal modality for the treatment of diaphyseal fractures of the forearm bones [5, 6, 7, 8]. However, disadvantages of plate fixation including injury to periosteum, disturbed periosteal blood supply, screw migration pose limitations for patients with extensive damage (30 % of bone length) and osteoporosis. Complication rate ranges from 6.0 to 22.0 % depending on the type of plates used [2, 3, 9]. Medical technologies of stable intramedullary nailing (IM)

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using new designs of interlocking IM forearm nails provide reliable bone contact of transverse fractures to avoid rotation and anoxia period reduced to 3 days [2, 10, 11, 12]. IM nailing ensures insufficient stability of oblique, spiral and comminuted forearm fractures leading to poor regeneration. Combined IM nailing with square nails (Kirschner wires) and additional bone fixation using S-shaped (for transverse fractures) and ring-shaped clamps (for oblique, comminuted cases) with shape memory is an alternative to interlocking IM nailing [1]. External fixation devices are known to be a reliable practice for forearm fractures at two and more levels, fracture-dislocations and comminution. Medical technologies of transosseous osteosynthesis continue to improve considering the anatomy and topography of the radius and ulna and a pattern of injury [13, 14].

Objective The purpose of the study was to evaluate the effectiveness of intramedullary nailing, plating, external fixation and combined techniques used to repair forearm shaft fractures of different severity based on comparative analysis of outcomes.

MATERIAL AND METHODS

Medical records of 153 patients with diaphyseal fractures of the forearm displaced longitudinally, translated, angulated and rotated, treated at different hospitals between 2000 and 2017 were reviewed. Participants were excluded from study groups if they were younger than 18 years and older than 65 years, had open fractures, injuries to nerves, vessels, muscles and tendons, bone loss of more than 5 cm, isolated intraarticular fractures and injury of more than 3 days. Control (n = 78; 51.0 %) and index (n = 75; 49.0 %) groups were established with regard to fixation technique used (Tables 1, 2).

A subgroup of patients with non-complicated forearm fractures including diaphyseal ulna and radius (S 52.1, S 52.2 ICD-10 codes), and both-bone forearm fractures (S 52.4) was identified to assess the effectiveness of the technique used to fix forearm injuries of different severity. Exact bone reduction and fixation were provided for different patterns of fractures (Table 1).

A subgroup of complicated forearm fractures included patients with fracture-dislocations (S 52.3, S 53.3, S 52.2, S 53.0, S 52.0, S 53.1), multiple forearm fractures (S 52.7) with either bifocal or comminuted injury to one or both forearm bones and bone loss of not more than 5.0 cm (Table 2).

Table 1

Bone fixation of isolated and combined non-complicated fractures of the forearm in patients of control and index groups

Bone fixation technique	**Localisation, pattern of injury, ICD-10 code**			
	Radius fracture S 52.3	Ulna fracture S 52.2	Combined diaphyseal both-bone forearm fracture S 52.4	**Total**
Control group				
Plate	8	16	10	34
IM nail	5	5	6	16
IM nail + plate	–	–	9	9
External fixation	–	–	2	2
Total	**13**	**21**	**27**	**61**
Index group				
IM nail + clamp	13	15	14	42
Plate + IM nail + clamp	–	–	3	3
External fixation + clamp	–	–	–	–
IM nail + clamp+ autologous graft	–	–	–	–
IM nail + clamp + porous implantation	–	–	–	–
Total	**13**	**15**	**17**	**45**

Table 2

Bone fixation of fracture-dislocations, multiple (bifocal) forearm fractures in patients of control and index groups

Bone fixation technique	Localisation, pattern of injury, ICD-10 code							
	Radius frx, dislocated ulna S 52.3, S 53.3	Ulna frx, dislocated radial head S 52.2, S 53.0	Olecranon and ulna shaft frx, dislocated forearm S 52.0, S 52.2, S 53.1	Multiple frx of the proximal ulna S 52.7	Multiple frx of the distal ulna S 52.7	Multiple both-bone forearm frx S 52.7	Multiple both-bone forearm and intraarticular comminuted radius frx S 52.7	**Total**
Control group								
Plate	5	1	–	–	–	1	–	7
IM nail	2	2	1	–	–	–	–	5
IM nail + plate	–	–	–	–	–	1	–	1
External fixation	–	–	–	–	–	4	–	4
Total	**7**	**3**	**1**	**–**	**–**	**6**	**–**	**17**
Index group								
IM nail + clamp	8	2	–	–	–	7	–	17
Plate + IM nail + clamp	–	–	2	–	–	–	–	2
External fixation + clamp	–	2	–	–	–	–	–	2
Autologous graft	–	–	–	–	2	–	–	2
Porous implantation	–	–	–	3	–	–	4	7
Total	**8**	**4**	**2**	**3**	**2**	**7**	**4**	**30**

Open reduction followed by fixation of broken bone was provided for all patients. Open reduction and Ilizarov external fixation were produced for intraoperatively revealed bone displacement with frame on. The distal radioulnar joint was fixed with transverse ulna and radius K-wire(s) following radius fixation and elimination of dislocation/subluxation in cases of Galeazzi fracture-dislocations (**Fig. 1**).

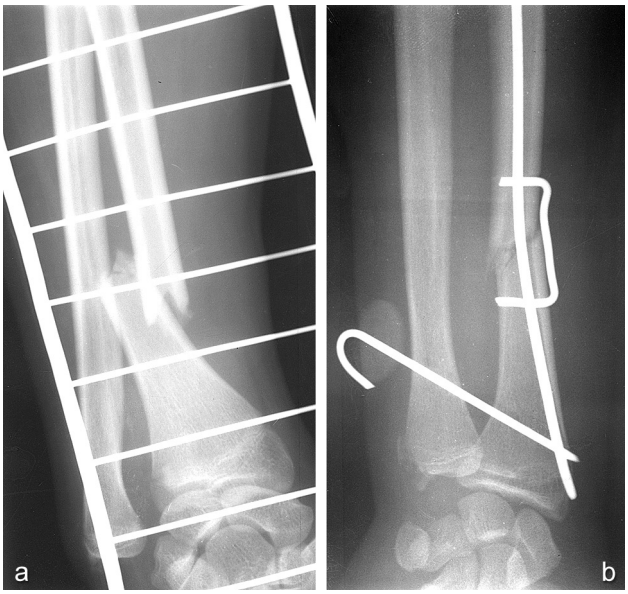

Fig. 1 Radiographs of a 22-year-old patient D. with radius fracture, ulna dislocation (Galeazzi fracture-dislocation) showing (a) preoperative view and (b) combined osteosynthesis and diafixation of the distal radius and ulna at 4 weeks

Radial head was repositioned by direct manual pressure anteriorly on the bone with elbow flexed at 90° and forearm in full supination in patients of control and index groups with ulna fracture and dislocation of radial head (Monteggia fracture-dislocations). Radial head was fixed with temporary wire and ulna reduced in an open manner and then fixed following reposition of the radial head at the level of ulnar notch (Table 2).

Monteggia fracture-dislocations of two patients were addressed with Ilizarov external fixation following closed reduction of radial head and ulna fixation with S-shaped clamp (Registration certificate № 2009/04558, article 13 of Appendix, declaration of conformity ROSS.RU.AYA79.D11341).

Distraction Ilizarov frame was applied in two patients with comminuted multifragment fractures of distal ulna and four patients with multiple injuries to forearm bones including compression intraarticular fracture of the distal metaepiphysis of the radius for bone lengthening and realignment. The device was removed after 2 to 21/2 weeks. Bone defect measured 5.0 cm after Ilizarov distraction and restoration of bone length due to impaired bone and non-viable small interstitial fragments. Defect of the distal segment of the ulnar shaft was repaired

with fibular autologous graft and fixed with memory shape S-shaped clamp and intramedullary stem. Multiple forearm fractures including intraarticular comminuted radius fracture were fixed with porous flat implants and memory shape clamps (Registration certificate № 2009/04558, article 13 of Appendix, declaration of conformity ROSS.RU.AYA79. D11341) for reconstruction of radius metaepiphysis and ulna fixed with IM nail and ring memory shape clamps. Bone loss of three patients with comminuted multifragment fracture of the upper third of ulna shaft was treated with cannulated porous cylindrical implant. The implant was fixed with memory shape ring clamps and IM nailing produced.

External immobilization was provided until bone healing in patients with both bone forearm fractures repaired with IM nail, plating of one bone and nailing of the other and patients who underwent grafting of bone defect. External immobilization was no longer than 2 weeks following stable bone fixation with plates and IM nails and additional fixation of exact bone reduction of non-complicated injuries. External immobilization lasted for 3 to 4 weeks in patients with fracture-dislocations, multiple injuries (comminuted, bifocal) after stable bone fixation with insufficient contact between the fragments.

Comparative analysis of outcomes achieved with different bone fixation techniques were assessed with criteria recommended by L.D. Anderson, D. Sisk, R.E. Tooms, W.I. Park (fracture healing time) [15] and T.G. Grace, W.W. Eversmann (grading of restored motion in injured limb) [16]. Patients were followed up to vocational rehabilitation but no longer than 12 months of admission.

Statistical data analysis was performed using Statistica 6.0 computer program. Non-parametric χ^2 test was used to evaluate significance of mean values and frequency of variables manifested in groups and subgroups. Yates's correction for continuity test was applied for less frequencies and two-tailed Fisher's exact test (a 2 × 2 contingency table) used for frequencies of less than 5. Statistical analysis was performed with hypothesis testing using a significance level of $p < 0.05$.

RESULTS

Bone healing was achieved within 21/2 months of radius fixation in 42 (93.3 %) out of 45 patients of index group with non-complicated isolated fractures and within 3 month of ulna and both forearm bone fixation. Full range of motion in the joints of involved limb, ability to work restored within 3 to 31/2 months after surgical intervention (Table 3). Three patients (6.7 %) developed radiologically verified bone healing within 51/2 months and ability to work restored within 6 months with outcome rated as fair (Table 3).

Good results were achieved in 47 (77.0 %) out of 61 controls with similar injuries. Reoperation was performed for five (8.2 %) patients due to secondary displacement. Delayed consolidation in absence of secondary displacement and construct migration was observed in 9 (14.8 %) patients who restored full ROM and ability to work within 61/2 to 7 months (Table 3).

Comparative analysis of IM nailing and plating in patients of control group showed advantages of plating ($\chi^2 = 5.329$, $p = 0.021$). Comparative analysis of plating and IM nailing in combination with memory shape clamps demonstrated no statistically significant differences ($\chi^2 = 1.192$, $p = 0.275$). No statistically significant differences were detected in outcomes of control and index groups with non-complicated fractures ($\chi^2 = 1.527$, $p = 0.217$).

Standard techniques of bone fixation (with no regard to fracture severity and pattern) applied for 17 controls with fracture-dislocations, multiple injuries of forearm bones resulted in 47.0 % of poor results (Tables 3, **Fig. 2**). The choice of modality was inadequate for a fracture pattern in a patient with ulna injury fixed with DCP plate and juxta-articular comminuted compression fracture of the distal radius fixed with IM nail. The constructs were replaced with external fixation, bone defect filled in with porous implant due to diastasis between bone fragments and broken nail (**Fig. 3**). The patient developed limited radioulnar deviation, pronation and supination within 7 months.

Patients with Monteggia fracture-dislocations underwent reoperation with Ilizarov external fixation and isolated radius and ulna fixation using R.R. Vreden Institute's technology due to ununited ulna, fracture and migration of IM nail and recurrent dislocation of radial head. Dislocation of radial head could not be

completely reduced. Annular ligament rupture was detected. The Ilizarov frame was removed; flexion, extension, supination and pronation appeared to be considerably limited. The patient refrained from annular ligament repair procedure (**Fig. 4**).

Comparative analysis of the effectiveness of different bone fixation techniques showed statistically significant differences (χ^2 = 4.399, p = 0.036) in control subgroups of patients with non-complicated and complicated fractures (Table 3).

Limited flexion, extension, supination, pronation and radioulnar deviation of 3–7° (outcomes rated as fair) persisted in 4 (13.3 %) out of 30 patients of index group with complicated injuries: two with multiple fractures including intra-articular compression fracture of the distal radius, Monteggia fracture-dislocation and Malgen's fracture-dislocation at 12-month follow-up. Bone healing, completely recovered function of the involved limb were seen in 26 (86.7 %) out of 30 patients of index group with complicated injury at 5-to-6-month follow-up. Comparative analysis of outcomes in index and control groups with fracture-dislocations and multiple injuries showed statistically significant differences (χ^2 = 6.649, p = 0.010).

Table 3

Results of bone fixation in patients of index and control groups

Bone fixation technique used	Results						Total	
	good		fair		poor			
	abs.	%	abs.	%	abs.	%	abs.	%
Control group								
Non-complicated fractures								
Plate	29	85.3	4	11.8	1	2.9	34	100.0
IM nail	8	50.0	5	31.3	3	18.8	16	100.0
IM nail + plate	8	88.9	–	–	1	11.1	9	100.0
External fixation	2	100.0	–	–	–	–	2	100.0
Total	**47**	**77.0**	**9**	**14.8**	**5**	**8.2**	**61**	**100.0**
Complicated fractures								
Plate	3	42.9	2	28.6	2	28.6	7	100.0
IM nail	1	20.0	–	–	4	80.0	5	100.0
Plate + IM nail	–	–	–	–	1	100.0	1	100.0
External fixation	3	75.0	–	–	1	25.0	4	100.0
Total	**7**	**41.2**	**2**	**11.8**	**8**	**47.1**	**17**	**100.0**
Index group								
Non-complicated fractures								
IM nail + clamps	40	95.2	2	4.8	–	–	42	100.0
Plate + IM nail + clamp	2	66.7	1	33.3	–	–	3	100.0
Total	42	93.3	3	6.7	–	–	45	100.0
Complicated fractures								
External fixation + clamp	2	100.0	–	–	–	–	2	100.0
Osteosynthesis + graft + clamp	2	100.0	–	–	–	–	2	100.0
Osteosynthesis + implant + clamp	5	71.4	2	–	–	–	7	100.0
IM nail + clamp	16	94.1	1	–	–	–	17	100.0
Plate + IM nail + clamp	1	50.0	1	–	–	–	2	100.0
Total	**26**	**86.7**	**4**	**13.3**	**–**	**–**	**30**	**100.0**

Fig. 2 Radiographs of a 32-year-old patient G. with bifocal fracture of ulna and radius showing (a) consolidated radius and ununited ulna fracture after plate removal; (b) 2 months of external fixation

Fig. 3 Radiographs of a 36-year-old patient P. with ulna fracture, comminuted compression juxta-articular fracture of the radius and dislocated ulna showing (a) broken IM nail, diastasis between radius fragments at 7 months of bone fixation; (b) Ilizarov external fixator applied and bone defect filled with porous implant at 2 weeks; (c) Ilizarov frame removed at 3 weeks

Fig. 4 Radiographs of a 19-year-old patient with Monteggia fracture-dislocation (fracture of ulna and dislocation of radial head) showing (a) preoperative views; (b) reoperation performed at 3 weeks; (c) Ilizarov frame removed, persisting subluxation of radial head

DISCUSSION

The choice of fixation construct largely relies on localization, pattern and severity of injury [3, 10, 13]. Bone healing with adequate anatomy, recovered function of the involved limb in patients with forearm fractures can be provided with elimination of all types of bone displacement, minimal surgical trauma and stable fixation. Good results of plating forearm fractures are reported in 92.8 to 96.7 % of the cases [5, 8]. Our series showed bone healing and completely restored function of the involved limb in 85.3 % of the patients with non-complicated fractures treated with plating.

Disadvantages of IM nails including absence of bone compression, likelihood of rotation can be improved by additional fixation with memory shape clamps [1]. Our observations showed equally efficacious plating and combined fixation of forearm bones. External fixation devices with wires, half-pins, wires-and-half-pins play a leading role in management of bifocal, multifragment fractures, fracture-dislocations [13, 14]. Infection developing in 17.2 to 19.1 % of the cases results in secondary bone displacement due to frame dismantling under necessity with fracture ununited

[13]. Additional bone fixation with memory shape clamps in our series was practical for maintaining alignment with 1 to 3 Ilizarov wires removed due to pin tract infection achieving consolidation. The possibility of isolated radius and ulna control made manipulations easier when bringing radial head down, reducing ulna or addressing displacement of either bone.

Combined bone fixation added by memory shape clamps provided good outcomes in 26 (86.7 %) out of 30 patients with complicated fractures and 7 (41.2 %) out of 17 controls with similar injuries indicating to statistically significant differences (χ^2 = 6.649, p = 0.010).

CONCLUSION

Intramedullary nailing with square nails was shown to be efficient in 50.0 % of patients with transverse, oblique fractures of one or both forearm bones and in 20.0 % of fracture-dislocations. The bone consolidated and function recovered in 85.3 to 95.2 % of the patients with of one or both forearm bones fractures repaired either with plating or combined methods with the use of shape memory clamps. Patients with fracture-dislocations, comminuted and segmental fractures showed good results in 75.0 % of the cases treated with external fixation and external fixation combined with shape memory devices, and in 42.9 % of cases repaired with plating.

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