International Journal of Surgery 70 (2019) 19–24

Contents lists available at ScienceDirect

International Journal of Surgery

journal homepage: www.elsevier.com/locate/ijsu

Original Research

A novel hybrid fixation versus dual plating for both-bone forearm fractures in older children: A prospective comparative study

Shaoyu Zhu[a,b], Di Yang[a,c], Chen Gong[a], Chunmao Chen[a], Liang Chen[a,*]

[a] Orthopaedic Department, The First Affiliated Hospital of Soochow University, 188 Shizi Street, Suzhou, Jiangsu, 215006, PR China
[b] Department of Orthopedics, Tongde Hospital of Zhejiang Province, Hangzhou, 310012, Zhejiang Province, China
[c] Department of Orthopedics, Zhejiang Provincial People's Hospital, Hangzhou, Zhejiang, 310014, China

ARTICLE INFO

Keywords:
Both-bone forearm fracture
Elastic intramedullary nailing
Open reduction and internal fixation

ABSTRACTS

Objective: The aim of the present study was to compare the clinical outcomes of hybrid fixation using elastic stable intramedullary nailing (ESIN) for the ulna and plate screw fixation for the radius (Hybrid group) with dual plating fixation for both-bone forearm fractures in children between 10 and 16 years of age.

Methods: Twenty-six patients were treated using a hybrid fixation struct and 30 patients were treated with dual plating fixation. The two groups were compared prospectively according to perioperative data and patient outcome measures.

Result: The hybrid fixation construct group had 26 patients, with a mean age of 13.27 years (range, 10–16 years) and the dual plate group had 30 patients, with a mean age of 13.33 years (range, 10–16 years). The groups were similar for sex, arm injured, fracture location. Incision length of ulna, duration of surgery and hospital costs were significantly different between the two groups ($P < 0.05$). There was no significant difference in either time to union or Price scores for function evaluation between the 2 groups ($P < 0.05$). Complication rates were also similar between the groups.

Conclusion: Hybrid fixation, using open reduction and internal fixation with a plate-and-screw construct on the radius and closed reduction and elastic intramedullary fixation of the ulna, is an acceptable method for treating both-bone diaphyseal forearm fractures in skeletally immature patients 10–16 years old. The small incision and less cost are the characteristics of this hybrid fixation.

1. Introduction

Forearm fractures are among the most common lesions in adolescents [1]. 81% of forearm fractures happen to children over the age of 5, with the peak of incidence between 10 and 12 years of age in females and 12 and 14 in males. Their incidence is thought to be increasing during the last decade [2].

Conservative treatment consists in carrying out a reduction on manoeuvre and long arm cast which remains a viable treatment option in children 10 years and older [3], the criteria for an acceptable closed reduction in this older group become more stringent because of their limited bone remodeling potential. Osteosynthesis is indicated in cases of open fractures and physis fractures or when conservative treatment fails [4]. The treatment goals are re-establishing axial and rotational stability and restoring functional range of motion in the upper extremity.

Greater controversy exists regarding the optimal method of fixation in children between the ages of 10 and 16 years [5]. The most common options for surgical intervention of pediatric forearm fractures include elastic stable intramedullary nailing (ESIN) and open reduction and plate screw fixation [6]. Elastic intramedullary nailing offers many potential benefits: improved cosmesis, reduced periosteal stripping, the ability to bridge segmental or comminuted fractures without large soft tissue dissections, and the avoidance of creating stress risers [7]. However, in recent years, some studies have reported many complications of ESIN fixation, including delayed union and nonunion of the ulna, skin irritation over prominent hardware, implant migration or failure, compartment syndrome, and wound problems [8–11]. Meanwhile, open reduction and plating allow a more anatomic repair for most fractures [6], which may result in more accurate restoration of the radial bow, which, although unproven, may more completely restore forearm rotation. But this approach has been criticized for the amount

* Corresponding author.
E-mail addresses: zsy7612169@126.com (S. Zhu), yangdi@hmc.edu.cn (D. Yang), gongchen1981@sina.cn (C. Gong), laomaohappy@163.com (C. Chen), chen_liang_1972@126.com (L. Chen).

https://doi.org/10.1016/j.ijsu.2019.08.002
Received 18 June 2019; Received in revised form 20 July 2019; Accepted 1 August 2019
Available online 10 August 2019

of soft tissue dissection and periosteal stripping required for exposure and fixation and an increased risk of refracture [12,13].

In an attempt to decrease the rate of complications and improve the clinical efficacy, we introduced a hybrid fixation, using an ESIN fixation for the ulna, and open reduction and plate screw fixation for the radius. It has not been reported before. Compared with dual plate fixation, hybrid fixation not only reduces soft tissue dissection and potentially refracture rates after implant removal, but also incorporates some advantages of ESIN fixation. The purpose of this study was to compare the radiographic and functional results of hybrid fixation constructs to plate and screw fixation in treating both-bone forearm fractures in skeletally immature older children and adolescents from 10 to 16 years of age.

2. Patients and methods

Our institutional review board granted permission for this prospective study. The work has been reported in line with the STROCSS criteria [14]. Between 2015 and 2017, 56 patients, with a mean age of 13.3 years (range 10–16 years), had a both-bone forearm fracture that was treated by either dual plate fixation constructs (dual-plate group) or hybrid fixation constructs (Hybrid group) of both the radius and ulna. All surgery was performed by five specialists of pediatric traumatology.

The inclusion criteria were: (1) in the middle third or of the forearm with greater than 10° of angulation or 30° of malrotation after attempted closed reduction or (2) a middle third open both-bone forearm fracture. Exclusion criteria were: (1) Montaggia, Galeazzi, and pathological fractures as well as children with polytrauma; (2) neuromuscular paralysis and injuries of the central nervous system; (3) fixation of only one bone; (4) fixation of two bones with dual ESIN.

2.1. Demographics and perioperative data

Demographics data of patient, mechanism of injury and fixation method were recorded. Complication rates, time for fracture union and final range of motion were evaluated in susequent follow up. Incision length of ulna, time to surgery, the duration of surgery, times of fluoroscopy and hospital costs were recorded as perioperative data.

2.2. Operative technique

The operative technique was done under general anesthesia. Fracture fixation was performed under tourniquet control, Reduction of the simpler fracture was undertaken firstly. All pate and ESIN were from DePuy Synthes, USA.

For dual plating fixation constructs, open reduction and internal fixation of the ulna was performed using the direct approach to the subcutaneous ulnar shaft. The radius was exposed with a standard anterior Henry approach or radius-dorsal approach. The dynamic compression plates were used for both the radius and ulna. Reduction was obtained and provisionally fixated; fluoroscopic image intensification was used to verify rotational alignment and reduction of both fractures. Fixation of the implants was then definitively secured.

For hybrid constructs, the patient was placed on the table and the image intensifier was used to localize the placement of skin incisions. The ulna was pinned from proximal to distal through a small oblique hole, created with an appropriate sized drill bit, just proximal to the physis. When the nail reached the fracture site, the fracture was reduced by manipulation and traction under image intensifier control. If unsuccessful, a mini-open approach was used, exposing only enough of the fracture site to obtain and hold reduction during reaming and nail insertion. Once satisfied with reduction, alignment, and provisional fixation of both fractures, the straight rod was removed and an appropriately sized elastic intramedullary nailing was inserted into the ulna. The plate on the radius was then definitively affixed to the bone. An above elbow plaster cast was applied and maintained for 3 weeks for this group.

In both groups, postoperatively, wound dressing and pain control were used if necessary. Physiotherapy was started as early as possible. Patients were followed up at 15 days, six weeks, three months, six months and one year tie for clinical radiological evaluation of union and functional outcome.

2.3. Radiological evaluation

The preoperative forearm radiographs were obtained to classify all fractures according to the Orthopaedic Trauma Association (OTA) classification of diaphyseal forearm fractures [15]. Nonunion, malunion or other complications were noted, union beyond 3 months was defined as “delayed union” and beyond 6 months as “non-union”. Radiographic union was defied as bridging callus on anteroposterior (AP) and lateral radiographs.

2.4. Clinical evaluation

At the last follow-up, Clinical results were evaluated according to the criteria developed by Price [16] which graded as follow: excellent: if no complaints with strenuous physical activity or a loss of pro-supination of < 10°; good: if mild complaints with strenuous activity and/or 11°–30° loss of forearm rotation; fair: if subjective complaints during daily activities or 31°–90° loss of forearm rotation and all other results were considered poor. And we definite the “excellent”、“good” and “fair” as satisfactory, “poor” as unsatisfactory result.

2.5. Complications evaluation

Complications were categorized as “minor” (resolution with observation or minimal intervention) or “major” (requiring return to the operating room or resulting in significant long-term sequelae).

2.6. Statistical analysis

The *t*-test for independent samples was used to compare the 2 groups for age at time of injury, duration of surgery, time to fracture union and the clinical results. We used the Fisher exact probability test for analysis of our categorical data when accounting for small sample sizes. For all calculations, P value < 0.05 was considered statistically significant. Data were analyzed using Statitial Package for Social Sciences (SPSS version 19.0, Chicago, Illinois).

3. Results

3.1. Patient characteristics

Twenty-six patients, 15 boys and 11 girls, were treated with hybrid constructs and 30 patients, 15 boys and 15 girls, with dual plating. Average age for patients in the hybrid fixation was 13.27 years (range, 10–16 years) and in the dual plating group was 13.33 years (range, 10–16 years), there was no significant difference between them (P = 0.881). In the hybrid group, the fracture was on the right in 14 patients and the left in 12. In the dual plating group, the fracture was on the right in 15 patients and the left in 15. According to the OTA classification of diaphyseal forearm fractures, the Hybrid group had 13 patients with 22-A3, 9 patients with 22-B3, and 4 patients with 22-C1 fracture, whereas the dual plating group had 15 patients with 22-A3, 11 patients with 22-B3 fracture and 4 patients with 22-C1 fracture. The most common mechanism of injury was a fall onto an outstretched hand for both groups. 19 of 26 patients in the hybrid constructs group and 22 of 30 in the dual plating group. The demographic characteristics, such as age, sex, side of injury, OTA classification, and injury mechanism, were similar between the groups (p > 0.05; Table 1).

Table 1
Comparison of the general characteristics of the two groups.

General Information	Hybrid group (%)	D-plate group (%)	P Value
	N = 26	N = 30	
Age (yr)	13.27 ± 1.64	13.33 ± 1.54	p = 0.881
Gender			p = 0.861
Male	15 (57.7)	18 (60)	
Female	11 (42.3)	12 (40)	
Side of injury			p = 0.774
Left	12 (46.2)	15 (50)	
Right	14 (53.8)	15 (50)	
Injury mechanism			p = 0.935
Fall damage	19 (73.1)	22 (73.3)	
Traffic accident	5 (19.2)	5 (16.7)	
Other causes	2 (7.7)	3 (10)	
OTA classification			p = 0.972
22-A3	13 (50)	15 (50)	
22-B3	9 (34.6)	11 (36.7)	
22-C1	4 (15.4)	4 (13.3)	

Entries displayed as mean ± standard deviation for continuous variables, n (%) for categorical variables.

3.2. Perioperative data

The average incision length of ulna was 1.88 cm (rang, 1–4 cm) in the hybrid group and 6.03 cm (rang, 4–8 cm) in the dual plating group. There was significant difference between them. The average time from injury to surgery was 2.4 days (range, 1–5 days) in the hybrid group and 2.3 days (range, 1–5 days) in the dual plating group. There was no significant difference between them. The mean duration of surgery was significantly shorter (P = 0.001) for the hybrid constructs group, 46.92 min (range, 40–58 min), than that for the dual plating group, 56.6 min (range, 44–69 min). The mean times of intraoperative fluoroscopy was significantly more in the hybrid group than in the dual plating group (11.63 vs 4.73) (P < 0.01). The hospital costs was significantly less in the hybrid group than in the dual plating group (¥10.92×10^3 vs ¥13.50×10^3) (P < 0.01) Table 2

3.3. Radiographic and functional outcomes

No statistically significant difference was found in time to union between the hybrid group (10.81 weeks, range, 9–13 weeks) and dual plating group (10.42 weeks, range 9–14) with P = 0.352 (Table 3). No patients in either group had residual angulation, translation about the fracture sites, or radial malrotation, and no cases of nonunions were reported. Implant removal was performed in all children at an average of 8 months (range 5–12 months) after operation. Typical cases are shown in Fig. 1. The consent had been obtained from the parents for possible publication of the figures.

Most patients in both groups had full flexion and extension of the elbow and wrist at latest follow-up. According to the grading system of Price [16], the overall results in the hybrid plate–nail construct, at the last follow-up, were excellent in 15 cases (57.7%), good in 9 cases (34.6%), fair in only two case (7.7%). About the dual plating construct, the results were excellent in 17 cases (56.7%), good in 9 cases (30.0%), fair in 3 case (10.0), poor in 1 case (3.3%). Fisher exact test indicated that the satisfactory results were not significantly different between the groups (P = 0.79). Typical cases are shown in Fig. 2.

Table 2
Comparison of the perioperative data of the two groups.

	Hybrid group	D-plate group	P Value
Incision length of ulna	1.88 ± 1.10	6.03 ± 1.03	**p = 0.001***
Time to surgery (days)	2.42 ± 1.03	2.37 ± 1.03	p = 0.839
Duration of surgery (mins)	46.92 ± 5.59	56.6 ± 6.54	**p = 0.001***
Times of fluoroscopy	11.63 ± 1.81	4.73 ± 1.14	**p = 0.001***
Hospital costs (¥, $\times 10^3$)	10.92 ± 0.87	13.50 ± 0.66	**p = 0.001***

Entries displayed as mean ± standard deviation for continuous variables. *: There was a statistical difference between two groups. ¥ means Chinese currency unit, *yuan*.

Table 3
Radiographic outcomes, functional outcomes, and complications in the two groups.

	Hybrid group (%) N = 26	D-plate group (%) N = 30	P Value
fracture union (weeks)	10.81 ± 1.47	10.43 ± 1.50	p = 0.352
Functional Outcome			p = 0.790
Excellent	15 (57.7)	17 (56.7)	
Good	9 (34.6)	9 (30)	
Fair	2 (7.7)	3 (10)	
Poor	0 (0)	1 (3.3)	
Complications			
Major	2 (7.7)	2 (6.7)	p = 0.882
Minor	2 (7.7)	4 (13.3)	p = 0.496

Entries displayed as mean ± standard deviation for continuous variables, n (%) for categorical variables.

3.4. Complications

Postoperative complications occurred in 4 patients in the hybrid group, including two major complications (1 refracture, 1 radius nonunion) and two minor complications (2 superficial wound infection). The radius nonunion patient was a 14 years-old boy with a closed forearm shaft fracture, resulting in perfect alignment after operation. No systemic or local signs of infection were found. Fourteen weeks postoperatively, normal healing and remodeling of the ulna was seen, but no adequate healing of the radius was documented. Healing resumed finally united at 22 weeks after operation without any further intervention and without any functional limitation. Another patient with refracture was a 13-year-old girl who fell onto her arm almost three weeks after the hardware was removed. The fracture healed with closed reduction and cast immobilization for six weeks. What's more, there was 2 superficial infection at the site of entry of the ulna which was successfully treated with oral antibiotics and daily dressing.

In the dual plating group, there were 2 major complications (1 ulna delayed union, 1 radius refracture) and 4 minor complications (3 superficial wound infections, 1 superficial radial nerve palsies). The ulna with delayed union got union at 20 weeks after operation without any further intervention, which came out with good function. The radius refracture occurred in a 12-years old boy four weeks after late, he fell down again and the radius refracture. He underwent a second operation and the fracture healed. There was 3 superficial infection which was successfully treated with oral antibiotics and daily dressing. The superficial radial nerve palsies resolved spontaneously. Overall, there was no difference in complications between the groups (Table 3).

4. Discussion

Both-bone forearm fractures are among the most common injuries sustained by children and adolescents [1]. Recently, most both-bone forearm fractures in children between 10 and 16 years old can be successfully treated by closed means with excellent results. However, in some instances, the closed reduction is unacceptable and open reduction and internal fixation is needed [3,5,6]. Open reduction and internal fixation techniques typically use a 2-incision approach and exposure of the entire fracture to obtain adequate reduction and appropriate implant placement. This method allows for the potential to recreate the radial bow and affords axial and rotational control of the reduction, both critical elements in regaining forearm range of motion

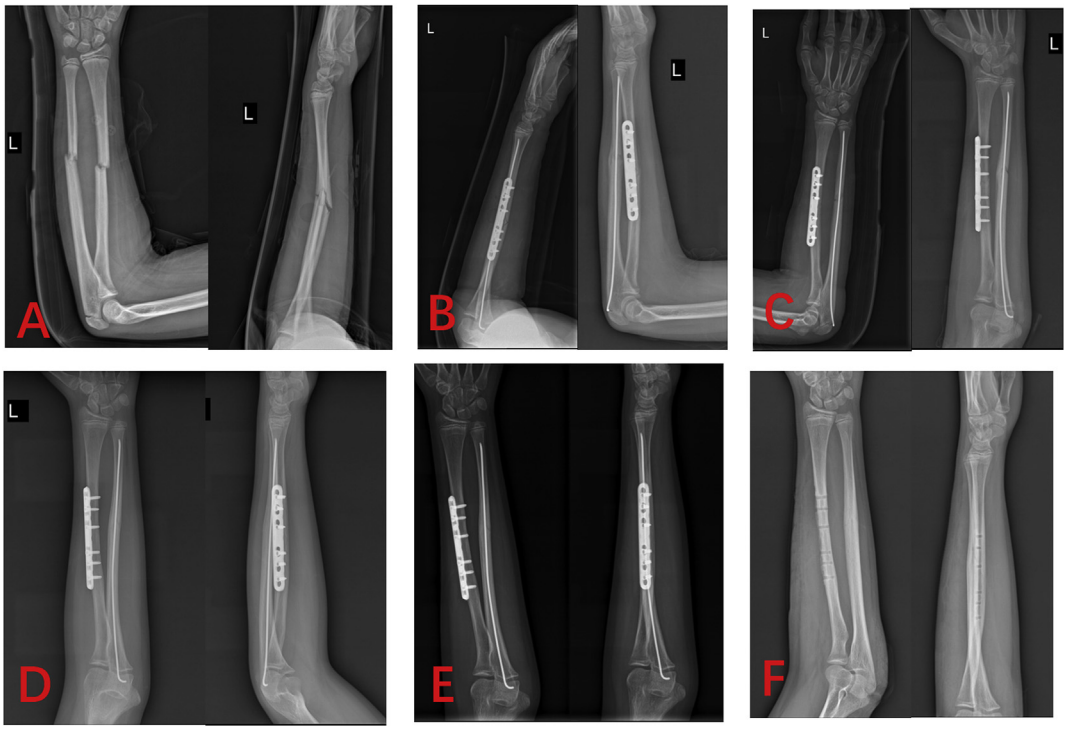

Fig. 1. A 13-year-old boy sustained forearm fracture in a falling accident with treatment of hybrid fixation construct with elastic intramedullary nailing of the ulna and plate fixation of the radius. A: preoperative anteroposterior and lateral radiographs of the forearm showing a fracture of the upper third of the radial and ulnar shaft. B: X-ray after surgery with cast. C: X-ray of one month after surgery. D:X ray of three months after surgery, fracture union. E: X ray of five months after surgery. F: X ray of removal the hardware.

and obtaining good functional outcomes [17]. To obtain adequate exposure, a significant amount of soft tissue dissection and periosteal stripping may be necessary, which has been hypothesized as a risk factor for nonunion [18,19].

However, the optimal method of surgical fixation in this age group is still controversial. Smaller incisions, shorter surgical times, and minimal dissection at the fracture site have been described as advantages of elastic intramedullary nailing over plating in children [20]. Flynn et al. [21] found that IM nailing often required open reduction, had a complication rate of 14.6%, and was less successful in children of 10 years of age and older. Therefore, they recommended a low threshold for the use of plate fixation in older patients requiring internal fixation. However, Joost's study caution against the use of single-bone fixation in all both-bone forearm fractures [22]. This method may lead to increased re-displacement and reduced clinical results, which maybe fail to provide rotational stability.

With the purpose of minimizing some of the disadvantages of ESIN fixation and incorporating some advantages of plate screw fixation, in our previous research [23], we introduced a hybrid fixation, plate screw fixation for the ulna with an ESIN fixation for radius, which is an acceptable method for treating both-bone diaphyseal forearm fractures in skeletally immature patients aged 10–16 years. Feng et al. [24] also

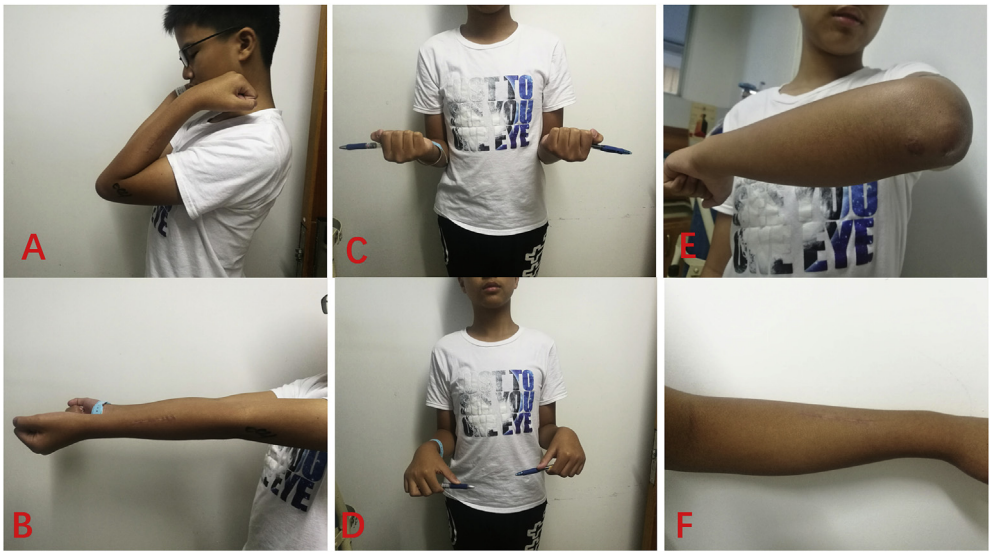

Fig. 2. The following up after five months of surgery of the 13-year-old boy treatment of hybrid fixation construct. A and B were good flexion and extension of the forearm. C and D showed the good rotation (protonation and supination) of the forearm. E and F were the two incisions of radius and ulna.

found that this hybrid fixation is superior in terms of the times of fluoroscopy intraoperatively, duration of immobilization postoperatively, delayed union rate of the ulna and the average time of bone union compared to dual ESIN fixation. However, we found for some fracture, the radius medullary cavity is too large, the elastic nail is not stable enough, and it is easy to cause fracture nonunion. So, we introduce hybrid fixation, combining plate screw fixation for the radius with an ESIN fixation for ulna in older children with both-bone forearm fractures. Titanium elastic nail was special for its good flexibility with anti-rotation performance to some extent, which can be remodeled according to the curvature of ulna [25]. Open reduction and internal fixation for the radius, offer an attractive alternative: preserving radial bow and affording forearm rotational control with radius plate fixation while reducing soft tissue dissection and potentially reducing refracture rates associated with implant removal [26]. What's more, it can be prebenting easily to make a fixation with two or more points in accordance with the fracture characteristics and location. Fixation with plate of ulnar made forearm more stable, the anti-rotation performance was further enhanced. Thus, patients did not need a long-time plaster cast applied, which was conducive to early exercise. In our study, an above elbow plaster cast was applied for only 3 weeks after.

Theoretically, this hybrid fixation construct minimizes some of the disadvantages of plate fixation and incorporates some advantages of intramedullary nailing: utilization of only 1 large incision, decreasing soft tissue dissection, placing stressshielding implants on only 1 fracture, and decreasing the amount of potentially irritating implants used [26]. What's more, the duration of surgery and the time of a tourniquet used intraoperatively of the significantly shorter were all significantly shorter than the dual plating group, which would beneficial to fracture healing and postoperative management. In our study, the mean duration of surgery was significantly shorter ($P = 0.001$) for the hybrid constructs group, than that for the dual plating group. But, the mean times of intraoperative fluoroscopy was significantly more in the hybrid group than in the dual plating group (11.63 vs 4.73). It indicated that the surgeon is subject to more X-ray radiation during this minimally invasive surgery.

Behnke et al. [26] compared open reduction and internal fixation using dual plating to a hybrid fixation construct with intramedullary nailing of the ulna and plate fixation of the radius in both-bone forearm fractures. They found the hybrid fixation is an acceptable method for treating both-bone diaphyseal forearm fractures in skeletally mature patients. So, we think ESIN fixation for ulna is also an acceptable method. But, however dual ESIN for forearm fractures in older children? It seems more minimal treatment. Delayed union and nonunion of the ulna after ESIN fixation of pediatric forearm fractures has been reported to be more common than previously assumed. A multicenter retrospective study reported that adolescent age, midshaft ulna fracture, open fracture, and open reduction of the fracture site were common features of delayed union after ESIN fixation [27]. Feng et al. [24] found the union rate of the ulna at three months postoperatively in the hybrid group was significantly higher than that in the dual-ESIN group for old children. Maybe for the old children between 10 and 16 years old, dual-ESIN can't provide sufficient stability. In our study, no statistically significant difference was found in time to union between the hybrid group (10.81 weeks) and dual plating group (10.42 weeks), it indicated that the hybrid group could provide sufficient stability for the old children between 10 and 16 years old.

Regarding complications in this study, delayed healing of fracture occurred in the two groups. But we found no significant differences between the two groups in terms of fracture union, all delayed unions were completely healed by 5–6 months. Greenbaum [28] reported that open reduction induces a local periosteal destruction leading to reduced blood supply to the injured bone and delayed callus formation. Wright and Glowczewskie [29] explained the healing delay by presence of a relative watershed zone in the intraosseous blood supply to the ulna in the mid-diaphyseal region. However, Using plate fixation, Ortega [30] did not have any delayed unions or nonunions in 16 patients younger than 13 years. In addition, all forearm fractures of 26 skeletally immature 4–16 years old, treated with either intramedullary nailing or ORIF with plates and screws, healed with a mean time to union of 3.5 months [31].

In our study, there were a trend toward a higher rate of excellent and good functional outcome and a relatively lower rate of complications in hybrid group. Overall, our results in this series are encouraging in demonstrating hybrid fixation constructs for diaphyseal both-bone forearm fractures in old children are a safe and acceptable method of stabilization. Meanwhile, we should also see the limitations of this study. The sample sizes and the non RCT design are also obvious weaknesses. Retrospective reviews limit the ability to standardize assessments of union. Additionally, non RCT studies in orthopaedic trauma do not necessarily allow for identification of factors influencing implant selection. Fracture pattern, soft tissue injuries, and surgeon comfort level with implants lead to inherent selection biases with clear potential to influence outcomes. Overall, many of our shortcomings could be addressed with future, prospective, and randomized investigations. In addition, the difference in surgeons' performance and selection bias may affect the generalizability of the results of this study.

5. Conclusion

It is our conclusion that despite our noted limitations, the similar rates of union, times to union, rates of complications, and early functional outcome to the dual plating construct group. But, less duration of surgery, shorter incision and less costs support the use of hybrid plate–nail constructs as an acceptable means of treating diaphyseal both-bone forearm fractures in children aged between 10 and 16 years.

Ethical approval

The study was approved by the Ethical Review Boards of The First Affiliated Hospital of Soochow University. Relevant Judgement's reference number: 201808134.

Sources of funding

There is no funding for my research.

Author contribution

C.L. and S.Y.Z. designed and performed study and D.Y. and S.Y.Z. wrote the paper. C.G. and C.M.C performed study.

Conflicts of interest

The authors have no conflicts of interest to declare. The consent had been obtained from the parents for possible publication of the figures.

Trial registry number

The Unique Identifying Number (UIN) from the http://www.researchregistry.com of the study is researchregistry4957.

Guarantor

Liang Chen.

Department of Orthopaedic Surgery, The First Affiliated Hospital of Soochow University, 188 Shizi Street, Suzhou, Jiangsu, 215006, P.R. China.

E-mail: chen_liang_1972@126.com.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Data statement

I wish to select a statement explaining why I am not linking to or uploading my research data (this statement will appear next to your article on Science Direct).

Data will be made available on request.

CRediT authorship contribution statement

Shaoyu Zhu: Conceptualization, Data curation, Validation, Visualization, Writing - original draft, Writing - review & editing. **Di Yang:** Data curation. **Chen Gong:** Formal analysis. **Chunmao Chen:** Formal analysis. **Liang Chen:** Conceptualization, Validation, Visualization, Writing - original draft, Writing - review & editing.

Acknowledgments

This study was partially supported by a research grant from National Natural Science Foundation of China (81371930, 81772312). Key Talented Man Project of Jiangsu Province (RC2011102) and Standardized Diagnosis and Treatment Project of Key Diseases in Jiangsu Province (BE2015641).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijsu.2019.08.002.

References

[1] J.L. Pace, Pediatric and adolescent forearm fractures: current controversies and treatment recommendations, J. Am. Acad. Orthop. Surg. 24 (11) (2016) 780–788.
[2] J.J. Sinikumpu, A. Lautamo, T. Pokka, W. Serlo, The increasing incidence of paediatric diaphyseal both-bone forearm fractures and their internal fixation during the last decade, Injury 43 (3) (2012) 362–366.
[3] L.E. Zionts, C.G. Zalavras, M.B. Gerhardt, Closed treatment of displaced diaphyseal both-bone forearm fractures in older children and adolescents, J. Pediatr. Orthop. 25 (4) (2005) 507–512.
[4] Y.Q. Sun, J. Penna, S.S. Haralabatos, W.V. Carrion, Intramedullary fixation of pediatric forearm diaphyseal fractures, Am. J. Orthoped. 30 (1) (2001) 67–70.
[5] A. Abraham, S. Kumar, S. Chaudhry, T. Ibrahim, Surgical interventions for diaphyseal fractures of the radius and ulna in children, Cochrane Database Syst. Rev. 11 (2011) CD007907.
[6] K MMr Baldwin, L.A. Tomlinson, R. Ramirez, J.M. Flynn, Both bone forearm fractures in children and adolescents, which fixation strategy is superior - plates or nails? A systematic review and meta-analysis of observational studies, J. Orthop. Trauma 28 (1) (2014).
[7] S.H.F.Y. Du, Y.X. Huang, X.S. Guo, D.D. Xia, Comparison of pediatric forearm fracture fixation between single- and double-elastic stable intramedullary nailing, Am. J. Therapeut. 23 (3) (2016).
[8] M.C. Cullen, D.R. Roy, E. Giza, A.H. Crawford, Complications of intramedullary fixation of pediatric forearm fractures, J. Pediatr. Orthop. 18 (1) (1998) 14–21.
[9] L. Ogonda, J. Wong-Chung, R. Wray, B. Canavan, Delayed union and non-union of the ulna following intramedullary nailing in children, J. Pediatr. Orthop. Part B 13 (5) (2004) 330–333.
[10] P.S. Yuan, M.E. Pring, T.P. Gaynor, S.J. Mubarak, P.O. Newton, Compartment syndrome following intramedullary fixation of pediatric forearm fractures, J. Pediatr. Orthop. 24 (4) (2004) 370–375.
[11] A. Jubel, J. Andermahr, J. Isenberg, A. Issavand, A. Prokop, K.E. Rehm, Outcomes and complications of elastic stable intramedullary nailing for forearm fractures in children, J. Pediatr. Orthop. Part B 14 (5) (2005) 375–380.
[12] C.A. Goldfarb, W.M. Ricci, F. Tull, D. Ray, J. Borrelli Jr., Functional outcome after fracture of both bones of the forearm, J. Bone Joint Surg. Br. Vol. 87 (3) (2005) 374–379.
[13] D.J. Westacott, R.W. Jordan, S.J. Cooke, Functional outcome following intramedullary nailing or plate and screw fixation of paediatric diaphyseal forearm fractures: a systematic review, J. Child. Orthop. 6 (1) (2012) 75–80.
[14] R.A.B.M. Agha, M. Vella-Baldacchino, R. Thavayogan, D.P. Orgillfor the STROCSS Group, The STROCSS statement: strengthening the reporting of cohort studies in surgery, Int. J. Surg. 46 (2017) 198–202.
[15] J.L. Marsh, T.F. Slongo, J. Agel, J.S. Broderick, W. Creevey, T.A. DeCoster, et al., Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee, J. Orthop. Trauma 21 (10 Suppl) (2007) S1–S133.
[16] C.T. Price, D.S. Scott, M.E. Kurzner, J.C. Flynn, Malunited forearm fractures in children, J. Pediatr. Orthop. 10 (6) (1990) 705–712.
[17] K.R. Reinhardt, D.S. Feldman, D.W. Green, D.A. Sala, R.F. Widmann, D.M. Scher, Comparison of intramedullary nailing to plating for both-bone forearm fractures in older children, J. Pediatr. Orthop. 28 (4) (2008) 403–409.
[18] S.Y. Wei, C.T. Born, A. Abene, A. Ong, R. Hayda, W.G. DeLong Jr., Diaphyseal forearm fractures treated with and without bone graft, J. Trauma 46 (6) (1999) 1045–1048.
[19] R.R. Wright, G.J. Schmeling, J.P. Schwab, The necessity of acute bone grafting in diaphyseal forearm fractures: a retrospective review, J. Orthop. Trauma 11 (4) (1997) 288–294.
[20] A. Antabak, T. Luetic, S. Ivo, R. Karlo, S. Cavar, M. Bogovic, et al., Treatment outcomes of both-bone diaphyseal paediatric forearm fractures, Injury 44 (Suppl 3) (2013) S11–S15.
[21] J.M. Flynn, K.J. Jones, M.R. Garner, J. Goebel, Eleven years experience in the operative management of pediatric forearm fractures, J. Pediatr. Orthop. 30 (4) (2010) 313–319.
[22] J. Colaris, M. Reijman, J.H. Allema, G. Kraan, P. van Winterswijk, M. de Vries, et al., Single-bone intramedullary fixation of unstable both-bone diaphyseal forearm fractures in children leads to increased re-displacement: a multicentre randomised controlled trial, Arch. Orthop. Trauma Surg. 133 (8) (2013) 1079–1087.
[23] L. Cai, J. Wang, S. Du, S. Zhu, T. Wang, D. Lu, et al., Comparison of hybrid fixation to dual plating for both-bone forearm fractures in older children, Am. J. Therapeut. 23 (6) (2016) e1391–e1396.
[24] Y. Feng, X. Shui, J. Wang, L. Cai, G. Wang, J. Hong, Comparison of hybrid fixation versus dual intramedullary nailing fixation for forearm fractures in older children: case-control study, Int. J. Surg. 30 (2016) 7–12.
[25] L. Wall, J.C. O'Donnell, P.L. Schoenecker, K.A. Keeler, M.B. Dobbs, S.J. Luhmann, et al., Titanium elastic nailing radius and ulna fractures in adolescents, J. Pediatr. Orthop. Part B 21 (5) (2012) 482–488.
[26] N.M. Behnke, H.R. Redjal, V.T. Nguyen, D.M. Zinar, Internal fixation of diaphyseal fractures of the forearm: a retrospective comparison of hybrid fixation versus dual plating, J. Orthop. Trauma 26 (11) (2012) 611–616.
[27] P.P. Schmittenbecher, G. Fitze, J. Godeke, R. Kraus, D. Schneidmuller, Delayed healing of forearm shaft fractures in children after intramedullary nailing, J. Pediatr. Orthop. 28 (3) (2008) 303–306.
[28] B. Greenbaum, L.E. Zionts, E. Ebramzadeh, Open fractures of the forearm in children, J. Orthop. Trauma 15 (2) (2001) 111–118.
[29] T.W. Wright, F. Glowczewskie, Vascular anatomy of the ulna, J. Hand Surg. 23 (5) (1998) 800–804.
[30] R. Ortega, R.T. Loder, D.S. Louis, Open reduction and internal fixation of forearm fractures in children, J. Pediatr. Orthop. 16 (5) (1996) 651–654.
[31] B. Wyrsch, G.A. Mencio, N.E. Green, Open reduction and internal fixation of pediatric forearm fractures, J. Pediatr. Orthop. 16 (5) (1996) 644–650.