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Original article

Surgical treatment of mid-shaft clavicle fractures by minimally invasive internal fixation facilitated by intra-operative external fixation: A preliminary study☆

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ABSTRACT

Background: Mid-shaft clavicle fractures are common and may require surgery. The objective of this study in adults with high-risk mid-shaft clavicle fractures was to evaluate the clinical and radiological outcomes of a minimally invasive surgical technique involving a minimally invasive approach, fracture reduction, temporary intra-operative external fixation, and locking plate internal fixation.
Hypothesis: This minimally invasive surgical technique for mid-shaft clavicle fractures ensures satisfactory radiographic fracture healing and medium-term functional outcomes, with a short immobilisation, rapid return to sports, and low complication rate.
Material and method: A retrospective review was performed of patients managed using our minimally invasive surgical technique between 1 January 2012 and 31 December 2016. The primary outcome measure was the 3-month radiographic healing rate. The secondary outcome measures were duration of post-operative immobilisation, 3- and 6-month QuickDASH scores, and post-operative complications.
Result: A total of 19 patients were included, 18 males and 1 female with a mean age of 37 years. Radiographic healing was consistently achieved within 3 months. Immobilisation duration was 3 weeks. The mean QuickDASH score was 23.75 after 3 months and 7.5 after 6 months. Return to sports occurred after 3 months. The only complication was transient paraesthesia in the distribution of the C8 nerve root in 1 patient.
Discussion: The management of mid-shaft clavicle fractures remains controversial. The high complication rates associated with conventional surgical techniques make treatment decisions difficult. A surgical technique characterised by temporary intra-operative external fixation to facilitate minimally invasive internal fixation may have a lower complication rate and shorter immobilisation requirements compared to conventional surgery.
Level of evidence: IV, retrospective observational study.

1. Introduction

Clavicle fractures are common injuries that contribute 3% to 5% of all fractures in adults. The fracture line may involve the lateral third, medial third, or mid-shaft of the bone [1]. Mid-shaft fractures, also known as Allman Type I fractures, account for 69% to 82% of all clavicle fractures [2]. Despite this high frequency, the optimal treatment of mid-shaft clavicle fractures in adults has long been a matter of debate. A consensus that surgery is required exists only for the small minority of patients with existing or threatening breaches in the skin; injury to nerves, blood vessels, and/or the lung; coexisting fractures of other parts of the upper limb; and bilateral clavicle fractures.

Several studies have investigated the indications of surgery in adults with mid-shaft clavicle fractures. According to one suggestion, more than 20 mm of initial shortening with no contact between the fragments and/or a third fragment may require surgery due to an increased risk of non-union and/or of poor functional outcomes, notably loss of mobility, strength, and endurance

☆ This study was reported as a free communication at the 2015 meeting of the *société française d'orthopédie et traumatologie* (SoFCOT). Submission for publication was then delayed to increase patient follow-up duration.

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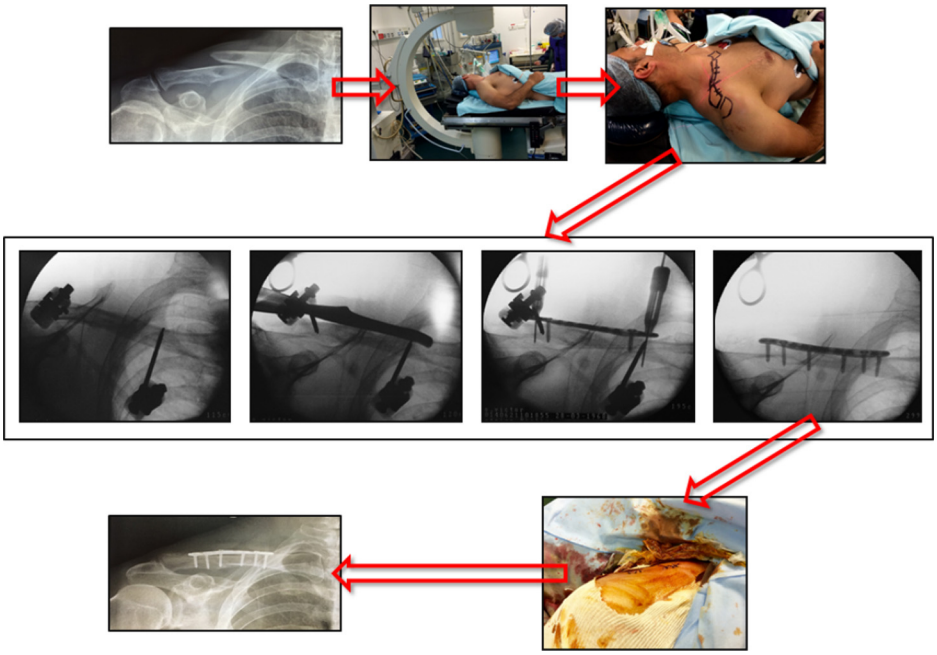

Fig. 1. The steps of the surgical procedure. A. Initial radiograph. B. Pre-operative installation. C. Intra-operative fluoroscopy view. D. Appearance of the skin incisions at the end of the procedure. E. Post-operative radiograph.

[3–6]. The conventional surgical treatment of mid-shaft clavicle fractures involves approaching the site of injury, reducing the fracture, and ensuring fixation by implantation of a compression plate [7]. This technique causes trauma to the tissues surrounding the clavicle, which is a membrane bone, thereby increasing the risk of non-union, surgical-site infection, and soft-tissue healing disorders [8–11]. A systematic literature review by Wijdicks et al. found that non-union rates ranged from 0% to 12% and infection rates from 0% to 20% [10].

Minimally invasive internal fixation after reduction with has been suggested to diminish the risk of surgical complications. The more limited approach to the site of injury would be expected to be less traumatic to the surrounding tissues and, therefore, to decrease the risk of post-operative complications [12]. Nevertheless, with a minimally invasive approach, assessing the fracture reduction criteria and achieving stable internal fixation may be more challenging [13]. Mal-union, notably involving rotational malalignment of the lateral clavicle, is a common source of pain and functional impairment [14,15]. In addition, insufficiently rigid internal fixation by intra-medullary pinning is associated with an increased risk of non-union [16].

The objective of this study in adults with high-risk mid-shaft clavicle fractures was to evaluate the clinical and radiological outcomes of a minimally invasive surgical technique involving a minimally invasive approach, fracture reduction, temporary intra-operative external fixation, and locking plate internal fixation. The working hypothesis was that this minimally invasive surgical technique ensures satisfactory radiographic fracture healing and medium-term functional outcomes, with a short immobilisation, rapid return to sports, and low complication rate.

2. Material and methods

A retrospective study was performed in adults with mid-shaft clavicle fractures managed at the orthopaedics and trauma centre of a university hospital in Clamart, France, between 1 January 2012 and 31 December 2016 using minimally invasive internal fixation facilitated by temporary intra-operative external fixation.

2.1. Patient selection

Our university hospital database was searched using the international classification of diseases 10th revision code S4200 (closed fracture of clavicle). Inclusion criteria were mid-shaft clavicle fracture sustained within the past 10 days and managed surgically by one of the three senior surgeons promoting the minimally invasive technique described herein (TB, BV et JCA) then followed-up for 1 year. Patients with missing clinical and/or radiographic data were not eligible for inclusion.

2.2. Operative technique

General anaesthesia combined with an interscalene block were administered (Fig. 1). The patient was supine on a transparent radiology table with a small pad under the scapular spine and the head turned away from the fractured side. The image amplifier was behind the head of the patient to allow fluoroscopic monitoring without hindering the surgeon. After fluoroscopic visualisation of the fractured clavicle, two 2-cm incisions were performed at a distance from the fracture line, one medially and the other laterally. The two incisions were extended down to the clavicular periosteum through the deltoid and trapezius muscles laterally and the pectoralis major and sternocleidomastoid muscles medially. Small Verbrugghe forceps were used to grasp each fragment. An external fixator pin was inserted in the anterior-to-posterior direction into the medial fragment then another into the lateral fragment. The joystick technique was then applied to reduce the fracture. The fragments were maintained in the proper position by attaching the intermediate radiolucent rod of the external fixator (Hoffmann II, Stryker Orthopaedics, Mahwah, NJ, USA). A rasp was then used to create an extra-periosteal pathway from one of the incisions to the other. An anatomical locking plate (Plaque Alians Clavicule, Newclip Technics, Haute Goulaine, France) was inserted from the lateral incision to the medial incision and fixed temporarily by placing a pin at each end. A bicortical non-locking screw was implanted into the dedicated aperture in the plate, on either side of the fracture site, to firmly apply the plate and, if needed, improve the reduction.

On each radiographic view of the fractured clavicle	Discontinuous cortex	Continuous cortex
No visible callus	1	4
Visible callus	2	3

Fig. 2. Radiographic Union Score (RUS) for the clavicle, adapted from Whelan et al.

The last step of internal fixation is the implantation of two bicortical locking screws, one on each side of the fracture site, to ensure internal fixation. After assessment by fluoroscopy, the external fixator is removed. The wound is closed in layers, starting with the muscles and ending with the skin. A removable elbow-to-body sling (Médisport, Ruaudin, France) is worn for 3 weeks, with no rehabilitation therapy.

The patients were discharged on the day after surgery if pain control was adequate. Rehabilitation therapy was started by a community physiotherapist 3 weeks after surgery. Both passive and active movements were used to gradually increase range of motion and muscle strength. Follow-up visits performed 3 weeks then 3, 6, and 12 months after surgery included a physical examination and two radiographs, an antero-posterior view and a 45° up-tilted view.

2.3. Outcome measures

The primary outcome measure was radiographic fracture healing within 3 months after surgery assessed based on a variant of the Radiographic Union Score (RUS) [17] suitable for the clavicle (Fig. 2). Fracture healing was defined as a score ≥ 4.

The secondary outcome measures were the rate of conversion from minimally invasive to conventional invasive surgery, operative time, duration of immobilisation, and function during daily activities after 3 and 6 months as assessed using the self-report QuickDASH questionnaire [18].

We recorded post-operative complications including surgical-site infections, non-union, and hardware-related problems. Surgical-site infection was defined for this study as a deep infection requiring revision surgery. Non-union was defined as an RUS value < 4 after 6 months. Hardware-related problems were defined as any cosmetic dissatisfaction and/or pain requiring hardware removal within 1 year after surgery.

2.4. Statistical analysis

The variables were described as mean ± SD and median (range). No statistical comparisons of groups was planned.

2.5. Ethical considerations

The study was conducted in compliance with the Declaration of Helsinki. As recommended, all patients received detailed information about the study.

3. Results

3.1. Patient selection

The database search identified patients managed for clavicle fractures (Fig. 3). Among them, 5 were excluded because they had another diagnosis, 25 because they had a lateral or medial clavicle fracture, and 26 because their clavicle fracture was managed non-operatively. Of the remaining 28 patients managed surgically for mid-shaft clavicle fractures, 9 were excluded because they were treated by a surgeon who was not among the three promoters of the surgical technique described herein (TB, BV, and JCA).

3.2. Study population

We included 19 patients, 18 males and 1 female with a mean age of 37 ± 15.2 years (median, 36.5 years; range, 15–67 years). The mechanism of injury was a motor vehicle accident in 5 patients, a cycling accident in 4 patients, a sports injury in 6 patients, and unknown in 4 patients. The decision to perform surgery was based on a type 2B2 fracture in the Robinson classification in 7 patients, a type 2B1 fracture with more than 20 mm of shortening in 6 patients, and a type 2B2 fracture with more than 20 mm of shortening in 6 patients.

3.3. Primary outcome measure

The mean RUS was 4 ± 0.46 (median, 4; range, 3–5) after 3 months and 6.2 ± 1.28 (median, 6; range, 4–8) after 6 months. Thus, all 19 fractures healed within 3 months.

3.4. Secondary outcome criteria

None of the patients required conversion from minimally invasive to conventional surgery. Mean operative time was 76.0 ± 21.2 min (median, 70 min; range, 55–120 min). Mean hospital stay length was 2.35 ± 1.30 days (median, 2 days; range, 1–7 days). All 19 patients wore the sling for 3 weeks and returned to sports after 3 months. Mean QuickDASH scores were 23.75 ± 7.9 (median, 25; range, 13.6–50.0) after 3 months and 7.5 ± 3.08 (median, 6.8; range, 2.27–15.9) after 6 months.

3.5. Complications

No intra-operative complications were recorded. No patient required hardware removal within 1 year after surgery or experienced abnormal sensation in the distribution of the supraclavicular nerve. Abnormal sensation in the distribution of the C8 nerve root was noted in 1 patient immediately after surgery. An electroneurophysiological study done 6 weeks after surgery was considered normal and the sensory disturbances resolved within 3 months. The hardware was removed more than 1 year after surgery in 5 patients, due to pain in 4 patients and to an unexplained skin ulcer in 1 patient.

4. Discussion

The findings from this study confirm the feasibility of a minimally invasive surgical technique for treating mid-shaft clavicle fractures. This technique involves a minimally invasive approach, fracture reduction facilitated then maintained intra-operatively by an external fixator, and internal fixation by a locking plate. This technique ensured fracture healing in all 19 patients, with satisfactory functional scores and a low complication rate. Its main drawback, shared with most plate fixation techniques for clavicle

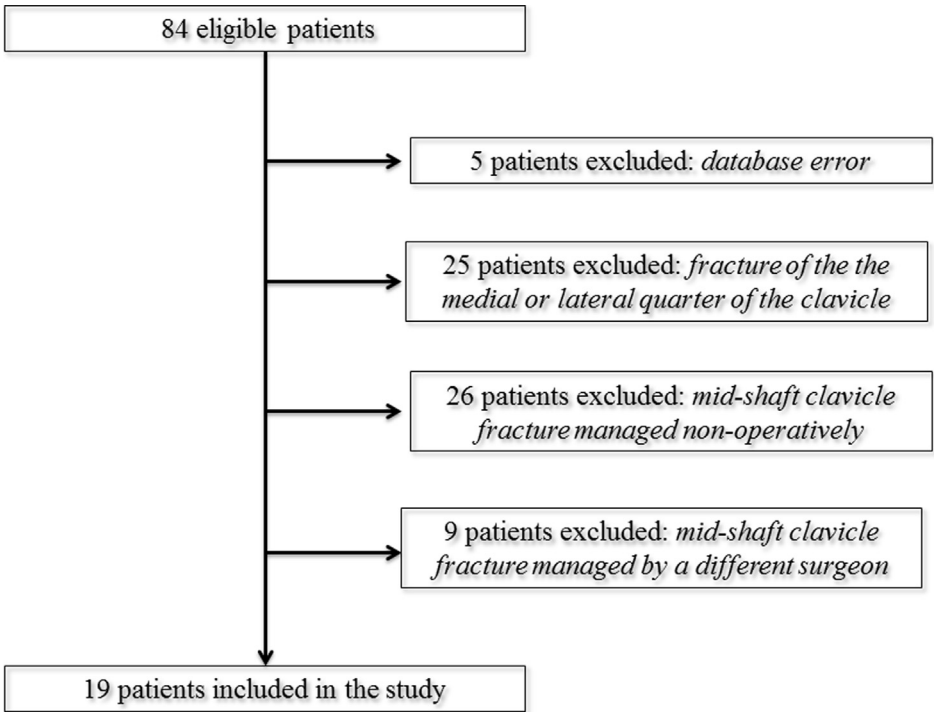

Fig. 3. Patient flow diagram.

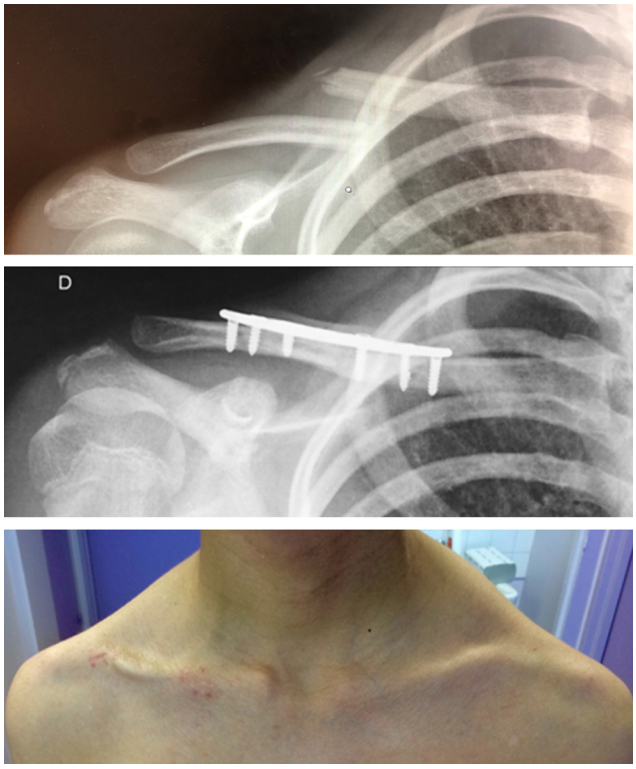

Fig. 4. Patients with a mid-shaft clavicle fracture responsible for more than 20 mm of shortening. A. Minimally invasive reduction and internal fixation. B. Healing documented after 3 months: the anatomical plate is visible under the soft tissues. C. RUS = 7.

fractures, is discomfort experienced by some patients at the site of the hardware (Fig. 4).

Many clinical and radiographic criteria for determining the surgical indications in patients with clavicle fractures have been suggested. However, they fail to cover all clinical situations [4–6]. The difficulty in making treatment decisions in these specific situations is due in part to the major difference between non-operative treatment, which is usually well tolerated, and surgery, which can result in iatrogenic injury (notably to nerves and blood vessels) and lead to post-operative complications (infection, non-union, and hardware-related problems) [19–21]. The availability of a surgical technique that minimises these adverse events would considerably facilitate treatment decisions. The preliminary study reported here suggests that our minimally invasive technique is feasible in everyday practice, does not increase the risk of intra-operative complications, and is associated with a low rate of post-operative complications (Fig. 5). It may therefore allow a broadening of surgical indications without increasing the risk of surgery-related adverse events.

Healing of a clavicle fracture managed by plate fixation remains challenging to evaluate in everyday practice. It is not possible to obtain radiographs of the clavicle in two perpendicular planes. At least one of the two incidences is made difficult to interpret by the presence of the fixation material. We therefore relied on the RUS developed by Whelan et al., which we adapted to the clavicle, to optimise our evaluation of radiographic fracture healing. The RUS considers both cortical continuity and the bony callus, which is often small in adults, to better assess the presence of, and time to, fracture healing. Volumetric computed tomography would, in theory, provide a better evaluation of bone healing [22,23]. However, our objective was to remain within the setting of standard care, which involves a radiographic assessment of fracture healing. Furthermore, computed tomographic images may be difficult to interpret due to artefacts generated by the fixation material, and the increased radiation exposure to the patient may not be warranted if the gains in terms of fracture healing assessment are minor.

Although surgery to treat mid-shaft clavicle fractures seems to provide high bone healing rates with low complication rates, a noticeable proportion of patients ask to have the fixation material removed due to pain, poor cosmesis, and/or functional impairment. Although our minimally invasive technique causes

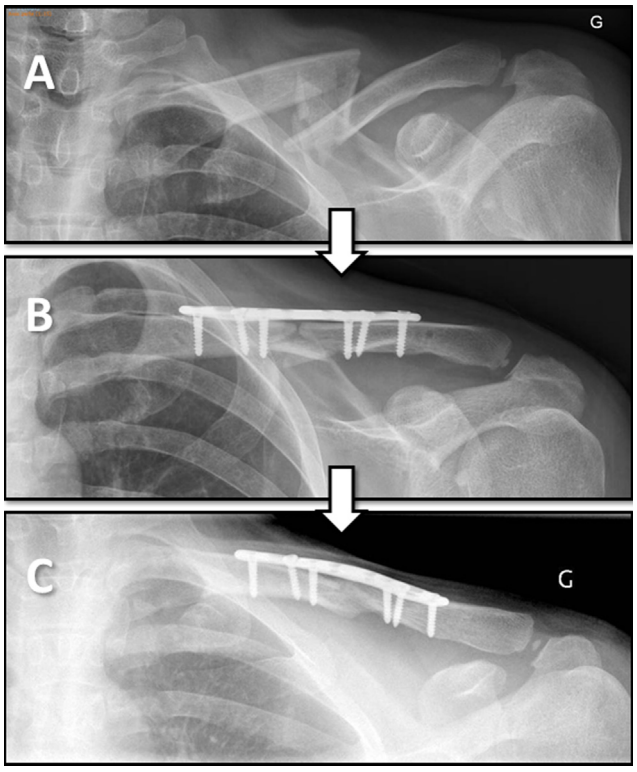

Fig. 5. Patient with a Robinson 2B2 mid-shaft clavicle fracture. A. Initial radiograph. B. Post-operative radiograph. B. Radiograph after 3 months.

only limited trauma to the soft tissues surrounding the clavicle, hardware-related problems may arise. In our study, hardware-related problems were defined as complications only if they occurred within the first year. Nonetheless, their frequency should be noted [23,24]. To our knowledge, despite advances in the quality of fixation materials and the availability of plate designs that are less bulky and better match human anatomy, no specific plate has been demonstrated to cause fewer long-term problems [25]. One solution may consist in positioning the plate on the anterior aspect of the clavicle. However, percutaneous plate implantation would then be more technically demanding. In addition, the inter-individual variations in clavicle curvatures may raise challenges. If the patient reports discomfort or dissatisfaction, plate removal is the only option. The plate can be removed percutaneously by gradually releasing its adhesions to the surrounding reactive membrane.

The implications of our study should be interpreted in the light of its limitations. The design was retrospective, the patients were not consecutive, and no control group was used. Selection bias may therefore have occurred. Nevertheless, these sources of bias probably had little impact on our findings given our objective of demonstrating feasibility of a surgical technique. The patients received standard follow-up, with no additional investigations such as strength testing, magnetic resonance imaging to assess soft tissue healing, or computed tomography to study the callus. The data provided by this study are relevant only to the technical feasibility of the procedure. The complications may have been underestimated, as only events responsible for clinical symptoms were recorded. Possible explanations to the transient sensation abnormalities in the distribution of the C8 root in 1 patient are excessive traction during reduction and direct injury by a drill bit. These procedures may have caused other injuries that were not detected because they caused no clinical symptoms. Finally, we did not compare the learning curve across the three surgeons. Surgeons may be reluctant to switch from their usual technique to another without knowing how long they will need to achieve a similar level of expertise.

In conclusion, for adults with mid-shaft clavicle fractures, a surgical technique involving temporary intra-operative external fixation to facilitate internal fixation through a minimally invasive approach may provide satisfactory outcomes with a low complication rate. If these findings are confirmed, the availability of this minimally invasive technique associated with a low complication rate may broaden the surgical indications for mid-shaft clavicle fractures.

Disclosure of interest

The authors declare that they have no competing interest.

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Contributions of each author

Thierry Bégué, Nasser Mebtouche, and Jean-Charles Aurégan conceived the study.

Jean-Gabriel Delvaque and Benoit Villain collected and analysed the study data.

Jean-Gabriel Delvaque, Thierry Bégué, Benoit Villain, Nasser Mebtouche, and Jean-Charles Aurégan wrote the manuscript.

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