Hybrid fixation of diaphyseal both bone forearm fracture versus dual plating in adolescence

Mohammed A. Hussien, Qassem T. Abdelsattar, Ahmed Elbadrawi, Ahmed K. El Ghazawy

Department of Orthopedic Surgery, Faculty of Medicine, Ain Shams University, Cairo, Egypt

Correspondence to Mohammed A. Hussien, M.D, Department of Orthopedic Surgery, Faculty of Medicine, Ain Shams University, 38 Abbassia Square, Next to Al-Nour Mosque, Cairo 1181, Egypt.
Tel: +20 114 594 5995; fax: +20225650478;
e-mail: drmohaliortho@gmail.com

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Purpose
To compare the clinical and radiological outcomes of hybrid fixation with its two types, versus dual plating in diaphyseal both bone forearm (BBF) fractures in adolescents.
Methods
A retrospective comparative study was carried out on 31 adolescents with a mean age of 13 years with BBF diaphyseal fractures (AO Foundation [AO]/Orthopaedic Trauma Association [OTA] 22-A3) managed by hybrid fixation (group A) or dual plating (group B). Evaluation included operative time, blood loss, time to union, range of motion, Price functional grading, and complications.
Results
The mean follow-up period was 24.5 months. The patients were divided into two group; group A (15 patients) and group B (16 patients). The mean operative time in group A was (60±7 min), and in group B was (82±8 min), with a highly statistically significant difference between both groups (P<0.001). Mean blood loss in group A was (67±15 ml) and in group B was (101±10 ml), with a highly statistically significant difference (P<0.001). Time for union ranged from (9±2 weeks) for the radius, and (10±1weeks) for the ulna. There was no significant difference in either time to union (radius P=0.449, and ulna P=0.156) or Price grading system (P=0.901) between both major groups. Only 1 case had a superficial infection which was managed conservatively.
Conclusion
Hybrid fixation with its two types is not only a considerable alternative to dual plating in the treatment of BBF fractures in adolescents achieving the same rate of union, and functional outcomes but also has the advantage of having a shorter operative time and minimal blood loss.

Keywords:
adolescence, both bone forearm fracture, dual plating, hybrid

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Introduction

Below the age of 10 years, most both bone forearm (BBF) fractures could be treated conservatively due to the high remodeling power [1,2]. Above the age of 10 years, conservative treatment is still an option for BBF fractures using casting [3], but there is a limitation in the criteria of acceptance of closed reduction, due to the decrease in remodeling power.

Surgical fixation is indicated for cases with diaphyseal BBF fractures with unaccepted reduction, lost reduction, unstable fractures, open fractures, compartment syndrome, neurovascular injury, complex fractures (Monteggia and Galeazzi), and association with humerus fractures (floating elbow) [4]. The goal of surgical fixation is to achieve union and regain rotational and axial stability, and forearm function. There is a controversy about the best method of fixation of BBF diaphyseal fractures in adolescence [5].

Intramedullary fixation by elastic stable intramedullary nail (ESIN) has many advantages such as short operative time, minor incision, minimal blood loss, less periosteal stripping, the ability to bridge comminuted or segmented fractures without needing excessive soft tissue dissection, and no stress riser creation [6]. In addition, intramedullary fixation has complications such as long fluoroscopic time, skin irritation, implant migration, compartment syndrome, long postoperative immobilization, higher rate of nonunion and delayed union in comparison to dual plating [7–11].

Open reduction and internal fixation (ORIF) by dual plating achieves anatomical reduction which increases

the chance of regaining the radial bow and forearm's full rotational function, nevertheless, this technique has many drawbacks such as extensive soft tissue dissection and stripping of the periosteum, increased risk of refracture after implant removal, long operative time, more blood loss, risk of synostosis, nerve injury, wound complications, and closure under tension [12–14].

The combination of intramedullary fixation by ESIN and dual plating in the form of a hybrid construct with its two types (plate ulna and ESIN radius) and (plate radius and ESIN ulna) can be a considerable method of fixation especially when employed correctly according to fracture location in the diaphysis, reducing the disadvantages and maximizing the advantages of both techniques.

Patients and methods

After Institutional Review Board approval, a retrospective study of adolescent patients with BBF fractures was conducted. Medical records for adolescent patients with diaphyseal BBF fractures managed by either hybrid fixation or dual plating technique were retrieved.

Inclusion criteria was ages between 10 and 14 years, displaced isolated simple diaphyseal both bone (AO/OTA 22-A3) fracture.

Exclusion criteria were Polytrauma patients, neurovascular injury, Open fractures, Pathological fractures, floating elbow, and complex forearm fractures patients (Monteggia, Galeazzi, intra-articular elbow or wrist fractures). Patients with less than 2 years of clinical and radiographic follow-up were also excluded from evaluation.

Patient charts and radiographs collected from the electronic medical record were reviewed for demographic data, AO/OTA classification, fixation type (hybrid vs. dual plating), operative time, intraoperative blood loss, time to union for radius/ulna, complications, and functional outcome scoring was evaluated according to Price functional grading [15] at the end of follow-up.

31 patients met the inclusion criteria between 2019 and 2021 and were enrolled in this study. These included two females and 29 males, with a mean age of 13 years. Informed written consent from a legal guardian was taken. The average delay time before surgery was 48 h.

Patients were divided into two groups: group A (Hybrid group) which included, group A1: Treated by plating for ulna and ESIN for radius, in patients with proximal and middle third diaphyseal fractures, and group A2: Treated by plating for radius and ESIN for ulna, in patients with distal third diaphyseal fractures. group B (Dual Plating group) including dual plating for both radius and ulna, in patients with diaphyseal fractures. Patient data and demographics are listed in (Tables 1 and 2).

Surgical technique

Surgery was done under general anesthesia, in a supine position with a translucent side table. Preoperative antibiotic administration continued for 2 days postoperatively, and a tourniquet was applied for all patients. Standard prepping and draping of the whole limb were done.

ORIF was done first in both group A1 and A2 to restore length and achieve stability followed by elastic nailing of the other bone. The diameter of the used nail was between 33 and 40% of the isthmus diameter.

Group A1: Plate ulna and ESIN radius: ORIF for the ulna using small dynamic compression plate (DCP) was done first to restore limb length through direct dorsal approach. Elastic nailing for the radius under image intensifier through distal entry point using physeal sparing technique was done with closed reduction and passing the ESIN.

Group A2: Plate radius and ESIN ulna: ORIF for the radius using small DCP was performed through the volar (Henry) approach first to restore radial bow and limb length. ESIN for the ulna under image intensifier through proximal entry point using physeal sparing technique with correction of angulation in the tip of ESIN to avoid distraction of fracture site was done.

Group B: Dual plating group: ORIF for the radius was performed first to restore the radial bow through the volar (Henry) approach, and ORIF for the ulna through the direct dorsal approach, both using small DCP.

Postoperatively, above elbow slab was used for two weeks. Postoperative plain radiography were done. An enhanced rehabilitation program was tailored. This included early range of motion that was gradually increased daily as tolerated starting from the 3rd week and progressing to the full range at 8 weeks compared with the other side.

Follow-up protocol: After their discharge, patients were followed up in the outpatient clinic at 2 weeks for incision healing.

Table 1 Patient data (age, sex, side, groups, operative time, blood loss, time to union, price functional grading)

Patient Number	Age (Years)	Sex	Side	Groups	Operative time (min)	Blood loss (ml)	Time to union (weeks)		Price functional grading
							Radius	Ulna	
1	12	Male	Right	A1	50	60	8	12	Excellent
2	12	Male	Right	A1	55	50	8	12	Excellent
3	13	Male	Right	A1	55	50	6	8	Good
4	11	Male	Left	A1	60	50	16	10	Good
5	14	Male	Left	A1	50	50	10	8	Excellent
6	12	Male	Right	A1	55	70	10	8	Excellent
7	11	Male	Right	A1	55	50	10	8	Excellent
8	14	Male	Right	A1	60	60	10	8	Good
9	14	Male	Right	A2	60	90	9	9	Excellent
10	13	Male	Left	A2	65	75	8	10	Excellent
11	13	Male	Left	A2	65	80	8	10	Excellent
12	11	Male	Right	A2	70	90	8	10	Good
13	14	Male	Left	A2	70	75	8	12	Excellent
14	14	Male	Right	A2	60	80	10	12	Good
15	10	Female	Right	A2	75	75	8	10	Excellent
16	11	Male	Right	B	80	110	8	10	Excellent
17	14	Male	Right	B	100	90	10	12	Good
18	14	Male	Left	B	95	120	8	10	Excellent
19	13	Male	Left	B	70	100	8	10	Excellent
20	13	Male	Left	B	75	100	10	12	Excellent
21	14	Male	Right	B	80	100	8	10	Good
22	12	Male	Left	B	80	90	8	10	Good
23	13	Male	Left	B	80	110	8	12	Excellent
24	14	Male	Right	B	80	90	8	10	Good
25	12	Male	Left	B	85	110	8	10	Excellent
26	13	Male	Right	B	80	100	8	12	Excellent
27	12	Male	Left	B	80	90	10	12	Good
28	14	Male	Right	B	85	110	8	10	Excellent
29	13	Female	Right	B	90	90	10	12	Excellent
30	13	Male	Right	B	75	100	8	8	Excellent
31	12	Male	Right	B	80	110	8	10	Excellent

Table 2 Age, sex, side, dominance, mode of trauma, and follow-up period

	Total *N*=31 *n* (%)	Group A (Hybrid) *N*=15 *n* (%)	Group B (Dual plating) *N*=16 *n* (%)	*P* value
Age (Years)	13±1	13±1	13±1	'*t*'=0.338
Sex				
Female	2 (6.5)	1 (6.7)	1 (6.3)	X^2=0.962
Male	29 (93.5)	14 (93.3)	15 (93.8)	
Side				
Right	19 (61.3)	10 (66.7)	9 (56.3)	X^2=0.552
Left	12 (38.7)	5 (33.3)	7 (43.8)	
Dominance				
Right	19 (61.3)	10 (66.7)	9 (56.3)	X^2=0.552
Left	12 (38.7)	5 (33.3)	7 (43.8)	
Mode of trauma				
FOOSH	30 (96.8)	15 (100.0)	15 (93.8)	Fisher exact test=0.516
Other	1 (3.2)	0	1 (6.3)	
Follow-up (months)	24.5	24	25	0.864

Radiological follow-up was done each month to assess any loss of reduction with early range of motion (ROM), and then every 2 months till the end of follow-up period. Fracture union was defined by the appearance of bridging callus at least in 3 out of 4 cortices and the absence of pain clinically at the fracture site. The mean follow-up period was 24.5 months.

Functional assessment at the last follow-up was done according to the Price functional grading [15] as follows:

Excellent: if no complaints presented with laborious activity or a loss of pronation-supination of less than or equal to 10°; good: if mild complaints presented with laborious activity and/or 11°–30° loss of forearm range of movement; fair: if complaints presented during daily activities or 31°–90° loss of forearm range of movement and all other results were considered poor. The loss of forearm rotation on the affected side was evaluated by comparing it to the rotation on the unaffected side, using a goniometer, with the patient's elbow in 90º of flexion and the arm at the side.

Data were analyzed using the Statistical Package for Social Sciences (SPSS version 25, IBM, Chicago, USA). Descriptive analyses were performed to obtain the means, SD, median, and interquartile range (IQR) and frequencies. Bivariate analyses were performed using independent samples *t*-test. Mann–Whitney test and Kruskal–Wallis test for continuous variables such as age, operative time, blood loss, period of follow-up, time to union, and range of motion. χ^2 test or Fisher's exact test for categorical variables such as sex, side of injury, dominance, mood of trauma, co-morbidities, associated injuries, functional outcome, and complication rate. For all analyses, *P* values less than 0.05 were considered statistically significant.

Results

The mean intraoperative blood loss for group A (Hybrid group) was (67±15 ml). Group A1 (59±14 ml), and group A2 (79±6 ml) was highly significantly lower than that for group B (Dual plating group) (101±10 ml, $P < 0.001$) (Table 3).

Also, regarding operative time, there was a highly statistically significant difference between group A (Hybrid) (60±7 min), group A1 (56±4 min), group A2 (68±5 min), and group B (Dual plating) (82±8 min, $P < 0.001$) (Table 3).

The mean time for radiological union in group A (Hybrid) for the radius was 9±2 weeks and for the ulna was 10±2 weeks, in group A1: radius (10±3 weeks) and ulna (9±2 weeks) (Fig. 1), and group A2: radius (8±1 weeks) and ulna (11±1 weeks) (Fig. 2), with no statistically significant difference from group B (Dual plating) as the radius (9±1 weeks) and the ulna (11±1 weeks) (for radius *P*=0.200, for ulna *P*=0.052) (Fig. 3), with no cases of nonunion (Table 3).

All patients in both groups had a full ROM of the elbow and wrist at the last follow-up, according to Price *et al.* [15] functional grading system. In group A (Hybrid) there were 10 (66.7%) patients in the excellent category and five (33.3%) patients in the good one. In Group A1: five (62.5%) patients were excellent, and three (37.5%) patients were good. In Group A2: five (71.4%) patients were excellent with the highest excellent frequency between the groups, and two (28.6%) patients were good. In group B (Dual plating) 11 (68.75%) patients were excellent and five (31.25%) patients were good with no statistically significant difference between groups (*P*=0.992). No cases with fair or poor results were reported (Table 4).

As for complications, only one case was treated for superficial infection by antibiotics and daily dressing and didn't require any further management. Union occurred without delay and the function was restored with excellent results according to Price grading system (Fig. 1). No postoperative implant irritation, deformity, loss of reduction, or implant failure was observed in our study population till the end of the follow-up period.

Discussion

Surgical fixation is usually employed in BBF diaphyseal fractures in adolescent patients above 10 years more often than younger patients due to strict criteria for acceptable closed reduction in this age group due to lower remodeling power [16].

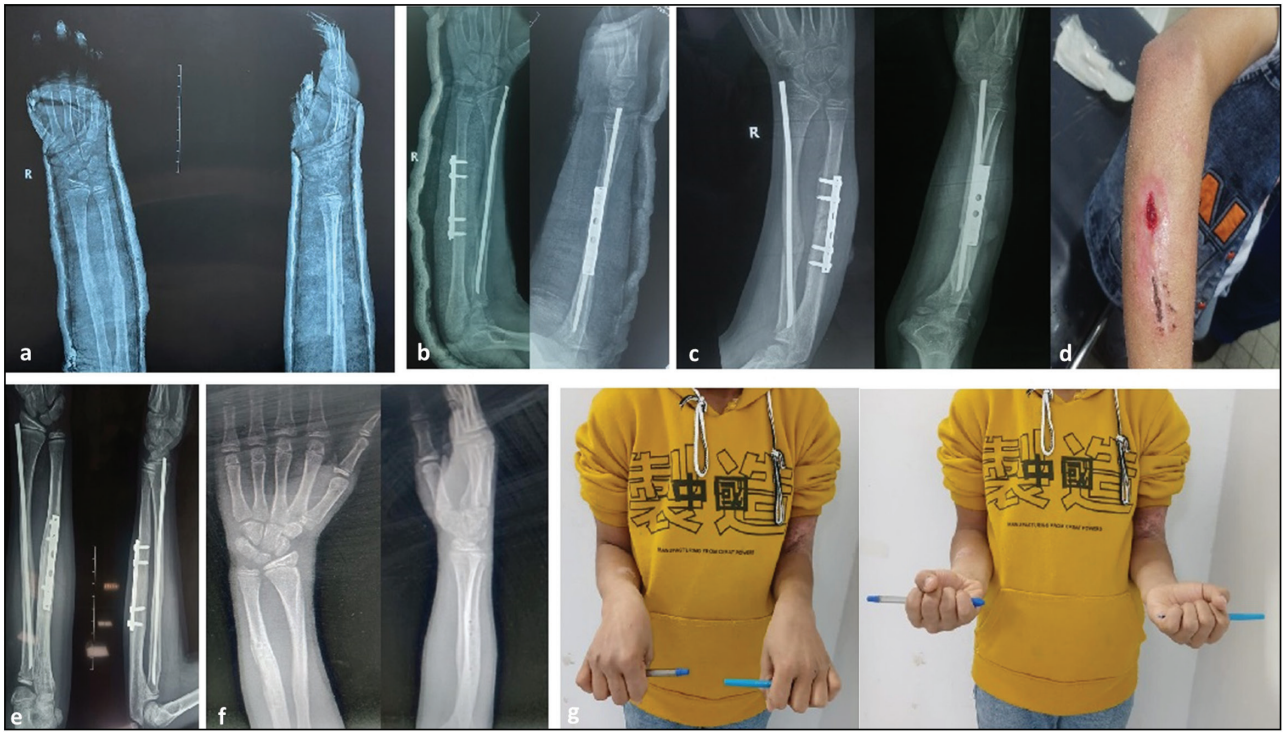
Either dual plating fixation or intramedullary fixation by elastic nail has both advantages and disadvantages,

Table 3 Operative time, blood loss, time to union (weeks), range of motion (ROM) at last follow-up, and ROM loss

	Total *N*=31	Group A (Hybrid) *N*=15	Group A1 *N*=8	Group A2 *N*=7	Group B (Dual plating) *N*=16	*P* value Mann–Whitney test
Operative time (min)	72±13	60±7	56±4	68±5	82±8	<0.001*
Blood loss (ml)	85±21	67±15	59±14	79±6	101±10	<0.001*
Time to union (weeks) Radius	9±2	9±2	10±3	8±1	9±1	0.449
Time to union (weeks) Ulna	10±1	10±2	9±2	11±1	11±1	0.156
ROM (last follow-up) Supination (85°)	79±2	78±3	78±4	79±2	80	0.216
ROM (last follow-up) Pronation (75°)	69±2	69±2	69±2	69±2	68±3	0.233
Supination ROM loss	6±2	7±3	7±4	6±2	5	0.236
Pronation ROM loss	6	6	6±2	6±2	7	0.263

ROM, range of motion

Figure 1



(a). Preoperative AP/Lateral plain X-ray (PXR) showing both bone forearm diaphyseal fractures (AO Foundation [AO]/Orthopaedic Trauma Association [OTA] 22-A3) (b). Immediate postoperative PXRs showing group A1 Hybrid fixation (Plate ulna + elastic stable intramedullary nail radius) (c). 1-month follow-up PXRs (d). 1-month follow-up superficial wound infection (e). 10-month follow-up PXRs showing full union (f). Last follow-up PXRs show a fully united fracture after removal of implant (g). Last follow-up ROM showed full supination/pronation.

so theoretically the combination of both methods in the form of a hybrid construct with its two types would maximize the advantages and at the same time minimize the drawbacks of each technique alone, especially when employing each type of hybrid construct according to the fracture location in the forearm diaphysis.

ORIF of radius fractures of proximal and middle third of the diaphysis through Henry approach theoretically encounter many difficulties such as bulky muscles. Also stripping of supinator and pronator teres muscles can decrease the strength of forearm rotational function. Additionally, there is a risk of nerve injury. These fractures are usually associated with marked soft tissue edema and ORIF for both fractures leads to more soft tissue damage aggravating the edema. Wound closure in turn will be under tension increasing the risk of compartment syndrome and wound dehiscence [17]. Using a hybrid construct (ORIF ulna and ESIN radius) can effectively decrease these risks in proximal and middle-third diaphyseal fractures.

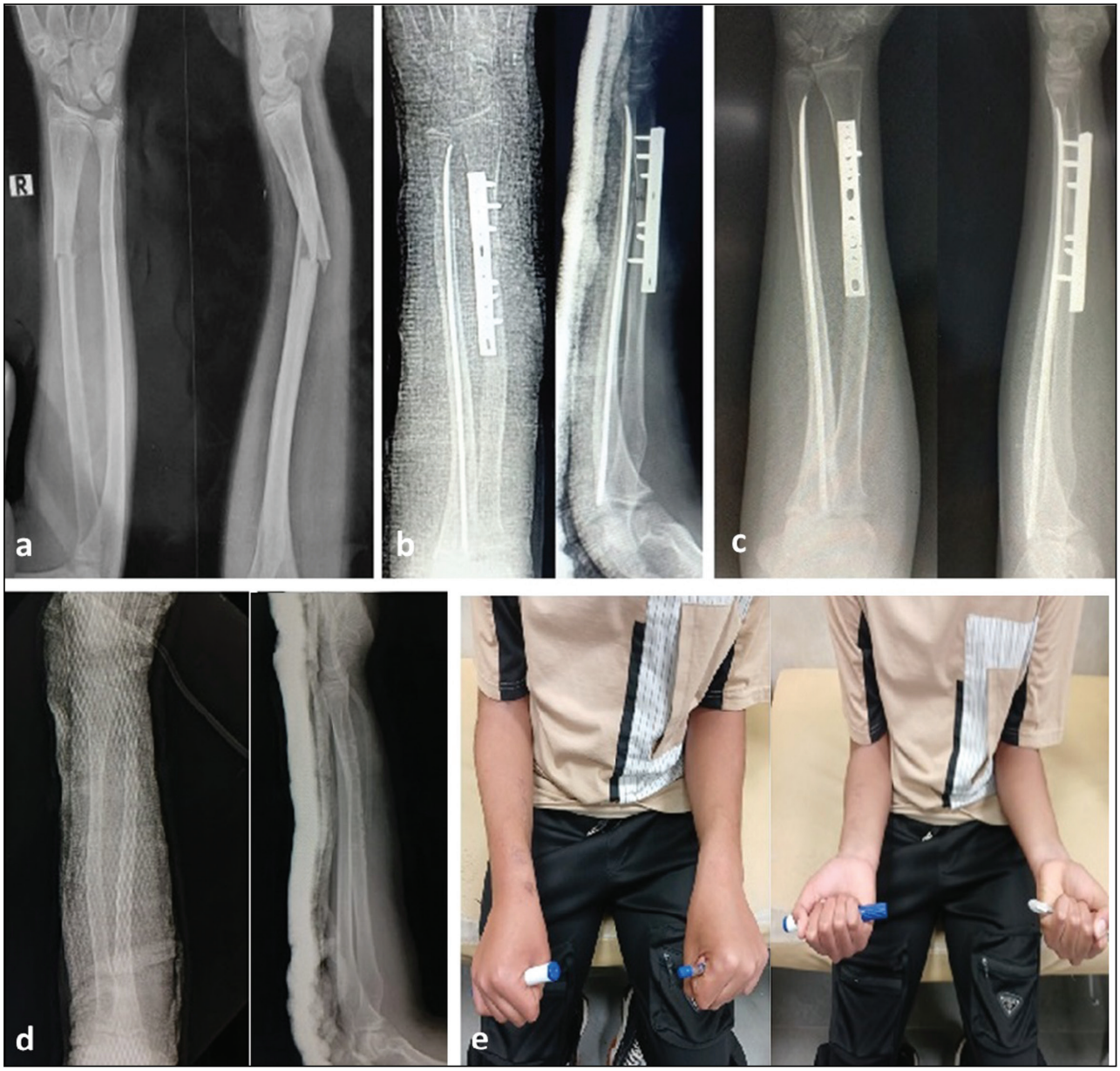
ORIF for the ulna is done through a subcutaneous direct dorsal approach with minimal bleeding attaining rotational stability, minimizing the postoperative immobilization period, and decreasing wound complication rate by using a single incision instead of two opposite large incisions as in dual plating [16].

ESIN for the radius introduced in a retrograde manner leading to compression of the fracture site and fitting to the medulla in this region thus achieving union without complications [18].

Salvi in 2006 [19], explained the different functions of the radius and ulna; the radius has more complex functions, such as pronation and supination, whereas the ulna plays a more important role in maintaining forearm stability, especially when subjected to buckling and torsional stress. Therefore, restoration of the original function of the ulna is necessary to rebuild forearm stability, and rigid plating of the ulna ideally restores this function.

Cai *et al.* in 2016 [16] reported that in the middle-third both bone fractures in skeletally immature patients aged 10–16 years, hybrid fixation by plate ulna and ESIN radius achieved physiological stability for fracture healing with low complication rates and when compared with dual plating, hybrid fixation had the same rate of union (P=0.63), complication rate (P=0.64) and functional outcomes (P=0.65) but with shorter operative time (P=0.001).

Figure 2



(a). Preoperative AP/Lateral PXR showing both bone forearm diaphyseal fractures (AO/OTA 22-A3) (b). Immediate postoperative PXRs showing group A2 Hybrid fixation (Plate radius + elastic stable intramedullary nail ulna) (c). 10-month follow-up PXRs (d). 12-month follow-up PXRs show a fully united fracture after removal of implant (e). Last follow-up ROM showing full supination/pronation.

Also in 2016, Feng *et al.* [20] found that hybrid fixation (plate ulna and ESIN radius) in adolescents shows less fluoroscopic times (P<0.01) and shorter postoperative immobilization than double ESIN (P<0.01). Added to that, authors reported that at three months follow-up, the union rate of the ulna is significantly higher in the hybrid group than that in the double ESIN group (P<0.05).

In this study, blood loss was lower, and operative time was shorter with highly statistically significant differences in group A1 (Hybrid group) when compared with group B (Dual plating group) (P<0.001). There was no statistically significant difference in time to union for the radius (P=0.200), or for the ulna (P=0.052), or in functional outcomes (P=0.992). No major complications were reported in either group and only one case of superficial infection was encountered in group A1 and was treated with daily dressing and a suitable antibiotic.

As for the distal third BBF diaphyseal fractures, the distal third radial medulla is wide so intramedullary fixation using elastic nail will not achieve the required stability for fracture union [21]. Plating for the radius in this location can achieve anatomical reduction, forearm rotational control, and preservation of the radial bow by a single large incision through a

Figure 3

(a). Preoperative AP/Lateral PXR showing both bone forearm diaphyseal fractures (AO/OTA 22-A3) (b). Immediate postoperative PXRs showing group B Dual plating fixation (c). 10-month follow-up PXRs (d). Last follow-up PXRs show fully united fractures (e). Last follow-up ROM showing full supination/pronation.

Table 4 Price functional grading

	Total *N*=31 *n* (%)	Group A (Hybrid) *N*=15 *n* (%)	Group A1 *N*=8 *n* (%)	Group A2 *N*=7 *n* (%)	Group B (Dual plating) *N*=16 *n* (%)	*P* value Chi-square test X^2
Price functional grading						
Excellent	21 (67.7)	10 (66.7)	5 (62.5)	5 (71.4)	11 (68.8)	0.901
Good	10 (32.3)	5 (33.3)	3 (37.5)	2 (28.6)	5 (31.3)	

relatively easy approach with less bulky muscles and minimal soft tissue dissection. At the same time, using closed reduction and ESIN of the ulna allows flexibility with antirotational action to some degree and the ability to remodel according to ulnar curvature [22].

Ogonda *et al.* [18] reported that antigrade ESIN ulna usually distracts fracture site by the distally applied force and its angulated tip causing delayed union. The Ogonda recommendations were to correct the angulated tip of ESIN to avoid fracture site distraction. Taking these recommendations into consideration, in

this study, group A2 (Hybrid group) showed no cases of delayed or non-union in the ulna.

Zhu *et al.* in 2019 [21] reported that hybrid construct (plate radius and ESIN ulna) in diaphyseal BBF fractures in adolescents between 10 and 16 years, had the same time to union (P=0.352), rate of union, rate of complications and functional results (P=0.79) as in double plating group, but with shorter operative time (P=0.001), shorter incision and less financial cost (P<0.01).

In this study: group A2 (Hybrid group) when compared with group B (Dual plating group), there were no statistically significant differences in time to union (radius P=0.200, ulna P=0.052) and functional outcomes (P=0.992). At the same time, blood loss was lower, and operative time was shorter with a highly statistically significant difference in group A2 (Hybrid group) (P <0.001), with no complications in both groups.

To sum up, our findings support that hybrid fixation with its two types is an effective technique with shorter operative time and lower blood loss than the dual plating technique achieving the same rates of union and functional outcomes.

Being a retrospective study was one of the main limitations of this study leading to selection bias that could affect the outcomes in addition to the small sample size. Additional biomechanical studies and randomized controlled trials are needed to further investigate the significance of this method and avoid these limitations.

Conclusion

Hybrid fixation with its two types not only offers a considerable alternative to dual plating in BBF fractures in adolescents, achieving the same rate of union, and functional outcomes, but has the advantage of having a shorter operative time and minimal blood loss. The use of (plate ulna and ESIN radius) in proximal and middle third diaphyseal fractures, and (plate radius and ESIN ulna) in distal third diaphyseal fractures are considered an attractive alternative to dual plating in this age group.

Ethical approval

'All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.' The study was approved by our institution's Ethical Committee of Scientific Research.

Informed consent

Informed consent was obtained from all individual participants included in the study. All parents consented to and were informed that data concerning this study would be submitted for publication.

All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by M.H. and A.E.G. The first draft of the manuscript was written by Q.A., and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Conflicts of interest

There are no conflicts of interest.

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