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Original Article

Augmentation of clavicular fractures by dual plating

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Abstract: Introduction: The clavicle displays significant motion across all three anatomical planes, which poses challenges for achieving rigid internal fixation. While adding a second plate can increase construct stability, concerns exist about the potential compromise of the periosteal blood supply. This study evaluated the union rate, complications, reoperation rates, and functional outcomes of using an extra periosteal dual-plate fixation as an alternative to the conventional single-plate fixation for acute clavicle fractures at 1-year follow-up. Methods: In this prospective study (May 2023-May 2024), 25 patients with acute clavicle fractures underwent open reduction and internal fixation within four weeks of injury. Dual orthogonal plating was performed in all cases meeting inclusion criteria (midshaft or lateral-third fractures) and also in patients requiring revision after failure of a primary single plate. All procedures were extraperiosteal to preserve blood supply. Patients were followed for a minimum of one year. Outcome measures included radiographic union (regular interval X-rays) and functional recovery assessed by the Constant-Murley shoulder score. Complications and any reoperations were recorded. Institutional ethical approval was obtained and informed consent was taken from all patients. Results: A total of 25 patients (7 females, 18 males; mean age 39.7 ± 10.0 years) were treated and followed for an average of 11.3 ± 4.1 months. Of these, 23 patients (92%) underwent dual plating primarily (20 midshaft [80%] and 3 lateral-end [12%] fractures), and 2 patients (8%) had dual plating as a revision after failed single plating. By final follow-up, all 25 fractures achieved full bony union with no cases of nonunion or implant failure. The average time to union was ≤3 months in 15 patients and >3 months in 10 patients; all delayed unions had healed by one year without additional intervention. Shoulder function improved steadily, with mean Constant-Murley scores of 76.2 ± 6.1 at 6 weeks, 83.5 ± 3.5 at 3 months, and 92.2 ± 3.0 at 6 months post-surgery. According to Constant score categories, 20 patients (80%) had "very good" shoulder function and 5 patients (20%) had "good" function at final follow-up. Complications were infrequent: 2 patients (8%) developed superficial wound infections (resolved with antibiotics), and 6 patients (24%) experienced implant prominence/irritation. No hardware breakage, loosening, or refracture occurred, and no patient required reoperation for hardware-related problems within the follow-up period. Conclusion: Dual-plate augmentation of acute clavicle fractures proved to be a reliable fixation strategy in this series, yielding a 100% union rate and a low incidence of complications. The application of a second plate in complex or highly unstable clavicle fractures did not adversely affect fracture healing or increase complication rates. In cases of failed single-plate fixation, revision with dual plating facilitated successful union and good functional outcomes. The primary drawback observed with dual plating was implant prominence in some patients, suggesting a need for further refinements to minimize hardware profile.

Keywords: Clavicle fracture, dual plate augmentation, biomechanics, nonunion, constant-murley score

Introduction

Clavicle fractures are common injuries of the shoulder girdle, accounting for roughly 5% of all adult fractures [1]. Most (>80%) of these fractures involve the mid-shaft of the clavicle [1, 2], which is the narrowest part of the bone with the least soft tissue coverage, making it susceptible to fracture from direct impact to the shoulder. Historically, many midshaft clavicle fractures (even if displaced or comminuted) were treated nonoperatively, given the clavicle's considerable remodeling capacity. However, more recent data have demonstrated that nonoperative management can result in a significantly higher risk of nonunion than previously appreciated. Modern series report nonunion rates up to ~15-20% with conservative treatment [1, 3], compared to much lower nonunion rates (on the order of 0-3%) after surgical fixation in simi-

lar fracture patterns [1]. Consequently, there has been renewed interest in surgical fixation of significantly displaced midshaft clavicle fractures, as operative treatment tends to yield higher union rates and improved patient satisfaction in adults [1]. For instance, randomized trials and meta-analyses have confirmed superior functional outcomes and lower nonunion rates with plate fixation versus nonoperative care for displaced midshaft fracture [1, 4].

One challenge in clavicle fracture fixation is the substantial motion of the clavicle in all three anatomical planes (sagittal, coronal, and axial). The clavicle can elevate and depress in the coronal plane, translate anteriorly/posteriorly in the sagittal plane (protraction/retraction), and rotate around its long axis in the horizontal plane. During arm elevation, the clavicle rotates approximately 30-40° posteriorly at the sternoclavicular joint and elevates about 15-30°, accommodating scapular motion [5]. This complex, multiplanar movement generates multi-directional stresses at the fracture site and on any fixation device. Inadequate fixation or hardware placement that does not account for these forces can lead to excessive interfragmentary motion and contribute to complications such as delayed union, nonunion, or hardware fatigue and failure. Known risk factors for clavicle fracture nonunion include not only the degree of displacement (fracture fragment overlap >20 mm) but also comminution and patient factors such as smoking and high-energy trauma [6, 7]. Notably, a displacement of more than 2 cm has been associated with a markedly increased nonunion risk [8], and significant shortening (>20 mm) can result in symptomatic malunion affecting shoulder function [8]. These factors underscore the need for a robust fixation construct in unstable clavicle fractures.

Various fixation techniques have been employed for clavicle fractures. Intramedullary devices (such as flexible pins or cannulated screws) have been used with some success in minimizing invasiveness, and external fixation has been tried in select cases of open fractures or poor skin conditions [5, 9]. However, plate osteosynthesis remains the most common method for displaced midshaft fractures, as it provides immediate stability. Standard plating typically involves a single superior or anteroinferior plate. While outcomes with single-plate fixation are generally good, plate prominence and hardware irritation requiring removal are relatively common drawbacks [3, 10]. In an effort to enhance construct stability and potentially reduce hardware-related complications, dual-plate fixation (often using a low-profile supplemental plate in addition to a primary plate) has been explored. This “dual plating” can be configured orthogonally (e.g. one plate superior and another anterior) or in complementary positions, and is usually done extraperiosteally to preserve blood supply [8]. Early technical reports showed that extraperiosteal dual plating could achieve high union rates without increasing complications [8]. Biomechanical studies further validate that dual mini-fragment plate constructs provide significantly greater stiffness in axial and bending loads compared to a single 3.5 mm plate [11], which suggests better resistance to the multi-planar forces experienced by the clavicle during shoulder motion. Recent clinical evidence indicates that dual plating yields union rates comparable to single plating while decreasing the incidence of hardware removal for implant irritation [3]. A 2022 systematic review by Sheth et al. found that dual plating had similar overall complication rates and fracture healing as single plating, but with a significantly lower odds of patients requiring secondary surgery for symptomatic hardware removal [3]. Additionally, a newly published retrospective series reported that low-profile dual plating achieved 100% fracture healing and reduced re-intervention rates relative to single plating [10]. These findings from the literature support the rationale that dual plating can augment fixation stability in complex clavicle fractures without compromising bone healing.

Objective: The objective of this investigation was to compare the incidence of non-union, prognosis, and complications at 6-12 months subsequent to surgical intervention for clavicle fractures, analyzing the utilization of extra-periosteal dual-plate fixation as an alternative to conventional single-plate fixation. We hypothesized that the addition of a second plate would not compromise bony union or increase complications.

Materials and methods

Study design and patient selection

This study was a prospective observational analysis of patients with acute clavicle fractures treated at our institution between March 2021 and March 2023. Institutional Review Board approval was obtained prior to study initiation, and all patients provided informed consent for both the surgical procedure and inclusion in the study. The inclusion criteria were: (a) patients aged 20-60 years with an acute clavicular fracture (midshaft or lateral third) indicated for surgical fixation (displaced or at risk of nonunion), (b) fractures classified as AO/OTA types 15.2 (midshaft) or 15.3 (lateral end), (c) those indicated for dual-plate osteosynthesis in the acute setting (within 4 weeks of injury), and (d) patients with normal pre-injury shoulder function. We also included patients who had initially received a single plate fixation at an outside center but suffered implant failure and underwent revision surgery with dual plating at our hospital, as they met the intent of evaluating dual-plate outcomes. Exclusion criteria comprised: (a) medial-end clavicle fractures (AO/OTA 15.1), (b) open fractures, (c) skeletally immature patients, (d) pathological fractures, (e) associated neurovascular injury, and (f) concomitant injuries to the ipsilateral shoulder girdle or extremity that could affect rehabilitation.

A total of 25 patients met the selection criteria and were enrolled in the study. There were 7 females (28%) and 18 males (72%), with an average age of 39.68 ± 9.96 years (range 25-58 years). The right clavicle was involved in 14 cases (56%) and the left in 11 cases (44%). The mechanism of injury was road traffic accident in 12 patients (48%), a fall from height in 8 patients (32%), and a direct impact or other trauma in 5 patients (20%). According to the AO/OTA classification, 22 patients (88%) had midshaft fractures (15.2) and 3 patients (12%) had lateral-third fractures (15.3). Thus, dual plating was employed for all acute midshaft or lateral clavicle fractures meeting these criteria. In practice, the decision to perform dual-plate fixation was made for comminuted or highly unstable fracture patterns and in cases where improved multi-planar stability was desired; simpler fracture patterns could be managed with a single plate, but during the study period we opted for dual plating in eligible cases to evaluate its efficacy. Additionally, as noted, 2 patients (8%) in the series had initially been managed with a standard single superior plate elsewhere and presented with hardware failure; these were revised to dual plating in our institution and included in the analysis as "revision cases".

Surgical technique

All surgeries were performed under general anesthesia with the patient placed in a beach-chair position, which facilitated fluoroscopic visualization and reduction of the fracture. After sterile preparation, a 7-8 cm incision was made along the anterior-superior aspect of the clavicle centered over the fracture site. Skin, subcutaneous tissue, and platysma fascia were incised in line with the clavicle, and flaps were gently elevated. The fracture hematoma was evacuated and minimal periosteal stripping was done to preserve blood supply. Once exposed, the fracture fragments were reduced anatomically using reduction clamps.

For fixation, a 3.5-mm locking compression plate (LCP) or a 3.5-mm reconstruction plate was contoured and applied as the primary plate. In most cases, we placed the primary plate on the anterior aspect of the clavicle (anteroinferior surface). We opted for superiorly-based neutralisation plates due to their ability to minimise the prominence of this hardware and enhance stability in the anterior-posterior plane of the clavicle fracture fixation (**Figures 1**, **5**).

We ensured that the dual plates were positioned such that one countered superior-inferior bending forces and the other countered anterior-posterior forces and torsion. In our experience, placing the larger plate anteriorly and the low-profile supplementary plate superiorly provided stable fixation while reducing subcutaneous prominence of hardware. This dual-plate construct distributes load and is intended to better withstand multi-planar bending, rotational stress, and shear forces concurrently, thereby reducing the stress borne by any single implant or screw [8, 12]. All plates were applied in an extraperiosteal fashion (i.e., without stripping the periosteum beneath the

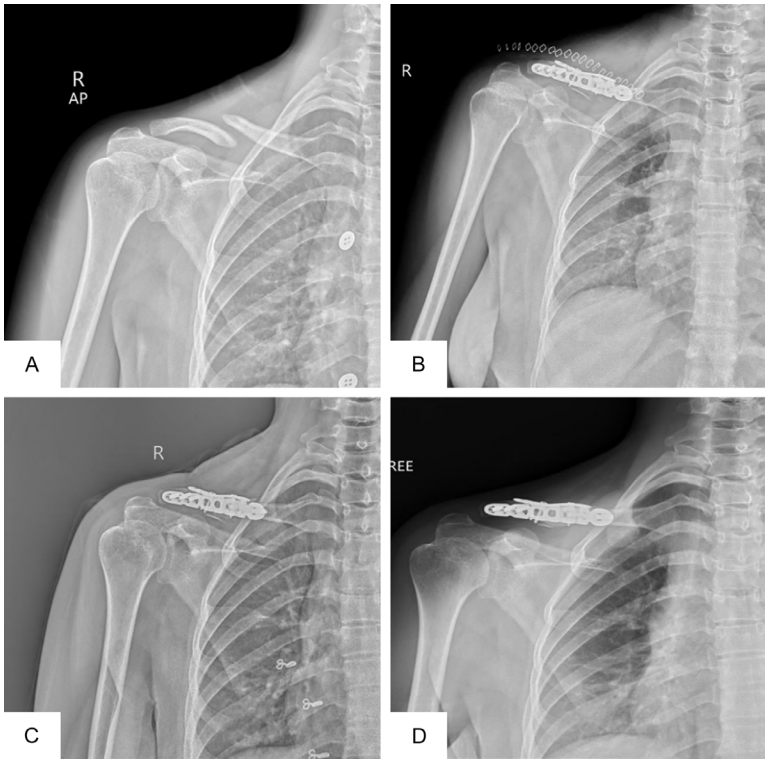

Figure 1. Radiographs of a 35 year old female sustaining right side clavicular fracture during a road traffic accident. A. Pre-operative radiograph showing a displaced mid shaft clavicular fracture. B. Post-operative radiograph showing augmentation by dual plating (anterior and superior plate). C. Follow-up radiographs at 3 months show some attempt of the union. D. The final follow-up radiograph at 6 months showed an uncomplicated union.

plate) to protect the vascular supply to the bone.

For lateral-end fractures (AO 15.3), a specialized lateral clavicle locking plate was used as one of the implants [13]. In those cases, a pre-contoured lateral clavicle plate was applied superiorly to secure fixation into the distal fragment (which often involved the acromioclavicular joint region), and a smaller augmentation plate was placed on the anterior aspect of the lateral clavicle to buttress the fracture from another plane (**Figure 4**). Care was taken in these lateral fractures to avoid violation of the acromioclavicular joint with screws; this was confirmed under C-arm fluoroscopy.

After fixation, thorough irrigation was done. The surgical wound was closed in layers (fascia, subcutaneous tissue, and skin). A sterile dressing was applied. The arm was supported in a sling for approximately 2 weeks post-operatively for comfort and soft tissue healing. Early passive and pendulum shoulder exercises were initiated within the first 1-2 weeks as tolerated. Active range-of-motion and light strengthening exercises were gradually introduced after 2-3 weeks once initial healing was evident, with the guidance of a physiotherapist. Patients were typically advanced to full shoulder activity by around 6-8 weeks post-op, depending on fracture healing progress.

Outcome measures and follow-up

Patients were followed clinically and radiographically at regular intervals. Follow-up visits were scheduled at 6 weeks (~1.5 months), 3 months, 6 months, and 12 months after surgery. At each visit, standard anteroposterior and cephalad-tilt radiographs of the clavicle were obtained to assess fracture healing (union) status. Radiographic union was defined as the presence of bridging callus or cortical continuity across the fracture site on at least three of four cortices on biplanar radiographs, accompanied by the absence of pain at the fracture site on clinical examination. Delayed union was defined as lack of radiographic union by 3 months post-injury, and nonunion was defined as failure to achieve union by 9 months post-injury or if no progression of healing was seen on consecutive radiographs over a 3-months period. Clinical union was corroborated by the absence of tenderness at the fracture site and the patient's ability to move the shoulder without pain.

We evaluated functional outcomes using the Constant-Murley shoulder score at 6 weeks, 3 months, and 6 months follow-up. The Constant-Murley score is a 100-point composite measure of shoulder function, incorporating pain (15 points), activities of daily living (20 points), range of motion (40 points), and strength (25 points). Higher Constant scores indicate better

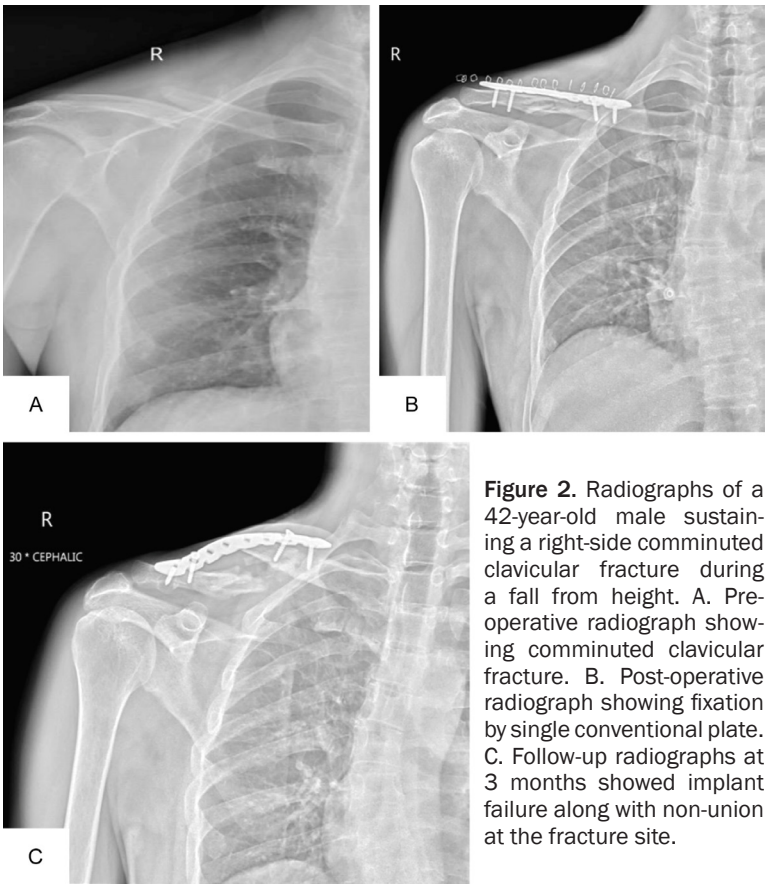

Figure 2. Radiographs of a 42-year-old male sustaining a right-side comminuted clavicular fracture during a fall from height. A. Pre-operative radiograph showing comminuted clavicular fracture. B. Post-operative radiograph showing fixation by single conventional plate. C. Follow-up radiographs at 3 months showed implant failure along with non-union at the fracture site.

shoulder function. In this study, we categorized Constant scores in qualitative terms for convenience of interpretation: we considered scores ≥90 as "very good/excellent", 80-89 as "good", 70-79 as "fair", and below 70 as "poor". Patients were asked to complete the subjective portions of the score (pain and daily activities), and objective measurements of range of motion and strength were performed by the surgeon or a physical therapist.

All complications during follow-up were recorded. We specifically noted any implant-related complications such as wound dehiscence, infection, implant prominence causing patient discomfort, screw loosening, plate breakage, or refracture of the clavicle. Any secondary surgical procedures (reoperations) - for example, for infection irrigation, hardware removal, or non-union repair - were documented.

Statistical analysis

Statistical analysis was performed using SPSS software (v18.0; SPSS Inc., Chicago, IL). Descriptive statistics were used to summarize patient demographics and baseline characteristics. Continuous variables (e.g. age, Constant score) are presented as mean ± standard deviation. Categorical variables (e.g. union achieved or not, complications occurrence) are presented as counts and percentages. For comparative analysis, given that our study was primarily observational with a single cohort, we did not have a control group of single plating to directly compare outcomes. However, we did compare our union rates and complication rates with historical data from literature. Additionally, within our cohort we used appropriate statistical tests to explore any associations: for example, independent t-tests were used to compare mean Constant scores at different time points, and chi-square or Fisher's exact tests were used to evaluate relationships between categorical variables (such as complication rates in subgroups). A P value <0.05 was considered statistically significant.

Results

Patient demographics and fracture characteristics

The cohort consisted of 25 patients with acute clavicle fractures treated by dual plating. Pertinent demographic and injury data are summarized in **Table 1**. There were 7 women and 18 men with an average age of 39.7 years (SD ± 9.96). The injury laterality was right side in 14 cases (56%) and left side in 11 cases (44%). High-energy mechanisms were common, with road traffic accidents accounting for 48% of injuries and falls from height 32%, while the remaining 20% were due to direct blows or other trauma. According to AO/OTA classification, 22 patients (88%) had midshaft fractures (15.2 classification) and 3 patients (12%) had fractures of the lateral third (15.3).

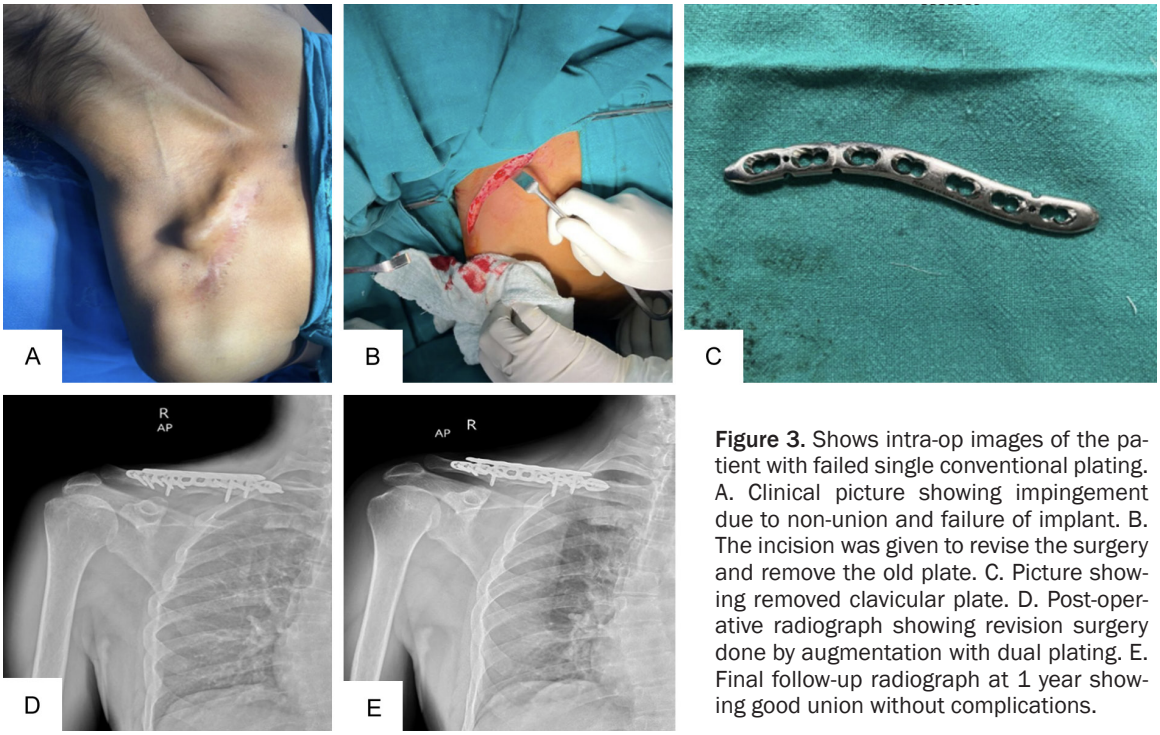

Figure 3. Shows intra-op images of the patient with failed single conventional plating. A. Clinical picture showing impingement due to non-union and failure of implant. B. The incision was given to revise the surgery and remove the old plate. C. Picture showing removed clavicular plate. D. Post-operative radiograph showing revision surgery done by augmentation with dual plating. E. Final follow-up radiograph at 1 year showing good union without complications.

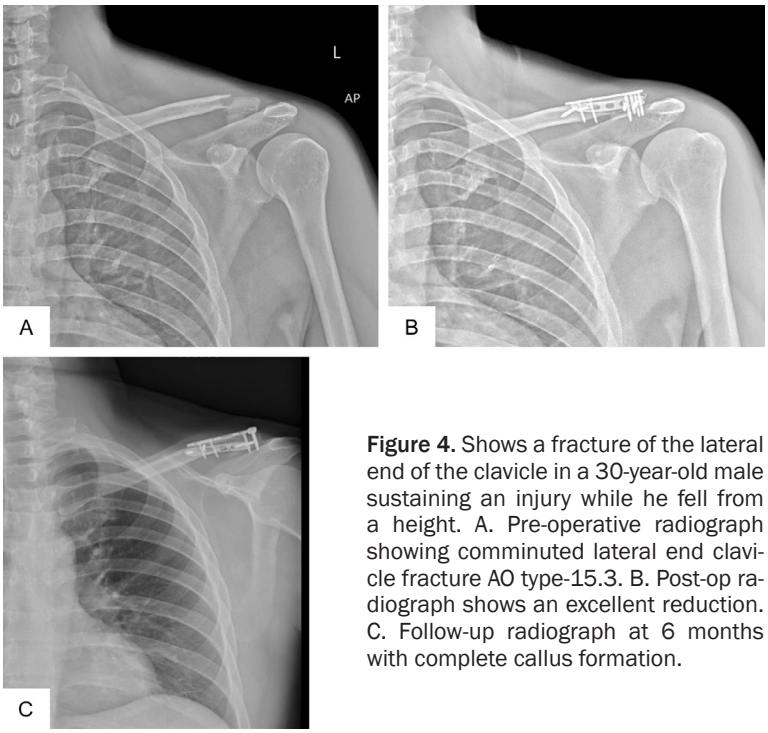

Figure 4. Shows a fracture of the lateral end of the clavicle in a 30-year-old male sustaining an injury while he fell from a height. A. Pre-operative radiograph showing comminuted lateral end clavicle fracture AO type-15.3. B. Post-op radiograph shows an excellent reduction. C. Follow-up radiograph at 6 months with complete callus formation.

All 25 patients underwent operative fixation with a dual-plate construct as described. In 23 patients (92%), dual plating was the primary fixation method for their acute fracture. The remaining 2 patients (8%) had initially been treated with a single plate (at outside institutions) but experienced implant failure; these were successfully revised with dual plating in our center (**Figures 2**, **3**). Thus, our series included both acute primary dual plating and revision cases augmented with dual plates.

Figure 1A, **1B** illustrates the clinical application of dual plating in a comminuted midshaft clavicle fracture: panel A shows the fracture pre-fixation, and panel B shows the fracture stabilized with a superior and an anterior plate. **Figure 1C**, **1D** shows follow-up X-Rays at 3 and 6 months respectively with uncomplicated union (**Figure 1**).

Fracture union outcomes

All patients were observed for a minimum of 12 months or until bony union was achieved. By final follow-up, all 25 fractures (100%) had united radiographically and clinically. The average time from injury to surgery was 2.6 ± 0.9 days

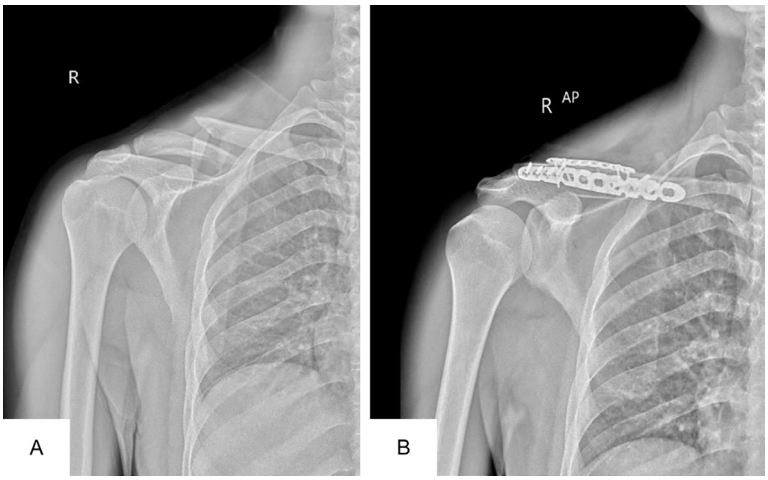

Figure 5. Shows the management of a 50-year-old male with comminuted mid-shaft clavicular fracture by dual plating augmentation. A. Pre-operative radiograph. B. Final follow-up radiograph at 1-year follow-up with complete callus formation and good Constant Murray scores.

Table 1. Clinical results and demography of clavicle fractures augmented by dual plating

Patient variable	Group Value
Age	
Average (years), mean ± SD	39.68 ± 9.96
Range (years)	25-58
Sex	
Female	7 (28%)
Male	18 (72%)
Mode of injury	
RTA	12 (48%)
FFH	8 (32%)
Others	5 (20%)
AO/OTA classification	
15.2	22 (88%)
15.3	3 (12%)
Cases types	
Fresh Dual plating	23 (92%)
Failed single conventional plate	2 (8%)

(see **Table 2** for timeline data). Fracture healing was rapid in most cases: 15 patients (60%) showed evidence of radiographic union (bridging callus) by the 3-months visit. The remaining 10 patients (40%) took more than 3 months to achieve full radiographic union; these were considered delayed unions, often corresponding to the more comminuted fractures. Notably, 4 patients (16% of the cohort) did not show bridging callus at the fracture site at the 6-week and 3-months x-rays, raising initial concern for delayed healing. However, with continued protected weight-bearing and rehabilitation, all of these 4 patients went on to unite by the 6-months follow-up without requiring any further surgical intervention. The two patients who underwent revision dual plating after initial plate failure also achieved solid union by the 1-year mark with the dual-plate construct, with no recurrent hardware issues. We did not encounter any case of persistent non-union in this series. The 100% union rate observed with dual plating in our study is consistent with or better than union rates historically reported for single-plate fixation in similar fracture populations [8]. Additionally, no instances of hardware failure (such as plate breakage or screw pull-out) were noted during the course of follow-up, attesting to the mechanical robustness of the dual-plate fixation.

Functional outcomes

All patients were assessed for shoulder function using the Constant-Murley score (see **Table 3**) during follow-up (except three patients who missed one or more interim clinic visits but returned by final follow-up). The Constant scores improved progressively over time, reflecting recovery of shoulder function. At 6 weeks post-op, the mean Constant score was 76.23 ± 6.11 (out of 100). By 3 months, the mean score had increased to 83.50 ± 3.53. At 6 months (the time of final functional evaluation in clinic), the mean Constant-Murley score reached 92.20 ± 2.98, indicating most patients had regained near-normal shoulder function. These serial improvements were statistically significant ($P<0.01$ for 6 weeks vs 3 months, and for 3 months vs 6 months). At final follow-up, 20 patients (80%) had Constant scores in the excellent range (≥90 points), and the remaining 5 patients (20%) had scores in the good range (80-89 points). No patient had a fair or poor functional outcome by these criteria. Patients reported high satisfaction with the procedure, and those who had been unable to use the affected arm prior to surgery (due to

Table 2. Associated parameters measurement

Variable	Group Value
Time from injury to operation (days)	2.60 ± 0.88 days
Duration of operation (minutes)	
Average	55 ± 8.25
Range	45-70
Average Blood Loss (ml)	173.55 ± 23.11
Intra-operative reduction quality	
Excellent	20
Good	3
Satisfactory	2
Poor	0

Table 3. Outcome by constant murley score assessment

Duration at assessment	Group Value (Mean and SD)
1.5 months	76.23 ± 6.11
3 months	83.50 ± 3.53
6 months	92.20 ± 2.98

Table 4. Post-operative assessment & complications in patients

Parameters	Group Value
Duration of follow up (months)	
Average	11.33 ± 4.11
Range	6-23
Union time (months)	
Average	5.31 ± 1.66
<3 months	15
>3 months	10
Complications	
Superficial Skin infection	2 (8%)
Implant impingement and irritation	6 (24%)
Implant failure	0
Non-union	0
Total	8 (32%)

fracture instability) were able to return to daily activities and work by around 3-4 months post-injury, on average. Of note, by 3 months post-surgery, many patients already demonstrated substantial functional recovery, correlating with the union progress; even the few who had delayed radiographic union by 3 months still showed improving function, likely because the dual plate provided sufficient stability to allow early mobilization. These results suggest that dual plating provided a stable construct that permitted early functional use of the limb and ultimately excellent shoulder performance in the year following injury.

Complications

Postoperative complications in this cohort were relatively minimal and are detailed in **Table 4**. There were no major intraoperative or perioperative complications such as neurovascular injury, pneumothorax, or anesthesia-related issues. Two patients (8%) developed a superficial wound infection in the postoperative period. These infections presented with mild erythema and drainage at the incision site within 2-3 weeks after surgery. Both cases were managed successfully with a course of oral antibiotics and local wound care; the infections resolved without necessitating implant removal, and both patients went on to full fracture union.

The most common issue encountered was hardware prominence/irritation. A total of 6 patients (24%) reported some degree of discomfort at the clavicle region due to the implant, particularly the plate that was placed on the superior aspect in our construct. Some studies utilising mini-fragment plates have reported rates of implant removal of up to 4.2%, indicating good tolerability to dual plates [14]. In most cases, this was described as a mild prominence or rubbing sensation under the skin, noticeable when wearing backpacks or straps or during certain shoulder movements. There were no cases of painful restriction of shoulder motion caused by hardware, but the awareness of the plate was a noted complaint. This was expected to some extent, as clavicle plates (especially superior ones) are known to be palpable in slender individuals. We attempted to mitigate this by using a low-profile plate for augmentation and by placing the larger plate anteriorly; nevertheless, implant palpability remained an issue for roughly one-third of patients. None of these patients requested elective plate removal within the 1-year follow-up, as the symptoms were tolerable, but they were counselled that hardware removal could be considered after bone healing if the irritation persisted.

Importantly, no patient experienced implant failure (such as plate bending or breakage) or

screw loosening throughout follow-up. The dual plating appeared to provide sufficient strength to avoid hardware fatigue even in those who resumed high-demand activities. There were also no cases of refracture after implant removal or at the ends of the plate during the follow-up period. One potential concern with rigid fixation is stress shielding leading to osteoporosis under the plate; while we did not specifically measure bone mineral density changes, we did not observe any adverse effects like refracture in the region of the original fracture or adjacent to the hardware. Finally, aside from the two infections noted, there were no other complications such as nonunion (as stated, all fractures united), nor any need for re-operation in our cohort within the study period. In summary, dual-plate fixation in our series did not result in an increased complication rate relative to expected rates for single plating; on the contrary, certain complications like nonunion or fixation failure were absent in our group. Minor implant-related irritation was the primary drawback, aligning with known issues in clavicle fracture surgery.

Table 4 provides an overview of the clinical outcomes, including union times, Constant scores, and complications.

Discussion

Midshaft clavicle fractures typically result from a high-impact force to the shoulder, and the middle third of the clavicle is the most frequent fracture site (approximately 80-85% of clavicle fractures occur in this region) [8]. The traditional approach to displaced midshaft clavicle fractures leaned towards nonoperative management, owing to earlier reports suggesting a low nonunion rate and the clavicle's ability to remodel even when shortened or malaligned. Neer and colleagues in the 1960s-70s reported nonunion rates under 1% for clavicle fractures treated without surgery [15]. However, those studies had limitations (e.g. inclusion of pediatric cases and lack of modern functional assessment) [15]. Subsequent research dramatically changed the understanding of these injuries. Hill et al. (1997) documented poor outcomes in markedly displaced midshaft fractures managed nonoperatively, with a higher incidence of nonunion and patient dissatisfaction [16]. More recent analyses have solidified that finding: Robinson et al. estimated the risk of nonunion to increase significantly with greater fracture displacement and comminution [8], and overall nonunion rates around 15% have been observed in adult patients treated conservatively [3]. By contrast, surgically treated clavicle fractures show union rates consistently between 91.1% and 100% in modern series [17]. In our study of dual plating, we achieved a 100% union rate, which is on the upper end of outcomes for operative treatment and underscores the effectiveness of stable fixation. This is in line with current literature on acute clavicle fracture fixation; for example, a recent dual plating series reported union in all cases by 4-6 months [10, 18], and a systematic review found no difference in union rate between dual and single plating (pooled union rate ~98-100%) [3]. The two cases of failed primary fixation in our series that were rescued by dual plating also illustrate that augmenting stability with a second plate can successfully achieve union in situations where a single plate construct had failed.

Dual-plate fixation as a concept for clavicle fractures stems from the idea of improving biomechanical stability and distributing forces across two implants. Biomechanically, a single superior plate is effective against inferior bending forces (preventing the fracture from angulating downward) but is less effective in controlling anterior-posterior instability and torsional forces. An anterior-inferior plate, conversely, better resists anterior-posterior bending [8]. By combining these two orthogonal plates, a dual construct provides enhanced rigidity in multiple planes [11]. Our surgical technique was designed to exploit this: the anterior plate acts as a bridge/neutralization plate and the supplementary superior plate acts as a buttress for vertical forces. The in vitro superiority of dual plating has been demonstrated; Kitzen et al. (2022) showed that dual mini-plate constructs had higher axial and bending stiffness than a single 3.5 mm plate [11]. We found in practice that none of our dual-plate fixations experienced hardware loosening or breakage, suggesting that stress was well-distributed. This is notable because traditional single plates can occasionally fail, especially in very unstable fractures or in patients who load the arm early [1]. In a recent retrospective by Reddy et al. (2023), no reopera-

tions were required for mechanical failure in the dual-plated group, whereas the single plate group had instances of hardware failure and secondary surgeries [6]. Our results mirror this robustness - despite early mobilization, the constructs held up without failure.

A primary concern with adding an extra plate is the potential for increased soft tissue dissection and devascularization of fracture fragments. In this context, we took care to apply plates extraperiosteally and avoid extensive stripping. The high union rate and lack of any nonunion in our series suggest that the biological healing was not adversely affected by the dual implants. This corroborates prior reports that dual plating, when done with minimal periosteal disruption, does not increase the risk of nonunion [8]. Preservation of blood supply is critical; to that end, we limited screw density near the fracture as well, following recommendations to reduce disruption and stress in comminuted zones [1]. All fractures, including the three lateral-end fractures in our study, healed without issue, indicating that dual plating is a viable option across different subtypes of clavicle fractures. In fact, our lateral clavicle fractures (which can be prone to nonunion due to ligamentous disruptions) united with dual plating, whereas historically these fractures often required supplementary fixation or had higher failure rates with a single plate or hook plate alone [8]. Thus, dual plating can be considered a favorable choice in managing increased fracture complexity, providing robust fixation without a trade-off in healing.

Our functional outcomes, as measured by Constant scores, were excellent and compare favorably with other studies. By 6 months, the mean Constant score was >92, which is on par with an uninjured shoulder for many individuals. Part of this success is likely due to the stability of fixation permitting early rehabilitation. Patients in our series began gentle motion exercises by 2 weeks and regained substantial function by 6 weeks. By 3 months most were pain-free and had good range of motion. These timelines align with those reported in the literature for operative management [19]. Notably, Chen et al. (2017) observed that while radiographic bridging might occur slightly faster with a single plate (possibly due to more interfragmentary motion stimulating callus), functional outcomes by 3 months were similar, and by 6 months there was no difference between single and dual plating groups in terms of shoulder scores [20]. Our findings support that dual plating does not impede the recovery of function; if anything, the early stability might facilitate confident movement. At 3 months post-op, our patients' Constant scores (averaging ~83) indicate good function, which is comparable to or better than historical controls for plated clavicles around that timeframe. By 6 months, the majority had excellent function, reflecting complete rehabilitation.

When considering complications, it is important to contextualise our results with those from single plating. The incidence of superficial infection in our series (8%) is within the typical range (generally 1-5% in most large series of clavicle ORIF [1], (although some studies report slightly higher if urgent trauma cases are included). These infections were minor and resolved without surgery. We attribute the low infection rate in part to the relatively small incision and careful soft tissue handling. No deep infections occurred. The absence of nonunion and hardware failure in our dual-plate group is an encouraging finding - recent meta-analyses report nonunion rates of 1-5% and hardware failure rates around 1-3% for displaced midshaft fractures treated with a single plate [1], so our zero incidence is noteworthy, albeit in a moderate sample size. It suggests that the dual-plate method provided a strong construct that prevented the typical failure modes that occasionally plague single plates (such as plate breakage at a screw hole near a fracture gap) [1].

The most prevalent issue was implant prominence. Clavicle hardware, especially on the superior surface, is well-known to cause irritation. In traditional single-plate fixation, the rate of symptomatic hardware prompting removal can be as high as 10-20% (and even up to 30% in some reports) [3]. One of the motivations for dual plating is actually to use lower-profile plates that might reduce this problem. For example, recent studies using two small plates (2.0 mm and 2.4 mm) have shown a significantly lower incidence of implant removal compared to a single large plate [10]. In our study, however, we still observed about one-third of patients with some hardware-related

discomfort. It's possible that because we often used a standard 3.5 mm plate as one component (augmented by a smaller plate), the profile was not as low as the "double mini-plates" used in other techniques [11, 21]. Indeed, Chen et al. noted implant prominence as a concern with dual plating if standard plates are used [20]. We attempted to mitigate this by placing the smaller plate in the more superficial position. Despite these efforts, the complaint rate of 24% indicates room for improvement. Importantly, none of our patients found it severe enough to undergo a second surgery within the first year. It may be that over a longer term, a few might opt for elective plate removal once the bone is fully remodeled (a consideration outside our follow-up window). Going forward, the use of dedicated low-profile plates or even newer materials might help address this drawback. Nonetheless, it should be emphasized that implant irritation did not translate into any functional deficit in our series; it was more of a patient comfort issue.

Overall, our findings align with the emerging consensus that dual plating can be implemented without adding undue risk, and it may provide tangible benefits in certain scenarios. Particularly in fractures with risk factors for failure - such as multifragmentary patterns, osteoporotic bone, or in patients who place high demands on the shoulder - a dual-plate configuration offers enhanced stability. Recent clinical evidence has suggested that adopting dual plating selectively (for example, in smokers with transverse fracture patterns) markedly lowered reoperation rates compared to sticking with single plating [6]. Our experience supports the notion that dual plating is a valuable tool in the armamentarium for difficult clavicle fractures.

Limitations

This study has several limitations that should be acknowledged. First, the sample size of 25 patients is relatively small, and the study was conducted at a single institution. A larger cohort would provide more statistical power to detect differences in outcomes and complications, and to better generalize the findings. Second, our study was not a randomized controlled trial; we did not have a concurrent control group of single-plate fixations for direct comparison. Our comparisons to single plating are therefore based on historical and literature controls, which could introduce bias given potential differences in patient populations or treatment protocols. Third, the follow-up duration was one year, which we consider adequate for assessing union and early complications, but longer-term outcomes (such as very late hardware issues or functional status beyond one year) were not captured. It is possible that some patients might choose to have hardware removal or experience issues after the one-year mark that we did not record. Fourth, although we aimed to standardize the dual-plate technique, there was some variability (e.g., choice of plate type, positioning of the small plate superior vs anterior in certain cases). We did not strictly compare outcomes between different dual plate configurations due to the small numbers, so we cannot definitively say if one configuration is superior to another in clinical practice. Fifth, we did not perform a formal cost or time analysis; dual plating may involve slightly longer operative time and the cost of an additional implant, which we did not measure, but these factors could be weighed in a health economics context. Lastly, patient-reported outcome measures more sensitive than Constant score (such as DASH or QuickDASH) were not used; incorporating those in future studies could provide a more nuanced view of patient satisfaction and function. Despite these limitations, we believe our study adds meaningful evidence regarding the safety and efficacy of dual plating. Future research, ideally in the form of larger multicenter trials or randomized studies, will help to further clarify the role of dual plating and identify which patients benefit the most from this approach.

Conclusion

Open reduction and internal fixation of acute, displaced clavicle fractures using an extraperiosteal dual-plate technique is a dependable treatment option, especially in cases of highly comminuted fractures or situations where additional fixation is desired due to poor bone quality or risk factors for nonunion. In our series, dual plating achieved a 100% union rate and excellent functional outcomes at one year, without an increase in complications relative to historical results of single plating. Biomech-

anically, the dual-plate construct provided robust stability in multiple planes, and clinically it succeeded even in two cases where single plating had failed. The addition of an augmentation plate did not compromise the healing process, likely owing to careful surgical technique preserving blood supply. Dual plating can thus be utilized in acute clavicle fracture management (and in revision scenarios) to enhance fixation security. The primary downside observed was implant prominence in some patients; thus, further refinement in implant design (low-profile plates) or technique may be beneficial to minimize hardware irritation. Overall, our findings suggest that, with proper technique, dual plating is a safe and effective strategy for managing complex clavicle fractures, and we encourage continued investigation through larger studies to fully establish its indications and long-term outcomes.

Disclosure of conflict of interest

None.

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