Displaced Midshaft Clavicle Fractures in Adolescents: Outcomes with Flexible Intramedullary Nail Fixation

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ABSTRACT

Introduction: This study reports radiological and functional outcomes, surgical times, and intraoperative radiation exposure in patients aged 10–18 years with simple displaced midshaft clavicle fractures treated with flexible intramedullary nails, stratified by reduction type (open vs closed). **Materials and Methods:** Retrospective analysis of prospectively collected electronic medical record data. Adolescents with acute, displaced, noncomminuted clavicular shaft fractures treated with flexible intramedullary nails and with 1-year follow-up were included. **Results:** Sixteen patients were included (mean age, 14 years). Mean time from injury to surgery was 9.3 days. Seven patients required open reduction, mainly when delays exceeded 11 days. Procedures using closed reduction had longer intraoperative radiation exposure times. Fracture union occurred by 6 weeks. The Constant–Murley score improved from 83.35 at 6 weeks to 95.88 at 1 year. Osseous adaptation was observed in some patients, with an increase in clavicular diameter. **Conclusions:** Flexible intramedullary nailing is an acceptable option for treating simple displaced midshaft clavicle fractures in adolescents. When time from injury exceeds 10 days, open reduction should be considered to reduce intraoperative radiation exposure.

Keywords: Clavicle fracture; intramedullary nail.
Level of Evidence: IV

Fracturas diafisarias desplazadas de clavícula en adolescentes. Resultados con clavos elásticos endomedulares

RESUMEN

Introducción: El objetivo de este estudio fue evaluar los resultados obtenidos en adolescentes con fractura completas simples desplazadas del tercio medio de la clavícula tratados con clavos elásticos endomedulares, la evolución clínico-radiológica, la complicaciones, la duración del procedimiento y de la exposición a la radiación según el tipo de reducción. **Materiales y Métodos:** Análisis retrospectivo de datos recopilados prospectivamente de las historias clínicas electrónicas. Se incluyó a adolescentes con fracturas agudas desplazadas no conminutas de la diáfisis clavicular que habían sido tratados con clavos endomedulares flexibles y tenían un seguimiento de 1 año. **Resultados:** El estudio incluyó a 16 pacientes. La edad promedio era de 14 años. El tiempo promedio hasta la cirugía fue de 9.3 días. Siete pacientes necesitaron reducción abierta, principalmente debido a retrasos superiores a 11 días. El tiempo de exposición a la radiación intraoperatoria fue mayor en los procedimientos que incluyeron reducciones cerradas. La consolidación ósea ocurrió en 6 semanas. El puntaje de la escala de Constant-Murley mejoró de 83,35 a las 6 semanas a 95,88 al año. Se observó una adaptación ósea en algunos pacientes, con un aumento del diámetro de la clavícula. **Conclusiones:** Los clavos endomedulares son una alternativa aceptable para el tratamiento de las fracturas simples desplazadas del tercio medio de la clavícula en la población adolescente. Para reducir el tiempo de exposición a la radiación intraoperatoria, es recomendable considerar la reducción abierta cuando el tiempo de evolución sea >10 días.

Palabras clave: Fractura de clavícula; clavo endomedular.
Nivel de Evidencia: IV

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INTRODUCTION

Clavicle fractures account for about 15% of fractures in childhood and adolescence, most commonly at the midshaft.[1,2] In this population, nonoperative care remains the first-line treatment because simple fractures rarely progress to nonunion and even malunions often remodel owing to late medial and lateral physeal closure.[3,4] However, remodeling potential depends on skeletal (bone) age: approximately 80% of clavicular growth is achieved by age 9 in girls and by age 12 in boys, so remodeling after adolescence is limited.[5] Together with recent reports showing poor tolerance of nonunion and malunion in this group, especially in athletically active adolescents, this has shifted some indications toward reduction and internal fixation.[1,4,6-9]

Loss of bone length is a common complication of conservative treatment and can significantly impair function.[3,10-15] Plate-and-screw fixation is widely used but carries risks such as neurovascular injury and peri-implant fracture, particularly in children and adolescents.[3,11,12,16,17] These concerns have increased interest in elastic intramedullary nailing in this population, given lower complication rates.

The aim of this study was to report outcomes in adolescents treated with flexible intramedullary nails, including clinical and radiographic evolution, complications, and the effect of approach and implant diameter on operative time and fluoroscopy time.

MATERIALS AND METHODS

We performed a retrospective study of patients operated on between June 2021 and June 2023 by the same surgeon at two clinics. Inclusion criteria: complete midshaft clavicle fractures (Allman Group I), simple closed traumatic fractures with >2 cm displacement (overlap/shortening or diastasis) in any radiographic plane (Robinson type 2B1) despite figure-of-eight bandage or sling, age 10–18 years.[18] Exclusion criteria: fractures >3 weeks old; comminuted fractures (Robinson 2B2); open, pathologic, or insufficiency fractures; buckle or greenstick fractures; prior clavicle fracture or refracture; and <1 year of clinical–radiographic follow-up.

The variables analyzed were: age; complications; need for an incision at the fracture site (open reduction); days to surgery; operative time and intraoperative fluoroscopy time; nail diameter; Constant–Murley score (6 weeks, 3 months, 1 year); and radiographic evolution (union and adaptive changes) at 1 year.

Because the minimal clinically important difference for Constant–Murley in diaphyseal clavicle fractures is unknown, we referenced the general shoulder literature value of 10.4 points.[19]

Surgical Technique

Patients were positioned beach-chair with a Philadelphia collar and eye protection. Combined anesthesia (sedation plus brachial plexus block) and antibiotic prophylaxis were administered per protocol. The operative field (hemithorax and affected upper limb) was prepared with double preoperative washing using 4% chlorhexidine soap and antisepsis with chlorhexidine digluconate plus alcohol (20 mg chlorhexidine digluconate and 0.49 ml ethyl alcohol [Laboratorio Bohm S.A., Madrid, Spain]); sterile drapes and an arm holder (Trimano Fortis® Support Arm, Arthrex®) were used. A 1.5-cm incision was made along Langer's lines, 3 cm medial to the fracture site. Closed reduction and internal fixation with a flexible intramedullary nail (Stryker® T2 Kids; titanium Ti-6Al-4V ELI, ASTM F136; ISO 5832-3; Type II anodized; laser-etched diameter bands; diameters 1.5, 1.75, 2.0, 2.25 mm) were performed under direct fluoroscopy with the C-arm contralateral to the operative side. Nail diameter was selected at ~40% of the intramedullary canal measured on preoperative AP radiographs; if not exact, the larger diameter was chosen to avoid an overly flexible construct. Nails were inserted straight (without prebending). An entry portal was created in the anterior cortex 4–6 cm medial to the fracture with a 3.2-mm awl and soft-tissue cannula. After closed reduction with two reduction forceps, the chosen nail was advanced under fluoroscopy using a universal T-handle driver. The nail was cut with a pin cutter and seated into cancellous bone of the lateral fragment using an impactor and slotted hammer, leaving 5–7 mm of the nail proud at the medial fragment cortex. No end caps were used.

If closed reduction could not be achieved (with forceps or terminal bending), a 3-cm incision at the fracture site was made for open reduction.

Postoperative care: sling for 3 weeks (removed for home exercises: passive forward flexion to 90°, external and internal rotation). At 3 weeks, the sling and wound sutures/staples were removed; from week 4, passive and active motion were progressed.

RESULTS

According to the inclusion criteria, nineteen patients underwent elastic intramedullary nailing during the study period; three were excluded (two lost to 1-year follow-up; one refracture operated after 2 months following initial conservative care of an angulated fracture, Robinson 2A2). Sixteen patients were analyzed (Figure 1).

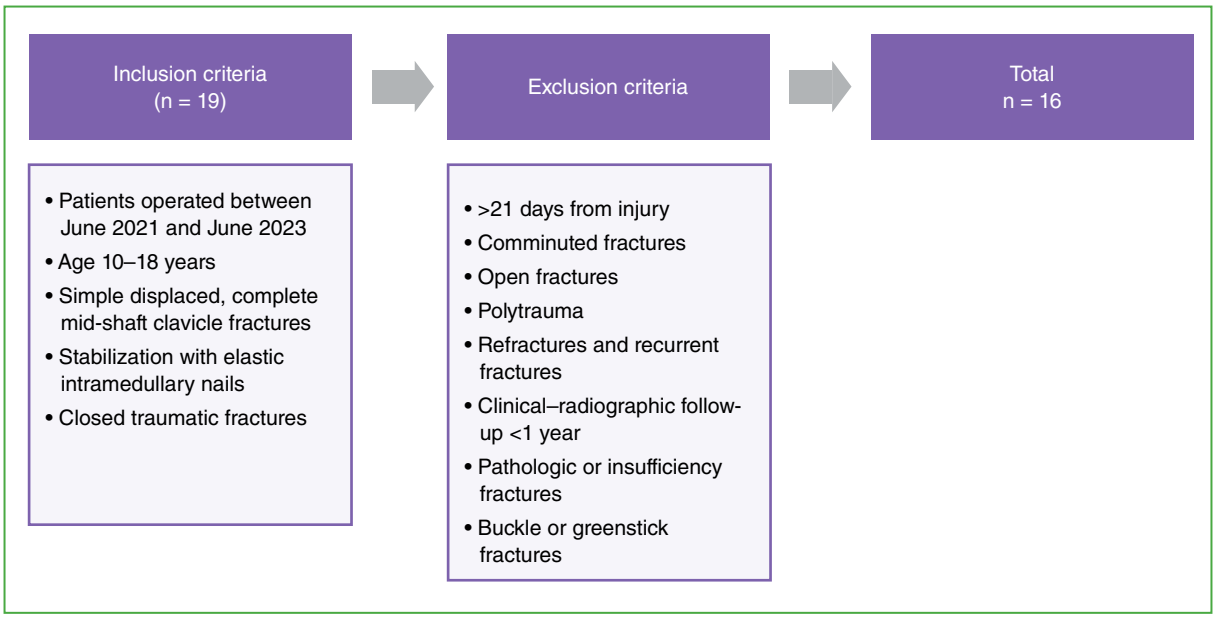

Figure 1. Flowchart showing progression from 19 initially treated patients to the 16 included in the analysis.

Mean age was 14 years (range 13–16; SD 0.99). Mean time from injury to surgery was 9.3 days (range 4–17; SD 4.7). All cases requiring a second approach (n = 7) for open reduction had ≥11 days of evolution, except one 5-day case in which a 1.5-mm nail could not cross the fracture due to excessive flexibility; this did not occur with larger nails in patients operated before day 10. Twelve 2.0-mm nails, four 1.75-mm nails, and one 1.5-mm nail were used.

To evaluate the statistical significance of the difference in times between the two groups, Student's t-test was used for independent samples with unequal variances.

Confidence intervals were calculated using Student's t distribution because the sample size was small (n = 16). The critical t-value corresponding to a 95% confidence level and 15 degrees of freedom is approximately 2.131. Operative and fluoroscopy times by technique are shown in the Table.

Table. Operative and fluoroscopy times by technique.

Category	Mean	Standard deviation	95% confidence interval	Sample size	p
Overall operative time	53 min	± 17.3 min	43.79-62.21 min	16	-
Overall fluoroscopy time	149 s	± 138.5 s	75.21-222.79 s	16	-
Closed reduction					
Operative time	63 min	± 11.3 min	54.30-71.70 min	9	0.005
Fluoroscopy time	240 s	± 122.5 s	145.86-334.14 s	9	0.001
Open reduction					
Operative time	40 min	± 14.4 min	26.71-53.29 min	7	0.005
Fluoroscopy time	33.8 s	± 9.59 s	24.95-42.65 s	7	0.001

There were significant differences in operative time (t = 3.475, p = 0.005) and fluoroscopy time (t = 5.030, p = 0.001)

Clinical and Functional Outcomes

The mean Constant-Murley scale score at 6 weeks was 83.35 (SD ± 3.70), and reached 94.47 (SD ± 2.03) at 3 months, time of medical discharge. This score remained at 95.88 (SD ± 2.49) at 12 months (Figure 2). From month 3 onward, no patient reported pain with activities of daily living, sports, or at end-range motion.

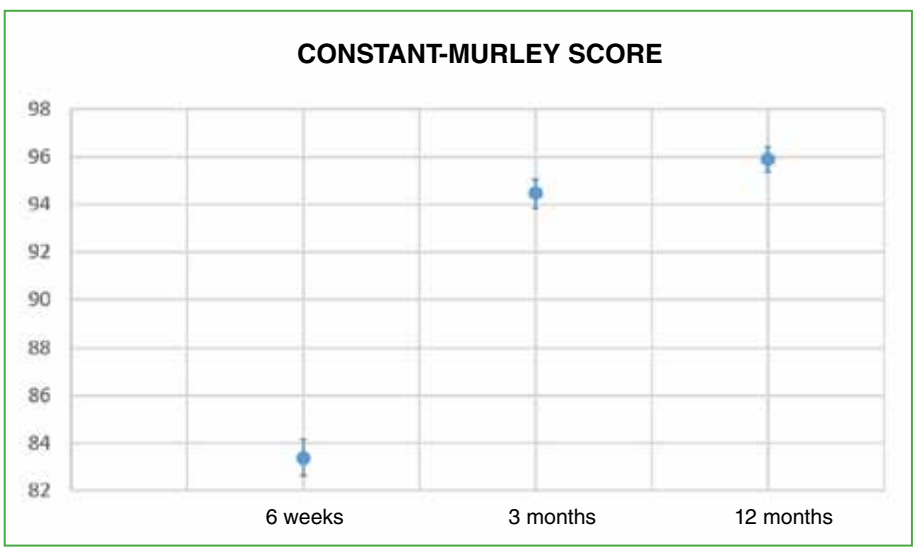

Figure 2. Constant-Murley scores at 6 weeks and at 3 and 12 months.

Bone Union and Adaptive Changes

Mean time to radiographic union, defined as bridging callus across at least two thirds of cortical contact in two views (AP clavicle and 45° caudo-cephalic), was 6 weeks. No hardware removal was required. There were no nonunions, delayed unions, infections, hardware migration, or discomfort associated with it.

Fracture healing and adaptive remodeling were documented at all follow-ups. Although union averaged 6 weeks, an increase in clavicular diameter outside the callus, consistent with periosteal reaction, was noted in 7 cases at 3 months and persisted at 12 months; the clavicle had not returned to preinjury diameter during this interval as part of the bone remodeling process (Figure 3). A single incision was used in 4 cases and a dual-incision approach in 3.

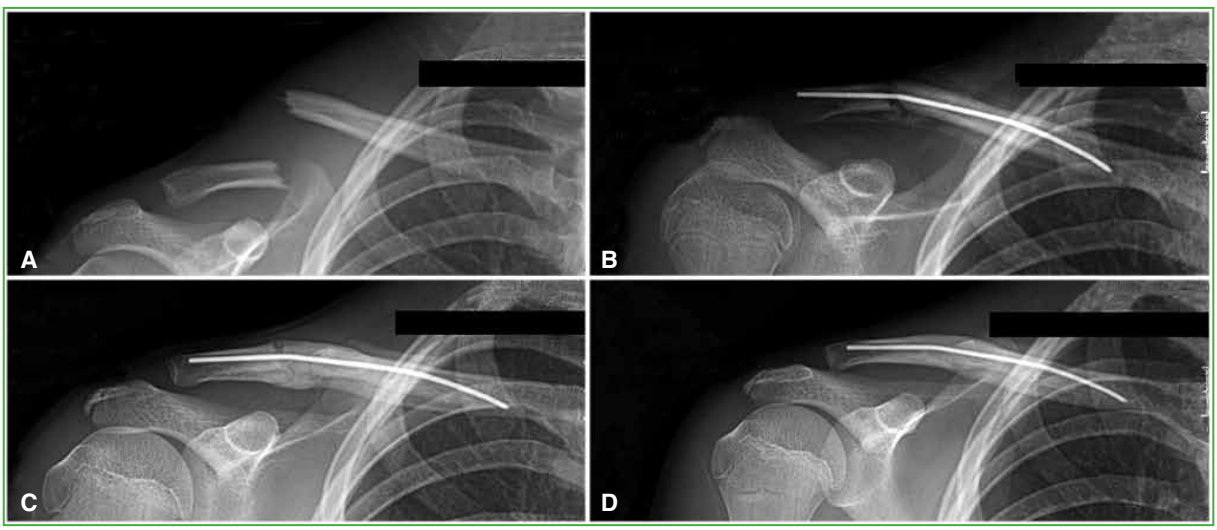

Figure 3. AP radiographs of the right clavicle. **A.** Simple midshaft fracture in a 13-year-old boy. **B.** Two weeks post-op via medial incision. Periosteal reaction not attributable to fracture callus. **C.** Nine weeks: partial ossification of the periosteal reaction with increased cortical thickness. **D.** One year: advanced remodeling without full return to original diameter.

Complications

One patient had nail angulation without breakage or other associated complication (Figure 4). Clinical evolution matched the cohort (Constant–Murley: 84 at 6 weeks; 95 at 6 months; 97 at 12 months).

DISCUSSION

The diameter of the intramedullary nail determined the need to open the fracture site. A 1.5-mm nail often necessitated opening the fracture site due to implant flexibility. Although some authors have performed a second incision and open reduction of the fracture when using nails larger than 2 mm, we have not had the need to use diameters > 2 mm, so this has not been our experience. Rapp et al. placed 2-2.5 mm nails in 24 adolescents.[7] Frigg et al. used 2-3 mm nails in 34 patients; however, the sample included both adolescents and adults.[20] Frye et al. used 2.8-4.5 mm nails in 17 adolescents.[21]

A medial entry facilitates identifying the medial clavicle, eases manipulation compared with a lateral entry, and minimizes risk to adjacent neurovascular structures. A single-incision technique has cosmetic appeal but increases intraoperative fluoroscopy time eightfold, substantially increasing radiation exposure to the patient

and surgical team. While fluoroscopy times have been reported across many orthopedic procedures, specific data for clavicle fractures are lacking.[22] This is relevant, as cumulative radiation exposure increases surgeons' cancer risk.[23,24]

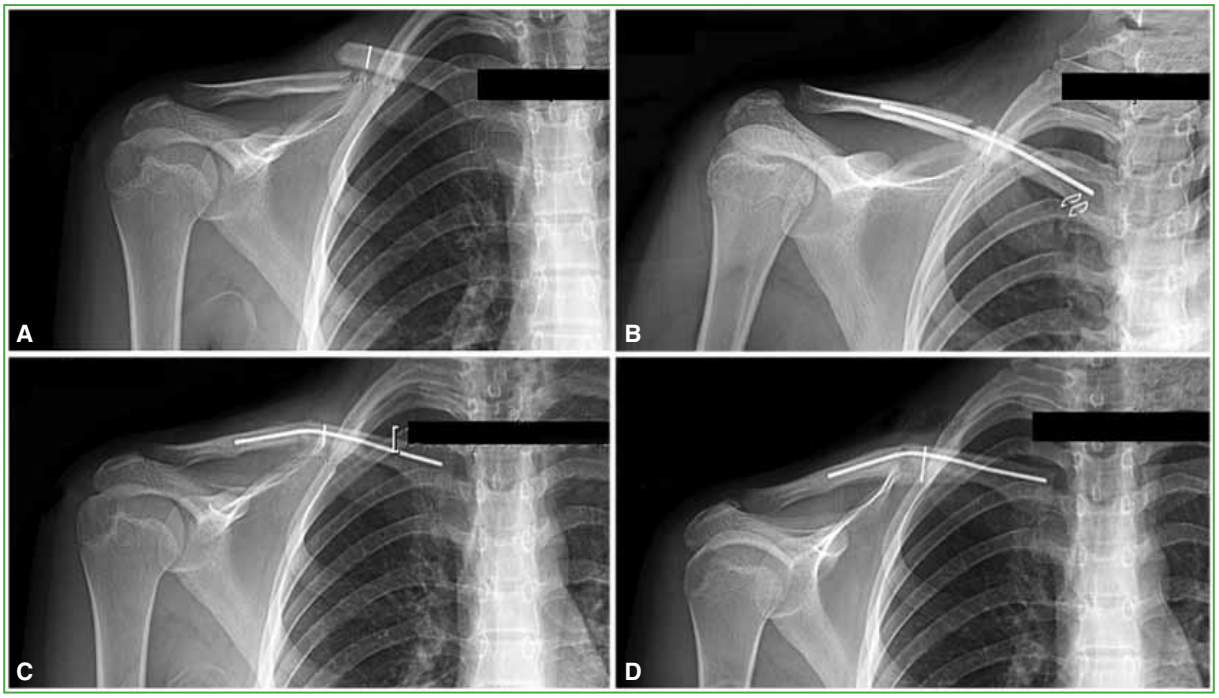

Figure 4. AP radiographs of the right clavicle. **A.** Simple midshaft fracture in a 14-year-old girl. **B.** Immediate post-op (note staples from single medial approach). **C.** Nine weeks: union signs without periosteal reaction, but nail angulation. **D.** One year: advanced adaptive remodeling with mature compact bone formation (predominantly inferior, compression side) and completed union.

With early postoperative shoulder motion after stabilization with intramedullary nailing, a malunion rate of 7% (95%CI 4-11) has been reported.[25]

We observed one nail angulation without malunion (angle <30°), delayed union, or nonunion. This occurred because, at the fracture ends, four times of loads are present: axial load, two bending moments (AP and lateral), and torsion. With a single intramedullary nail, typical in the clavicle's narrow canal, the construct chiefly controls axial load. For this reason, we indicate the use of a sling for 3 weeks (to limit bending) and no forward flexion >90° before week 4 (to limit torsion).

Although traditionally diaphyseal clavicle fractures in children were thought not to progress to nonunion and to remodel completely if malunited, recent evidence shows that painful nonunion and symptomatic shortening malunion can follow nonoperative care.[4,14] The most common clinical and radiographic expression of malunion is loss of bone length, which is inherent to conservative treatment, and occurs in 71% of displaced fractures, with shortening> 2 cm in most cases.[3] In adolescents, both weakness and dissatisfaction have been associated with ≥18 mm shortening in males and ≥14 mm in females, reflecting poorer tolerance than in adults.[10] Another complication of conservative treatment of displaced fractures with malunion is refracture, which may occur up to 6 months after the index injury.[15]

Bone shortening may also occur with elastic intramedullary nail stabilization. Shortening of 1 cm has been reported in 5-50% of cases.[26-28] This was due to the inclusion of comminuted fractures in the studies. Our series comprised simple patterns; therefore, shortening was not expected after reduction.

Some authors advise not advancing the nail beyond 3 cm past the fracture to avoid distal lateral migration[3,13] In our series, we advanced to this distance in most cases, impacting the nail in the lateral segment without cortical breach.

In adults, the most commonly used fixation method to stabilize midshaft fractures is anatomical plating with screws. However, beyond already known complications of this implant (neurovascular injury during screw placement, hypoesthesia inferior to the incision, hematoma), specifically in children and adolescents, fixation with plate and screws can cause complications, such as peri-implant fracture in patients who practice contact or collision sports, pain, growth restriction, postoperative discomfort in the soft tissue adjacent to the plate, and the consequent need for removal (close to 100% in this population).[3,11,12,16,17] For these reasons, there is increasing interest in the use of elastic nailing in this population.[13]

Implant-related complications (nail migration, soft tissue irritation) are the most documented in the literature and mostly occur in the first 3 months after surgery.[25] However, the patients in our series did not have complications that required hardware removal. We believe that this was due to the fact that, in our sample, we excluded both comminuted and lateral clavicle fractures, which are prone to this complication when treated with an elastic intramedullary nail.[29] We consider that one year of radiographic follow-up is sufficient to rule out loosening of the osteosynthesis material or its migration.

Elastic intramedullary nailing generates a predominantly periosteal callus that can be more exuberant inferiorly (compression side) than superiorly (tension side). In children and adolescents, osteoblasts in the inner cellular layer of the thick periosteum are able to generate neoformed bone tissue more rapidly. The increase in bone thickness as a consequence of the periosteal reaction (and outside the area of the bony callus) that we have documented in this study is not a feature that has been evaluated in previous studies on clavicle fractures. Our 1-year follow-up cannot determine whether later remodeling restores preinjury diameter; additional imaging would add unnecessary radiation.

In our case series, Constant–Murley scores improved by 6 weeks, consistent with prior reports,[30] likely related to restricting forward elevation beyond 90° for 6 weeks, given the nail's limited rotational stability compared with plates.

One limitation of our study is that it did not include patients <12 years, because, in this population, we indicated conservative treatment due to the high residual remodeling potential in the face of eventual malunion. On the other hand, the 1-year follow-up in skeletally immature patients may be too short to evaluate the outcomes and complications in the medium and long term. Another limitation is its retrospective design and lack of control group. Its strengths are that it includes a homogeneous cohort and that the patients were operated on by the same surgeon.

CONCLUSIONS

Flexible intramedullary nails are a valid option for simple, displaced midshaft clavicle fractures in adolescents. Periosteal reaction with increased cortical thickness after elastic intramedullary nailing had no clinical or functional consequences.

Open reduction should be considered when time from injury exceeds 10 days or when a 1.5-mm nail is required; although it adds an incision, it shortens operative time and, crucially, reduces fluoroscopy exposure.

Conflicts of interest: The authors declare no conflicts of interest.

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