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Intramedullary Implant Choice and Cost in the Treatment of Pediatric Diaphyseal Forearm Fractures

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ABSTRACT

Objectives: The aim of this study was to compare outcomes and costs between titanium elastic nails (TENs), stainless steel elastic nails (SENs), and Kirschner wires (K-wires) in the treatment of pediatric diaphyseal forearm fractures with intramedullary fixation.

Design: Retrospective cohort study.

Setting: Level 1 Pediatric Trauma Center.

Patients/Participants: A total of 100 patients (65 male and 35 female) under 18 years of age with diaphyseal forearm fractures treated with intramedullary fixation were included in the study.

Intervention: Patients received single or both bone intramedullary fixation with either TENs, SENs, or K-wires.

Main Outcome Measurements: Time to radiographic union, complication rate, surgical time, and average cost per implant.

Results: 100 patients were included in the study. 31 patients were treated with TENs, 30 with SENs, and 39 with K-wires. No significant difference in time to radiographic union, complication rate, or surgical time was found between the three types of fixation. Average time to union was 9.4 weeks ± 5.4 weeks and complication rate was 12.9% for TENs, 10.0% for

SENs, and 12.8% for K-wires. There was a significant difference in cost per implant, with an average cost of $639, $172 and $24 for TENs, SENs, and K-wires respectively (p<0.001).

Conclusions: The present study demonstrates no difference between TENs, SENs, and K-wires in the treatment of pediatric diaphyseal forearm fractures with regards to outcome, time to union, surgical time or complication rates. Given the significant cost difference between these implants, we recommend surgeons consider modifying their implant selection to help mitigate cost.

Level of Evidence: Therapeutic Level III.

Key words: pediatric; forearm fracture; elastic stable intramedullary nailing; fracture radius and ulna; cost

Introduction

Pediatric diaphyseal forearm fractures are common injuries accounting for 13-40% of all fractures in children, and over 10% of all fractures seen in U.S. emergency departments every year.[1,2,3] The vast majority of these injuries can be treated with closed reduction and cast immobilization with excellent results.[4,5] However, when nonoperative management fails, intramedullary fixation can provide a minimally invasive means to an acceptable reduction and fracture union.[6,7,8]

Elastic stable intramedullary nailing (ESIN) of pediatric forearm fractures has been described utilizing various implant designs with excellent results. Titanium elastic nails (TENs), stainless steel elastic nails (SENs) and standard Kirschner wires (K-wires) are three commonly used intramedullary implants (Figure, Supplemental Digital Content, http://links.lww.com/JOT/A8).[8,9,10] TENs and SENs are precontoured at the tip to help negotiate the medullary canal and allow for balanced three-point fixation. Some authors recommend titanium implants,[6,12] however, K-wires have been shown to yield successful outcomes and have been suggested as a cost-effective alternative to prefabricated nails.[13,14,15]

Two studies were identified directly comparing K-wires to precontoured implants in the treatment of pediatric forearm fractures.[13,14] Both of these studies were small in size and did not include analysis of implant cost. Given the large cost difference between implants, a more comprehensive cost and outcome analysis is warranted.

The purpose of this study was to determine if there is a difference in outcome between three commonly used intramedullary implants: titanium elastic nails (TENs), stainless steel elastic nails (SENs) or stainless steel Kirschner wires (K-wires). Furthermore, this study aimed to elucidate whether a statistically significant cost difference exists between these implants.

Materials and Methods

Between January 2004 and September 2014, patients under the age of 18 with diaphyseal forearm fractures (OTA 22A & 22B) treated with intramedullary fixation at a single institution

were retrospectively reviewed. Pathologic fractures, radial neck fractures, and patients with inadequate follow-up were excluded.

Patients received single or both bone fixation with titanium elastic nails (TENs) [Synthes, West Chester, PA], stainless steel elastic nails (SENs) [Berivon, Meridian, MS], or stainless steel Kirschner wires (K-wires) [Brassler, Ventura, CA]. Implant choice was based on surgeon preference. Standard surgical technique for intramedullary nailing of forearm fractures was used. For fractures of the radius, the implant was inserted in a retrograde fashion, just proximal to the physis on the radial or dorsal border. A 2.5 or 3.5 millimeter drill was used to create a starting hole for insertion. Ulna fractures were treated in an antegrade fashion, with the implant inserted transphyseal from the proximal aspect of the olecranon. TENs and SENs were inserted using devices provided in their corresponding instrument trays along with standard instrument sets. K-wires were inserted using devices available in standard instrument trays. Stability of reduction and fixation was confirmed intraoperatively prior to conclusion of the procedure.

Postoperatively, patients were immobilized in a plaster splint or fiberglass cast. Short or long arm casts were continued until good evidence of healing was demonstrated on radiographs. Postoperative physical therapy was not routinely ordered. Patients were followed for a minimum of 4 months. All radiographs were analyzed by two authors. Radiographic union was defined as the presence of bridging callus at 3 out of 4 cortices on two orthogonal films.

Data was collected on time to radiographic union, surgical time, range of motion, complications, and cost of the implants for each patient. Cost data was gathered from the hospital’s accounting

records and represents the true cost of each individual implant used. Cost was adjusted to 2014 US dollar values in order to normalize the reporting of this data. An analysis of variance (ANOVA) and post-hoc statistical analyses were used to determine whether any significant differences existed between the groups.

Results

Initial search yielded 301 patients with a total of 100 patients meeting inclusion criteria. There were 35 girls and 65 boys, mean age was 9.15 years (2.02-18.16 years). The majority (97%) of the injuries were low energy trauma. 69 patients fractured both radius and ulna, 24 had isolated radius fractures, and 7 had isolated ulna fractures. 24 patients had open fractures; the remaining 76 had closed fractures. 57 cases required open reduction while the remaining 43 were performed closed (Table 1).

The study groups included 31 patients treated with TENs, 30 patients treated with SENs, and 39 patients treated with K-wires. There was no statistically significant difference in time to radiographic union (p=0.154 radial union, p=0.807 ulnar union) or complication rate between the three groups.

Average time to radiographic union for all three implants combined was 9.4 weeks ± 5.4 weeks with TENs averaging 10.1 weeks ± 4.8 weeks, SENs 9.4 weeks ± 6.0 weeks and K-wires 9.0 ± 5.5 weeks (Fig. 1). The complication rate was 12.9% (4 patients) for TENs, 10.0% (3 patients) for SENs, and 12.8% (5 patients) for K-wires. Specific complications are listed in *Table 2*. Most complications were minor, the majority of which were refracture (5 patients). Four patients

required an unplanned additional surgery and 2 patients required oral antibiotics for superficial infections.

Hospital accounting records were used to collect the actual cost of implants for each individual patient. There was a significant difference in the cost of each implant with an average cost of $639 per TEN, $172 per SEN, and $24 per K-wire ($p$<0.001) (Fig. 2). Additionally, data on operative time from incision to close was evaluated (Table 1). No statistically significant difference existed between the groups. TENs had an average operative time of 79.26 minutes, 77.17 minutes for SENs, and 65.43 minutes for K-wires.

Discussion

The treatment of choice for the majority of pediatric diaphyseal forearm fractures remains closed reduction and immobilization.[4,5] Factors such as patient age, residual angulation, rotation, fracture level, and instability may necessitate surgical intervention in order to preserve forearm function.[16,17] Intramedullary fixation offers a minimally invasive means of maintaining acceptable reduction until fracture union with relatively minor risk of complication.[6,7,8,18] Available literature would suggest that intramedullary stabilization of pediatric forearm fractures with TENs, SENs, or K-wires can lead to successful outcomes.[8,9,10]

Only two studies were identified that offer a comparison between prefabricated ESINs and standard Kirschner wires in the treatment of pediatric forearm fractures.[13,14] In 2003, Calder *et al*. compared 36 patients treated with K-wires to 24 patients treated with ESINs and found 16% and 9% complication rates respectively, but this difference was not statistically significant. They

concluded that although ESINs do provide theoretical advantages, they do not appear to significantly improve outcomes. In 2007, Majed *et al*. compared 11 patients treated with K-wires to 12 patients treated with Nancy nails and found no difference in outcomes. They recommended that if ESINs are not available, K-wires can be used instead. Both of these studies used Nancy nails, which are typically titanium, but neither specifically mentions the material of the implants. Neither study mentions an evaluation of radiographs, nor did they collect data on the cost of implants used. The goal of our investigation was to directly compare these three implant types and provide a more comprehensive analysis of outcomes and cost.

Our study contains 100 patients making it the largest comparison of K-wires to ESINs in current literature. We collected data on multiple outcome measures as well as actual implant costs from the hospital's accounting database. The above analysis shows no statistically significant difference in any outcome measure between TENs, SENs and K-wires. Furthermore, our data demonstrates a significant difference in cost between these implants. One titanium elastic nail had an average cost of $639 making this implant significantly more expensive than precontoured stainless steel elastic nails or Kirschner wires. Some authors recommend titanium implants because of their elastic properties being more similar to bone, and superior results in some biomechanical studies.[11,12] In a 2014 review, Truntzer *et al*. suggest that titanium implants are used more often than stainless steel because their properties allow improved insertion and rotation while still providing adequate stabilization. There are multiple publications discussing apparent superiority of titanium orthopedic implants to stainless steel with regard to biocompatibility, modulus of elasticity, osseointegration, corrosion resistance, and magnetic resonance imaging compatibility.[20,21,22,23,24]

In our review of the literature, we were unable to find any biomechanical or clinical studies demonstrating superiority of TENs in the treatment of pediatric forearm fractures. There is one biomechanical study showing superior compressive and torsional stability in femoral fracture models treated with TENs compared to SENs,[12] but this study has been contradicted by subsequent clinical studies.[25,26] In 2008, Wall *et al.* compared femoral shaft fracture outcomes in 56 patients treated with TENs to 48 treated with SENs and found a higher rate of major complications and malunions in patients treated with TENs. It has been suggested that surgeon bias towards the use of titanium nails may be due to a greater perceived ease of insertion of these implants.[25]

As with any implant, there are pearls and pitfalls worth highlighting when using intramedullary K-wires. These implants can easily be contoured prior to insertion to allow for three-point contact if desired. The absence of the precontoured hook can aid in passing the wire across small diameter medullary canals as well as facilitate easier removal. The authors prefer to use a drill to make a starting hole with all intramedullary forearm fixation but some surgeons find this unnecessary and an opportunity for additional cost savings by eliminating the need for a drill bit. The start point in the distal radius can be made radially or dorsally and can impact ease of wire passage depending on the specific fracture morphology. Both starting points risk injury to the superficial branch of the radial nerve, although these are usually transient neurapraxias.[27,28] The dorsal starting point can facilitate wire passage but there is growing recognition of the risk of extensor pollicus longus rupture with this approach. There have been several techniques described to help avoid tendon injury. While several mechanisms of injury have been suggested,

the exact etiology remains unknown, but is likely multifactorial.[28,29] If a dorsal starting point is desired, the authors recommend an adequate length incision to visualize and protect the extensor tendons, and bending and cutting the end of the wire as to avoid tethering or abrading the tendons. The ends of the wires can be left exposed or buried depending on surgeon preference.[30] In older children, standard K-wires may not be long enough to adequately span the fracture, as they typically have a maximum length of 22.5 centimeters. A thorough intraoperative examination of stability should be performed prior to cast or splint application. This will determine whether there is adequate implant length spanning the fracture site. *Figure 3* shows two cases where K-wires achieved adequate stability without spanning the entire diaphysis. In situations where K-wire length is insufficient, the authors recommend moving to a SEN for a longer implant with less additional cost.

Cost-effective surgical practice is a growing area of interest, especially in the field of orthopaedics.[31,32,33,34] With rising healthcare costs providers are often looking for ways to decrease the financial burden of surgery. The results of the present study would suggest that a surgeon can safely replace over $1000 worth of titanium implants in one of these procedures with one or two $20 K-wires. It could be argued that this cost difference is insignificant when considering the total cost of surgery and hospital stay but considering how common these injuries are, implant selection could contribute to significant healthcare savings in the long-term.

Limitations of the present study are consistent with those of a retrospective review. Patients were not randomly assigned to each implant type exposing them to possible selection bias based on surgeon preference. Follow up minimum of 4 months has the potential to underestimate

complications, however this should theoretically be equal among the three groups. The complication rates were similar among the groups and consistent with those described in current literature. Our definition of radiographic union can potentially overestimate healing. This was chosen because the relatively routine postoperative course of these patients can lead to decreased number of visits or a greater time interval between visits once bridging callous is noted on radiographs. Finally, our cost data was gathered from the hospital's accounting database and did reflect variations in payment for implants based on prenegotiated contracts depending on the patient's insurance. However, these variations are minimal for these particular implants and should be distributed evenly among the three groups.

In conclusion, the present study demonstrates no difference between TENs, SENs, and K-wires in the treatment of pediatric diaphyseal forearm fractures with regards to outcomes, time to union, or complications rates. Given the significant cost difference between these implants, we recommend surgeons consider modifying their implant selection to help mitigate cost.

Fig. 1

Graph showing average time to union for each implant group

Fig. 2

Graph showing average cost per implant for each implant group

Fig. 3

Postoperative radiographs of a A. 12 year-old female and B. a 13 year-old male treated with single bone K-wire fixation. Adequate intraoperative stability was achieved despite insufficient K-wire length to span the entire diaphysis.

Table 1

Comprehensive demographic data on patients in each implant group

Table 2

Comprehensive cost and outcome data on patients is each implant group

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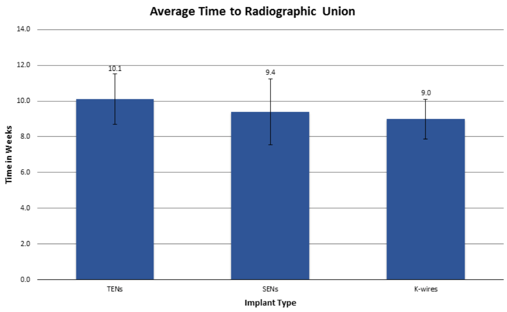
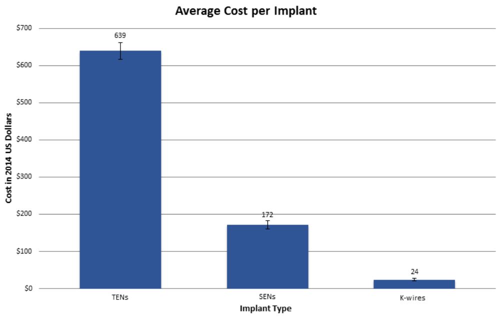
Table 1

Demographic Information	TEN (31)	SEN (30)	K-wires (39)
Average patient age (years)	10.16 ± 3.22	8.75 ± 3.37	8.64 ± 3.53
Range patient age (years)	5.03 -18.16	3.35 -17.72	2.02 -14.03
Sex (M/F)	9 F, 22 M	12 F, 18 M	14 F, 25 M
Side (R/L)	8 R, 23 L	12 R, 18 L	13 R, 26 L
Bones involved			
Radius only	12	3	9
Ulna only	0	3	4
Both	19	24	26
Bone implanted			
Radius only	24	9	18
Ulna only	5	18	19
Both	2	3	2
Fracture pattern: Radius			
Proximal third	6	5	7
Middle third	22	16	18
Distal third	3	6	10
Fracture pattern: Ulna			
Proximal third	0	1	2
Middle third	16	21	18
Distal third	3	4	9
Neurovascular injuries	0	0	0
Open fractures	7	12	5
Surgical reduction			
Closed	12	8	22
Average operative time (minutes)	63 ± 21	61 ± 32	58 ± 26
Range operative time (minutes)	28 -105	22 -100	24 -98
Open	19	22	17
Average operative time (minutes)	91 ± 26	83 ± 31	76 ± 26
Range operative time (minutes)	36 -133	22 -143	23 -104

Table 2

Outcomes	**TENs (31)**	**SENs (30)**	**K-wires (39)**
Implant size: Radius (mm)			
Average	2.33 ± 0.28	2.36 ± 0.2	2.14 ± 0.48
Median	2.5	2.3	2.4
Mode	2.5	2.3	1.6
Range	2.0 -3.0	2.3 -3.0	1.6 -3.0
Implant size: Ulna (mm)			
Average	2.38 ± 0.44	2.29 ± 0.08	2.20 ± 0.56
Median	2.25	2.3	2
Mode	2	2.3	2
Range	2.0 -3.0	2.0 -2.5	0.9 -3.0
Number of implants used	33	33	44
Average cost per implant ($)	639 ± 124	172 ± 62	24 ± 18
Complications			
Refracture	2	1	2
Hardware prominence requiring revision surgery	1	1	0
Hardware removal requiring sedation	1	0	0
Wound dehiscence	0	1	0
Cast abrasion	0	0	1
Pin site infection requiring PO antibiotics	0	0	1
Stitch abscess treated with PO antibiotics	0	0	1
Total Complication rate (%)	*12.9*	*10*	*12.8*


Average Time to Radiographic Union
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Time in Weeks
10.1
9.4
9.0
TENs
SENs
K-wires
Implant Type



Average Cost per Implant
Cost in 2014 US Dollars
$700
$600
$500
$400
$300
$200
$100
$0
639
172
24
TENs
SENs
K-wires
Implant Type


A
B