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UPPER LIMB

Outcomes of treatment of displaced midshaft clavicle fractures in adolescents using titanium elastic nails

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Abstract

Background: Literature on the functional outcomes following the treatment of closed, displaced midshaft clavicle fractures in adolescents is fairly limited. These fractures have traditionally been treated non-operatively; however, recent literature in adults shows improved outcomes with operative treatment, and it has been suggested that these results may translate to adolescents.

Study objective: To assess the effectiveness of titanium elastic nailing in the treatment of displaced midshaft clavicle fractures in adolescents.

Methods: Adolescent patients (age 13 to 17 years) with closed, displaced midshaft clavicle fractures sustained between 2008 and 2015, were treated operatively with a titanium elastic nail inserted in an unreamed fashion from the sternal end of the clavicle by a single surgeon. Post-operatively, patients were immobilised in a sling for six weeks and attended scheduled follow-up visits at two, six and 12 weeks. The nail was removed from 12 weeks onwards in all cases. All patients were assessed by the surgeon with regard to the radiological outcome, Constant shoulder score, scar quality and complications.

Results: Fifteen patients, 12 males and three females with a mean age of 14.9 years, were assessed. Fourteen patients went on to complete union by 12 weeks and the remaining one united by 20 weeks post-surgery. The difference in Constant shoulder scores between the affected and unaffected shoulders for 14 patients was below 11 at 12 weeks' follow-up and all patients were satisfied with their scar after 12 weeks. Two patients developed complications – one an iatrogenic perforation of the posterior cortex of the lateral fragment and one a haematoma after re-injury.

Conclusion: Operative treatment with a titanium elastic nail is a safe, minimally invasive and reliable treatment method for displaced, uncomminuted midshaft clavicle fractures in adolescents.

Level of evidence: Case series; Level IV evidence

Key words: clavicle, fracture, adolescent, intramedullary, nailing

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Introduction

Clavicle fractures occur commonly, comprising 2.6–5% of adult fractures[1] and 10–15% of paediatric fractures seen.[2] Fractures of the middle third of the clavicle account for approximately 80% of all clavicle fractures and are displaced in 48% of cases.[3]

Few studies have specifically investigated outcomes of surgical and nonsurgical management of clavicle fractures in children and adolescents, thus, most data are extrapolated from the adult literature.[4]

Displaced midshaft clavicle fractures have historically been overlooked as it was believed that these fractures uniformly heal without

complications.[5,6] Recent literature has challenged this belief and numerous studies in adults have revealed unacceptably high non-union rates (15.1%) as well as associated pain, loss of strength and rapid fatigability when these fractures were managed conservatively.[7-10]

Due to the excellent healing potential in children, even significantly displaced adolescent clavicle fractures have traditionally been treated nonsurgically.[11-13] A study by McGraw *et al*. in 2009 showed that little clavicle growth (20%) remains after nine and 12 years of age in girls and boys respectively, and adolescents thus have limited capacity to regain normal clavicle length, resulting in greater functional impairment compared to younger patients.[14]

Various studies have demonstrated that malunion of a midshaft clavicle frature with shortening of the clavicle alters the position of the glenoid fossa. This alters glenohumeral mobility and scapular rotation, leading to unsatisfactory results and loss of function.[15-17]

It has also only recently come to the attention of clinicians and researchers using patient-based outcome measures, as opposed to surgeon-based or radiographic outcomes, that patient dissatisfaction with conservative management of these fractures is unacceptably high.[10,18-21]

The successful outcomes achieved from fixation of displaced clavicle fractures in adults have raised new questions regarding treatment in the adolescent population and led some orthopaedic surgeons to search for and refine indications for fixation of clavicle fractures in skeletally immature patients, particularly in highly functional and active adolescents.[4]

Van der Have *et al*. retrospectively reviewed 42 adolescents with significantly displaced clavicle fractures and showed that symptomatic malunion was more common than initially thought. They also found that operative management of displaced midshaft clavicle fractures reliably restored length and alignment, and resulted in a shorter time to union, with lower complication rates than fractures treated non-operatively.[2]

The choice of operative treatment remains controversial and numerous fixation options are available.[1] Intramedullary nailing of the clavicle has been shown to have considerable advantages over other forms of fixation as there is limited periosteal stripping and minimal compression of the periosteal blood supply which promotes union.[22]

A 2003 study by Jubel *et al*. evaluating the use of titanium elastic nails in 58 displaced midshaft clavicle fractures, reported marked pain reduction and early restoration of shoulder function with excellent cosmetic results compared to plate fixation or conservative management.[23]

In a randomised trial of 60 patients with completely displaced midshaft clavicle fractures, Smekal and colleagues compared titanium elastic nailing with non-operative (sling) treatment. The authors concluded that the operative technique resulted in a decreased non-union rate, faster return to function, and provided a better long-term functional outcome compared with non-operative treatment.[24]

Figure 1. Pre-operative marking of proposed incision sites

Intramedullary fixation requires a smaller skin incision and minimal soft tissue dissection which results in a cosmetically acceptable scar and greater patient satisfaction. There is also less hardware prominence and a lower re-fracture rate when compared with plate fixation.[25]

The majority of intramedullary devices do, however, require removal after fracture union, but this can be achieved via a small skin incision, and some centres even remove the nail under local anaesthetic.[4]

Controversies regarding the management of displaced, closed midshaft clavicle fractures in adults are evident from the volume of literature available on this topic. The functional and patient-orientated outcomes of management of these fractures in skeletally immature patients, however, remain to be adequately investigated.[26]

Aim

The purpose of the study was to retrospectively evaluate the clinical outcomes of managing displaced midshaft clavicle fractures in adolescents using titanium elastic nails.

Materials and methods

The study was designed as a single-institution, retrospective chart review of a series of adolescent patients between the ages of 12 to 17 years who sustained middle-third clavicle fractures. All patients were treated surgically by open reduction and internal fixation with intramedullary placement of a titanium elastic nail between January 2008 and July 2015.

Approval was obtained from the Ethics Committee of the Faculty of Health Science, University of the Free State.

Convenience sampling was used and all patients who met the inclusion and exclusion criteria were included for review.

Inclusion criteria:

- 12 to 17 years of age
- Fracture of the middle third of the clavicle (Allman group I)[27]
- 100% fracture displacement[28]
- Minimum of 15 mm shortening[28]
- Skin tenting/tethering/threatened skin breakdown
- Neurovascular compromise attributed to the fracture
- Floating shoulder
- Poly-trauma patient
- Bilateral clavicle fracture

Exclusion criteria:

- Fracture comminution or displaced butterfly fragment at the fracture site

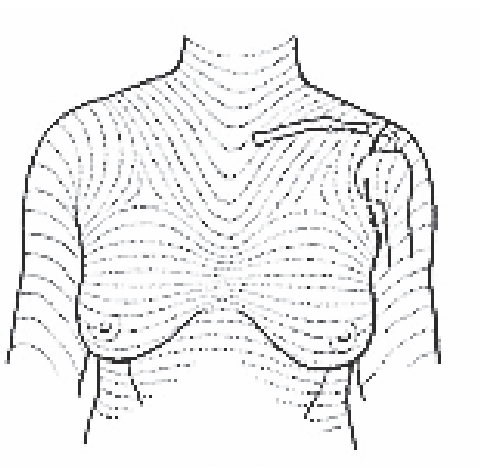

Figure 2. Illustration of Langer's lines

Surgical technique

All patients were placed in a shoulder sling and operated on the next available theatre list within three days of presentation.

All patients received prophylactic antibiotics pre-operatively and a general anaesthetic. Patients were then positioned supine on a radiolucent operating table with a folded operative drape placed between the scapulas.

A ± 2 cm incision was made over the medial end of the fractured clavicle and a second incision of ± 3cm was made over the fracture site, both along Langer's lines (*Figures 1 and 2*).

The entry point for the nail was then made 1.5 cm from the sternoclavicular joint using an awl, so as to avoid the medial physis of the clavicle (*Figure 3*).

The medial and lateral ends of the fracture were prepared while taking care to keep soft tissue stripping of the clavicle to a minimum.

A titanium elastic nail (De Puy, Synthes, Paoli, PA, USA), selected based on the diaphyseal diameter, was mounted on a Jacob's chuck. The fracture ends were aligned under direct vision and the titanium elastic nail inserted by hand in an unreamed fashion from medial to lateral across the fracture site under image intensifier guidance (*Figure 4*).

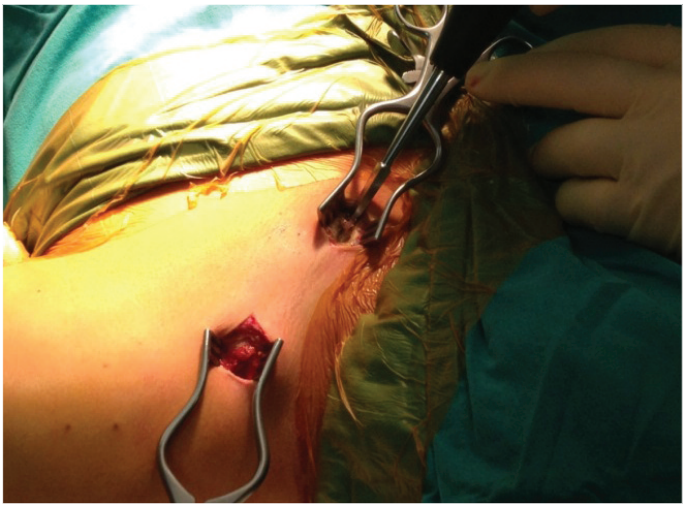

Figure 3. Entry point made with an awl 1.5 cm from sternoclavicular joint

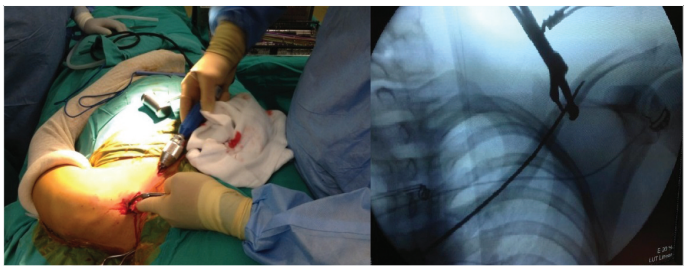

Figure 4. Titanium elastic nail insertion across the fracture site under image intensifier guidance

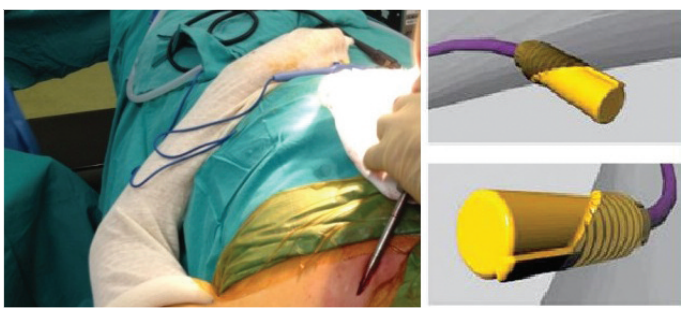

Figure 5. Placement of an end cap over the exposed medial nail end

The medial end of the nail was cut close to the cortex to minimise soft tissue irritation yet leaving sufficient length for extraction later. An end cap was placed over the exposed end and gently screwed into the entry point[23] (*Figure 5*).

The wound was closed in two layers with specific attention given to approximating the deltopectoral fascia and platysma muscle. The skin was then approximated using an absorbable sub-cuticular suture and the wound dressed.

Post-operatively, patients were immobilised in a sling and instructed to avoid overhead abduction and heavy lifting for the first six weeks. Patients then attended scheduled follow-up visits at two, six and 12 weeks post-operatively.

The wound was assessed by the surgeon at the two-week visit. Full range of motion of the affected shoulder was commenced at six weeks. The nail was removed in all cases and a full return to previous activity and sport was allowed six weeks after nail removal.

Assessment

Assessment comprised a review of the hospital records to ascertain the total time each patient spent in theatre and surgical notes reviewed to determine if any surgical complications occurred.

Radiological assessment of the affected clavicle was done by the surgeon using a standard anterior-posterior, and 15° cranial oblique view taken day one post-operatively to assess nail placement and fracture reduction, and again at six and 12 weeks to assess the rate of progression to union. Radiological union was defined as visible bridging callus or absent fracture line. Clinical union was described as no bony tenderness on clinical examination.

Each patient was evaluated clinically by the surgeon at the 12-week follow-up visit. Both the affected and unaffected arms were evaluated and scored according to the criteria as set out in the shoulder score of Constant and Murley (*Appendix 1*).[29] Data gained for both the affected and unaffected arms (maximum 100 points) were compared and the difference between their values documented.

Clinical evaluation of the surgical scar for cosmetic result was done both by the surgeon and the patient's parents at the 12-week visit. The result was graded as excellent if the scar was visible only on close inspection, satisfactory if the scar was easily noticeable and poor if there was any keloid formation.

Patient notes were reviewed to assess whether any complications or adverse events were experienced.

Secondary objectives that were evaluated included the mechanism of injury, sex, side fractured and size of titanium elastic nail inserted.

Statistical analysis

Functional outcome as indicated by the difference in Constant shoulder scores between the affected and unaffected limbs were statistically analysed by the Department of Biostatistics, UFS, using appropriate descriptive statistics.

Differences between the affected and unaffected limb were compared by means of Students' t-tests.

Categorical data like sex and side affected were reported using frequencies and percentages. Medians and means were used as the measures of centrality, and standard deviations and quartiles as indicators of spread.

Results

During the study period, 18 clavicle fractures in 18 patients were managed with intramedullary titanium elastic nails. Three patients had comminuted fractures and were excluded from the study. Data pertaining to theatre time and date of nail removal was unobtainable for four patients. Nine right and six left clavicle fractures were assessed. There were 12 male and three female patients. The mean age of the patients was 14.9 years (range 13–17 years).

Appendix 1: Data capture sheet: Shoulder Score of Constant and Murley

Constant Shoulder Score

Clinician's name (or ref) - - - - - - - - - - - - - - -

Patient's name (or ref) - - - - - - - - - - - - - - -

Answer all questions, selecting just one unless otherwise stated

During the past 4 weeks.....

1. Pain	2. Activity Level (check all that apply)	
○ Severe	○ yes ○ no	Unaffected Sleep
○ Moderate	○ yes ○ no	Full Recreation/Sport
○ Mild	○ yes ○ no	Full Work
○ None		

3. Arm Positioning	4. Strength of Abduction [Pounds]	
○ Up to Waist	○ 0	○ 13-15
○ Up to Xiphoid	○ 1-3	○ 15-18
○ Up to Neck	○ 4-6	○ 19-21
○ Up to Top of Head	○ 7-9	○ 22-24
○ Above Head	○ 10-12	○ >24

RANGE OF MOTION

5. Forward Flexion	6. Lateral Elevation
○ 31-60 degrees	○ 31-60 degrees
○ 61-90 degrees	○ 61-90 degrees
○ 91-120 degrees	○ 91-120 degrees
○ 121-150 degrees	○ 121-150 degrees
○ 151-180 degrees	○ 151-180 degrees

7. External Rotation	8. Internal Rotation
○ Hand behind Head, Elbow forward	○ Lateral Thigh
○ Hand behind Head, Elbow back	○ Buttock
○ Hand to top of Head, Elbow forward	○ Lumbosacral Junction
○ Hand to top of Head, Elbow back -	○ Waist (L3)
○ Full Elevation	○ T12 Vertebra
	○ Interscapular (T7)

Grading the Constant Shoulder Score
(Difference between normal and Abnormal Side)

>30 Poor 21-30 Fair 11-20 Good <11 Excellent

The Constant Shoulder Score is ☐

Table I: Summary of patients

Age	Sex	Mechanism of injury	Side injured	Nail size (mm)	Constant shoulder score	Time to fracture union (weeks)	Scar	Theatre time (minutes)	Nail removed (days)	Nail removal theatre time (minutes)
15	M	Rugby	Left	2	8	10	S	64	87	51
13	M	Rugby	Right	2	10	10	S	58	93	42
17	M	Rugby	Left	2	12	20	E	85	172	26
15	M	Rugby	Right	2.5	6	11	E	87	84	32
17	M	Rugby	Right	2.5	9	12	S	–	–	–
15	M	MVA	Right	2	10	12	E	77	330	106
14	M	MVA	Left	2	10	8	S	–	–	–
14	M	MVA	Right	2	10	8	S	–	–	–
13	F	Horse	Right	2	7	12	S	192	97	43
15	F	Horse	Left	1.5	5	8	E	78	126	39
16	M	Motorcycle	Right	2	7	10	S	97	114	31
16	F	Stairs	Left	2	10	12	S	32	123	31
17	M	Cycle	Left	2	6	10	S	60	107	26
14	M	Pole vault	Right	2	9	8	S	–	–	–
13	M	Red Rover	Right	2	6	12	E	68	126	31

Of the 15 fractures, ten were caused by a high-energy mechanism (*Table I*), most commonly involving rugby injuries (33%), motor vehicle accidents (20%) and falls from a horse (13.3%).

The indication for surgery in 13 patients was shortening of more than 15 mm while two patients had associated injuries which included a coracoid process fracture and ipsilateral femur fracture. No open clavicle fractures were reported.

The average time the patients spent in theatre from being wheeled in until leaving the theatre post-surgery was 81.6 minutes (range 32–192). After the poly-trauma patient that required concomitant open reduction and internal fixation (ORIF) of the coracoid process (192 minutes) was excluded, the average theatre time improved to 70.6 minutes.

The average size of the titanium elastic nail inserted was 2 mm (range 1.5–2.5 mm).

The surgical scars of five (33.33%) of the patients were assessed to be excellent while ten (66.66%) patients achieved a satisfactory result (*Figure 6*). No patient was assessed as having a poor cosmetic result.

The difference in Constant shoulder scores (value out of 100) between the injured and uninjured arms at the 12-week follow-up was below 11 for all but one patient (*Figure 7*). The mean value of these differences was 8.33 (range 5–12) which indicated an excellent overall result according to Constant and Murley (*Appendix 1*).

Fourteen of the 15 fractures (93.33%) achieved radiological and clinical union by 12 weeks post-operatively with an average time to union of 10.87 weeks (range 8–20 weeks) (*Figure 8*).

The Spearman correlation coefficients for Constant shoulder score and time to union was 0.5292 and indicated a poor relationship between these two variables.

Two complications occurred. There was one iatrogenic perforation of the postero-lateral cortex of the clavicle which was noted on the post-operative cranial oblique view radiograph and the nail was repositioned the following day (*Figure 9*).

One patient re-injured the operated clavicle one week after the initial surgery resulting in a haematoma at the fracture site. The haematoma was drained in theatre and work-up for infection yielded a negative result.

Figure 6. Clinical photo of a patient with a satisfactory scar at the 12-week follow-up visit

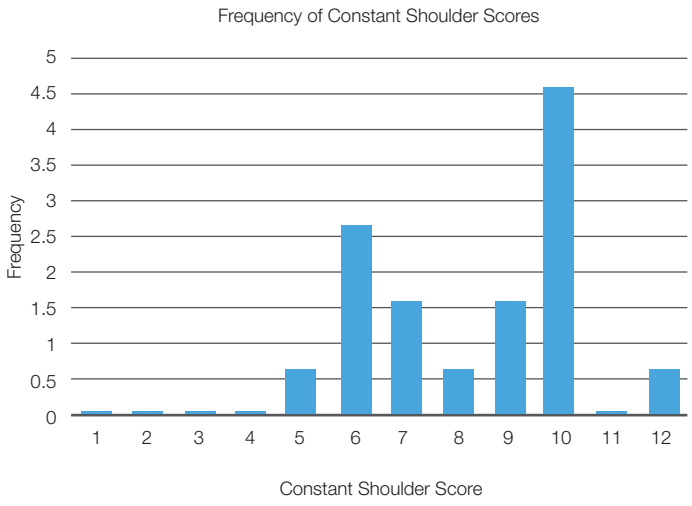

Figure 7. Frequency of Constant shoulder scores

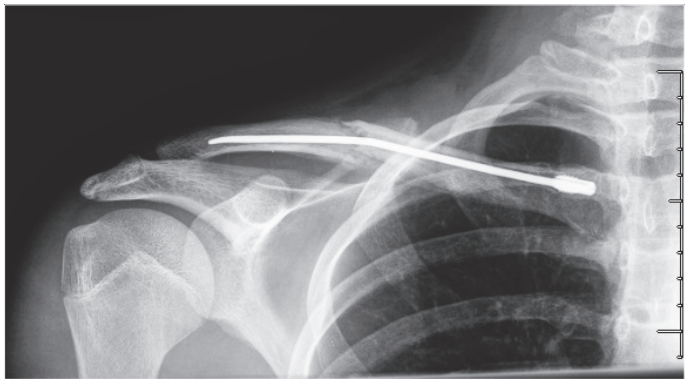

Figure 8. Radiograph at the 12-week follow-up showing healing callus at the fracture site

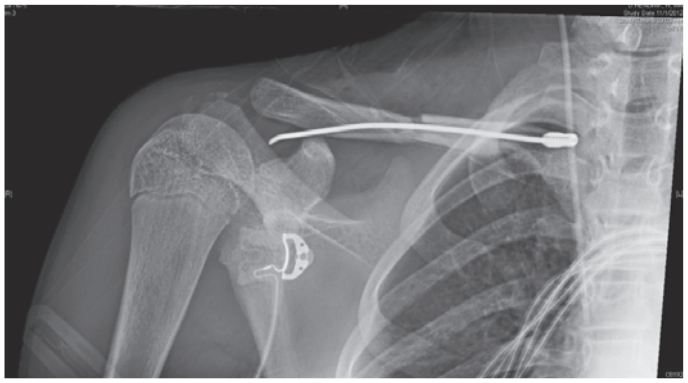

Figure 9. Post-operative cranial oblique radiograph showing nail penetration through posterior cortex

No patients reported irritation due to the protruding medial end of the nail despite the prominence of the end cap noted post-operatively (*Figure 10*).

No nail breakages occurred in this series. The nail was removed in all patients at a mean of 18.9 weeks (range 12–47 weeks) after the initial surgery. There was no shortening at the fracture site and no clinical or radiological evidence of implant migration at the time of nail removal. The average theatre time for nail removal was 41.6 minutes (range 26–106 minutes). No re-fractures occurred following nail removal.

Figure 10. Medial nail prominence evident at 12-week follow-up visit (arrow)

Discussion

This series shows that intramedullary fixation of displaced, midshaft clavicle fractures in adolescents with titanium elastic nails is an effective treatment modality.

The technique used in this series was first described by Jubel *et al*. in 2003.[23] The technique is not associated with a steep learning curve and is less than that required for other devices.[30] The theatre time is comparable to that required for both plating and other intramedullary techniques and better if one considers that our results were skewed by the one patient who required a simultaneous ORIF of the coracoid process.

In our study, all the fractures united and the Constant shoulder scores for the affected shoulder were excellent in all but one case, which is comparable to previously reported values in the literature.[21,24,31]

Hill *et al*.[10] showed that displaced fractures with shortening of 20 mm or more was predictive of higher non-union or symptomatic malunion rates. None of the fractures in our series healed with shortening of the clavicle. We have identified possible reasons for this. First, comminuted fractures were excluded from our study as Smekal *et al*.[24] showed that they were unable to restore clavicle length in comminuted fractures due to telescoping of the nail. Secondly, the end of the titanium elastic nail is wedged as far as possible into the lateral fragment of the clavicle under image intensifier guidance in two planes, taking care not to perforate the thin dorsolateral cortex. Thirdly, the use of an end cap over the medial end of the nail serves to limit medial migration of the nail and also increases rotatory stability of the implant.[32]

Chen *et al*.[33] reported that the medullary cavity of the adult clavicle (mean age 38.3 years) ranges from 2.8 to 3.0 mm in most patients and that a 2.5 mm nail is most commonly used. In our study, the average nail size was 2.0 mm which may be due to the younger age (mean age 14.9 years) of the patients in our series. Every attempt should be made to use a nail with a diameter more than half that of the canal as the middle of the clavicle is subjected to considerable tension, bending and torsional forces. Pain relief following internal fixation may also result in premature use of the arm that can subject the intramedullary device to significant stresses.[31]

In this series, open reduction was done for all of the fractures through a small vertical incision at the fracture site utilising a minimally invasive approach. This approach varies from those in the literature where, often, an initial attempt is made at closed reduction. Despite this, 50–85% of these cases eventually required an open reduction.[24]

We do not consider open reduction of the fracture to be disadvantageous as we still achieved a 100% union rate with no injury to the neurovascular bundle, though further review with a larger sample size is warranted.

Migration of the intramedullary implant has been reported in a number of studies.[24,31,32,34,35] Smekal *et al*. reported that 23% of their patients had medial nail protrusion.[24] Medial protrusion of the nail, though evident in most cases in our series, was not significant enough to necessitate removal of the hardware. Solutions to this common problem in the literature include the use of an end cap (Frigg *et al.*);[32] changing the insertion point from the centre of the medial clavicle to the lower bony edge (Mueller *et al.*);[31] or using a retrograde as opposed to an antegrade technique.[30,37]

With regard to the ongoing debate as to which operative technique is most appropriate, in a retrospective analysis between titanium elastic nails and reconstruction plates, Chen *et al*. showed a significantly shorter time to union with the nail group. The mean time to union in our series was the same as that of Chen *et al*. and comparable with that of conventional plating.[33,35,36,38]

In a 2015 meta-analysis of plate versus intramedullary fixation of midshaft clavicle fractures, Zhang *et al*. showed that intramedullary fixation was associated with a reduced surgery time, smaller incision, faster union rate and better shoulder function at six months.

Fewer metal-ware complications and re-fracture after metal-ware removal was also noted.[39] Other studies have shown that pain relief also tends to be better than with plating techniques or non-operative treatment[40] and allows for a more rapid return to sport.[23]

Assessment of the surgical scars in our series was done at the 12-week follow-up date. The outcomes can be expected to improve with the normal reparative process that occurs over time and warrants review of the scar again at one year post-surgery.

The two complications encountered in our series were minor and both were successfully managed. Lateral perforation of the cortex by the nail was only assessed post-operatively in our series, and we have subsequently modified our operative protocol to include assessing the final nail position intra-operatively using an image intensifier range from the maximum possible cranial-oblique view to a caudal-oblique view.

In our study, we opted to remove the nail in all cases, which differed from the existing literature, indicating wide practice variability.[2,11,38]

Numerous reports in the literature have proven a lower incidence of re-fracture following removal of an intramedullary device compared to that following plate removal.[25,39] The fact that no patients sustained re-fracture in our series may be attributed to our limited sample size and short period of follow-up. Despite this, all patients who participate in activities with high-energy mechanisms of injury should be warned about returning to activity too early following removal of the nail.

A final observation from this series is that despite its relatively long duration (90 months), only 15 patients met the criteria for inclusion into this study. This suggests that this type of injury is rarer than initially expected among adolescents, but further review with a larger sample size is needed.

The main limitations of this series include its retrospective design and limited sample size. Further drawbacks are the lack of patient-reported outcomes and short follow-up. All the patients were reviewed by the same surgeon who performed the initial surgery and hence the clinical examination may have been biased. Positives include the fact that all patients were operated by the same surgeon and exposed to the same operative environment.

Conclusion

Adolescents have unique characteristics distinguishing them from young children and adults, and as such, should be managed as a distinctly separate patient group.

Titanium elastic intramedullary nailing of displaced, uncomminuted, midshaft clavicle fractures in adolescents is a safe, minimally invasive and reliable surgical technique. The technique produces good cosmetic and functional results, and should be considered as an alternative to plate fixation or non-operative treatment.

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Compliance with ethics guidelines

Approval for the study was obtained from the Ethics Committee of the Faculty of Health Science, University of the Free State. The content of this article is solely the work of the authors.

References

1. Kashif Khan LA, Bradnock TJ, Scott C, Robinson CM. Fractures of the clavicle. *J Bone Joint Surg Am.* 2009;**91**:447-60.
2. Van der Have KL, Perdue AM, Caird MS, Farley FA. Operative versus nonoperative treatment of midshaft clavicle fractures in adolescents. *J Pediatr Orthop.* 2010;**30**(4): 307-12.
3. Postacchini F, Gumina S, De Santis P, Albo F. Epidemiology of clavicle fractures. *J Shoulder Elbow Surg.* 2002;**11**(5):452-56.
4. Pandya NK, Namdari S, Hosalkar HS. Displaced clavicle fractures in adolescents: Facts, controversies, and current trends. *J Am Acad Orthop Surg.* 2012;**20**:498-505.
5. Neer CS. Nonunion of the clavicle. *J Am Med Assoc.* 1960;**172**:1006-11.
6. Rowe CR. An atlas of anatomy and treatment of midclavicular fractures. *Clin Orthop Relat Res.* 1968;**58**:29-42.
7. Zlowodzki M, Zelle BA, Cole PA, Jeray K, McKee MD. Evidence-Based Orthopaedic Trauma Working Group: Treatment of acute midshaft clavicle fractures: Systematic review of 2144 fractures. On behalf of the Evidence-Based Orthopaedic Trauma Working Group. *J Orthop Trauma.* 2005;**19**(7):504-507.
8. McKee MD, Pedersen EM, Jones C, *et al*. Deficits following nonoperative treatment of displaced midshaft clavicular fractures. *J Bone Joint Surg Am.* 2006;**88**:35-40.
9. Ledger M, Leeks N, Ackland T, Wang A. Short malunions of the clavicle: An anatomic and functional study. *J Shoulder Elbow Surg.* 2005;**14**(4):349-54.
10. Hill JM, McGuire MH, Crosby LA. Closed treatment of displaced middle third fractures of the clavicle gives poor results. *J Bone Joint Surg Br.* 1997;**79**(4):537-39.
11. Kubiak R, Slongo T. Operative treatment of clavicle fractures in children: a review of 21 years. *J Pediatr Orthop.* 2002;**22**(6):736-39.
12. Silva SR, Fox J, Speers M, *et al*. Reliability of measurements of clavicle shaft fracture shortening in adolescents. *J Pediatr Orthop.* 2013;**33**(3):e19-e22.
13. Carry PM, Koonce R, Pan Z, Polousky JD. A survey of physician opinion: adolescent midshaft clavicle fracture treatment preferences among POSNA members. *J Pediatr Orthop.* 2011;**31**(1):44-49.
14. McGraw MA, Mehlman CT, Lindsell CJ, Kirby CL. Postnatal growth of the clavicle: birth to 18 years of age. *J Pediatr Orthop.* 2009;**29**(8):937-43.
15. Escola A, Vainionpaa S, Myllynen P, Patiala H, Rokhanen P. Outcome of clavicular fracture in 89 patients. *Ach Orthop Trauma Surg.* 1986;**105**:337-38.
16. Andermahr J, Jubel A, Elsner A, *et al*. Malunion of the clavicle causes significant glenoid malposition: A quantitative anatomic investigation. *Surg Radiol Anat.* 2006;**28**(5):447-5
17. Matsumura N, Ikegami H, Nakamichi N, *et al*. Effect of shortening deformity of the clavicle on scapular kinematics: A cadaveric study. *Am J Sports Med.* 2010;**38**(5):1000-1006.
18. McKee MD, Wild LM, Schemitsch EH. Midshaft malunion of the clavicle. *J Bone Joint Surg Am.* 2003;**85**(5):790-97.
19. Nordqvist A, Petersson CJ, Redlund-Johnell I. Mid-clavicle fractures in adults: End result study after conservative treatment. *J Orthop Trauma.* 1998;**12**(8):572-76.
20. Lazarides S, Zafiropoulos G. Conservative treatment of fractures at the middle third of the clavicle: The relevance of shortening and clinical outcome. *J Shoulder Elbow Surg.* 2006;**15**(2):191-94.
21. Canadian Orthopaedic Trauma Society: Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures: A multicenter, randomized clinical trial. *J Bone Joint Surg Am.* 2007;**89**(1):1-10.
22. Boehme D, Curtis R, De Haan J, Kay S, Young D, Rockwood D. Nonunion of fractures of the midshaft of the clavicle: Treatment with a modified Hagie intramedullary pin and autogenous bone grafting. *The J Bone Joint Surg.* 1991;**73A**(8):1219-26.
23. Jubel A, Andemahr J, Schiffer G, Tsironis K, Rehm KE. Elastic stable intramedullary nailing of midclavicular fractures with a titanium nail. *Clin Orthop Relat Res*. 2003;**408**:279-85.
24. Smekal V, Irenberger A, Struve P, Wambacher M, Krappinger D, Kralinger FS. Elastic stable intramedullary nailing versus nonoperative treatment of displaced midshaft clavicular fractures: A randomized, controlled, clinical trial. *J Orthop Trauma.* 2009;**23**(2):106-12.
25. Wang K, Dowrick A, Choi J, Rahim R, Edwards E. Postoperative numbness and patient satisfaction following plate fixation of clavicular fractures. *Injury.* 2010;**41**(10):1002-1005.
26. Namdari S, Ganley TJ, Baldwin K, *et al*. Fixation of displaced midshaft clavicle fractures in skeletally immature patients. *J Pediatr Orthop.* 2011;**31**(5):507-11.
27. Allman FL Jr. Fractures and ligamentous injuries of the clavicle and its articulation. *J Bone Joint Surg Am.* 1967;**49**:774-84.
28. Robinson CM, Court-Brown CM, McQueen MM, Wakefield AE. Estimating the risk of non-union following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg Am.* 2004;**86**(7):1359-65.
29. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res.* 1987;**(214)**:160-64.
30. King PR, Ikram A, Lamberts RP. The treatment of clavicular shaft fractures with an innovative locked intramedullary device. *J Shoulder Elbow Surg.* 2015;**24**(1):e1-6.
31. Mueller M, Rangger C, Striepens N, Burger C. Minimally invasive intramedullary nailing of midshaft clavicular fractures using titanium elastic nails. *J Trauma.* 2008;**64**:1528-34.
32. Frigg A, Rillman P, Perren T, Gerber M, Ryf C. Intramedullary nailing of clavicular midshaft fractures with the titanium elastic nail: Problems and complications. *Am J Sports Med.* 2009;**37**:352-59.
33. Chen YF, Zeng BF, Chen YJ, Wang HM, Xue JF, Chai YM, *et al*. Clinical outcomes of midclavicular fractures treated with titanium elastic nails. *Can J Surg.* 2010;**53**(6): 379-84.
34. Wijdicks FJG, Houwert RM, Millet PJ, Verleisdonk EJ, Van der Meijden OA. Systemic review of complications after intramedullary fixation for displaced midshaft clavicle fractures. *Can J Surg.* 2013;**56**(1):58-64.
35. Liu HH, Chang CH, Chia WT, Chen CH, Tarng YW, Wong CY. Comparison of plates versus intramedullary nails for fixation of displaced midshaft clavicular fractures. *J Trauma.* 2010;**69**;E82-7.
36. Van der Meijden OA, Houwert RM, Hulsmans M, Wijdicks FJG, *et al*. Operative treatment of dislocated midshaft clavicular fractures: plate or intramedullary nail fixation? *J Bone Joint Surg Am.* 2015;**97**:613-19.
37. Millet PJ, Hurst JM, Horan MP, Hawkins RJ. Complications of clavicle fractures treated with intramedullary fixation. *J Shoulder Elbow Surg.* 2011;**20**:86-91.
38. Mehlman CT, Yihua G, Bochang C, Zhigang W. Operative treatment of completely displaced clavicle shaft fractures in children. *J Pediatr Orthop.* 2009;**29**(8):851-55.
39. Zhang B, Zhu Y, Zhang F, Chen W, Tian Y, Zhang Y. Meta-analysis of plate fixation versus intramedullary fixation for the treatment of mid-shaft clavicle fractures. *Scand J Trauma Resusc Emerg Med.* 2015;**23**:27.
40. Chen YF, Wei HF, Zhang C, Zeng BF, Zhang CQ, Xue JF, *et al*. Retrospective comparison of titanium elastic nail (TEN) and reconstruction plate repair of displaced midshaft clavicle fractures. *J Shoulder Elbow Surg*. 2012;**21**(4):495-501.