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# Acromioclavicular joint dislocation with loop double endobutton fixation assisted by orthopaedic surgery robot positioning system

Chengzhi Yang[1†], Gang Liu[1†], Wanjie Lan[2], Lu Li[3], Renchong Wang[1], Jingli Tang[1], Hao Wu[1] and Juzheng Hu[1*]

## Abstract

**Objective** Acute acromioclavicular (AC) joint dislocation is a common orthopedic injury that can significantly impair shoulder function and reduce quality of life. Effective treatment methods are essential to restore function and alleviate pain. To investigate the short-term clinical efficacy of the minimally invasive closed-loop double endobutton fixation assisted by orthopaedic surgery robot positioning system (TiRobot) in the treatment of AC joint dislocation, and to evaluate its feasibility and safety.

**Methods** The clinical data of 19 patients with AC joint dislocation who underwent treatment with closed-loop double Endobutton fixation assisted by TiRobot between May 2020 and December 2022 were retrospectively analyzed. Visual Analog Scale (VAS) pain scores, the Constant Murley Score (CMS), and shoulder abduction range of motion were assessed and compared preoperatively and at the last follow-up. Computed tomography (CT) parameters of the acromioclavicular joint, including acromioclavicular distance (ACD), the distance between the upper and lower Endobutton (DED), the horizontal distance between the anterior edge of the distal clavicle and the anterior edge of the acromion (DACC), the diameter of the clavicular tunnel (DCT), and coracoid tunnel diameter (DC), were compared at 2 days, and 1 month after surgery, as well as at the last follow-up, along with the evaluation of intraoperative and postoperative complications.

**Results** The postoperative VAS, CMS, and shoulder-abduction range of motion were significantly improved compared with the preoperative (all, $P<0.05$). The statistical analysis showed no significant difference in the CT image parameters of the acromioclavicular joint at 2 days and 1 month after surgery(all, $P>0.05$). Comparisons of DCT and DC revealed statistically significant differences between the last follow-up and 1 month after surgery ($P<0.05$), and no statistically significant difference was found in ACD, DED, and DACC(all, $P>0.05$). There were no complications such as infection or vascular or neurological damage, no cases of rostral or clavicle fractures, loss of reduction, heterotopic ossification, shoulder stiffness, and no loosening or breaking of internal fixations.

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**Conclusion** Closed-loop double endobutton internal fixation assisted by TiRobot is an ideal method for the treatment of acute acromioclavicular (AC) joint dislocation. This method has the advantages of relatively simple operation, more accurate localization of bone tunnel during operation, less surgical trauma, and good recovery of shoulder function.

**Keywords** Acromioclavicular joint, Computer-assisted surgery, Joint dislocations, Robotics, Endobutton

## Introduction

Acromioclavicular (AC) joint dislocation is a frequently encountered shoulder injury in clinical practice. The management option is determined by its severity. Typically, Rockwood I and II lesions are treated non-surgically, and surgery is usually recommended for Rockwood type IV and V. However, Rockwood type III dislocations remain a challenging case in terms of optimal treatment [1], particularly for active individuals, younger patients, and athletes, where aggressive surgical intervention may enhance stability and shoulder function [2–4].

Currently, there are various surgical techniques for the fixation and reconstruction of the AC joint, yet no gold standard procedure has emerged [5]. Some commonly employed surgical methods include hook plate fixation surgery, closed-loop double endobutton technique, and suture anchor fixation [5, 6]. The clavicle hook plate is widely utilized in clinical practice due to its simplicity and efficacy [5]. However, with the increasing application of this method, complications like acromial impingement, subacromial bone resorption, postoperative shoulder pain, restricted shoulder mobility, and fractures around the plate have also been on the rise.

Recent in-depth studies on the anatomy and biomechanics of the AC joint have spurred the development and application of novel surgical approaches. Recently, the closed-loop double endobutton has been used to treat acute AC dislocations with good clinical results. Notably, this method has demonstrated superior performance in cyclic loading and strength compared to clavicle hook plate fixation techniques and other repair methods [7]. The technique of endobutton suspension fixation involves drilling bone tunnels in the clavicle and coracoid, relying on intraoperative C-arm fluoroscopy to establish these tunnels. However, tunnel deviation during endobutton placement,, especially in the coracoid, poses a risk of fractures. To ensure that the coracoid tunnel is ideally positioned at the central base, some researchers advocate arthroscopic guidance for precise tunnel positioning, though this adds to surgical complexity and potential shoulder joint trauma [8–11].

With the continuous development of technology, orthopedic robotic-assisted minimally invasive internal fixation techniques are increasingly finding application in the field of medicine. Since January 2020, the third-generation orthopaedic surgery robot TiRobot was introduced in our institute. In order to explore a procedure that is minimally invasive, effective, and has quick postoperative recovery, we use robot-assisted surgery to treat acromioclavicular joint dislocation. Under robotic assistance, we conducted minimal invasive closed-loop double endobutton suspension fixation surgery on 19 patients with acute AC joint dislocation. The objective was to evaluate the feasibility and advantages of the robot-assisted procedures, while also outlining specific considerations for the utilization of the orthopedic robotic system.

## Materials and methods

### Inclusion and exclusion criteria

The inclusion criteria included: (i)patients with Rockwood III-IV grade acromioclavicular joint dislocation; (ii) closed injuries with a duration of less than 3 weeks; (iii) absence of vascular and neural injuries; (iv) no associated fractures of the scapula, clavicle, or proximal humerus; (v) no evidence of osteoporosis; (vi) patients with good compliance.

The exclusion criteria included: (i) Open injuries; (ii) Chronic injuries; (iii) Patients presenting with concurrent shoulder cuff injuries or other shoulder joint traumas; (iv) Individuals with pre-existing shoulder dysfunction on the affected side or severe systemic medical conditions that make them unsuitable candidates for surgery; (v) Patients with significant comorbidities preventing them from tolerating anesthesia and surgery, including those with osteoporosis; (vi) Cases with incomplete follow-up data or a follow-up duration of less than 6 months, and individuals exhibiting poor compliance.

### General clinical data

The clinical data of 19 patients with fresh acromioclavicular joint dislocation between May 2020 and December 2022 were retrospectively analyzed (Fig. 1). Among them, there were 10 males and 9 females, with ages ranging from 19 to 53 years and an average age of (38±4.1) years. According to the Rockwood classification, there were 16 cases of type III and 3 cases of type IV. The mechanisms of injury included falls in 15 cases and traffic accidents in 4 cases, with no severe associated injuries. The time from injury to surgery ranged from 3 to 8 days, with an average of 4.5 days. Clinical and radiological presentations of the patients were consistent with the diagnosis. Preoperatively, all cases routinely underwent shoulder joint anteroposterior X-rays and shoulder joint CT scans. The

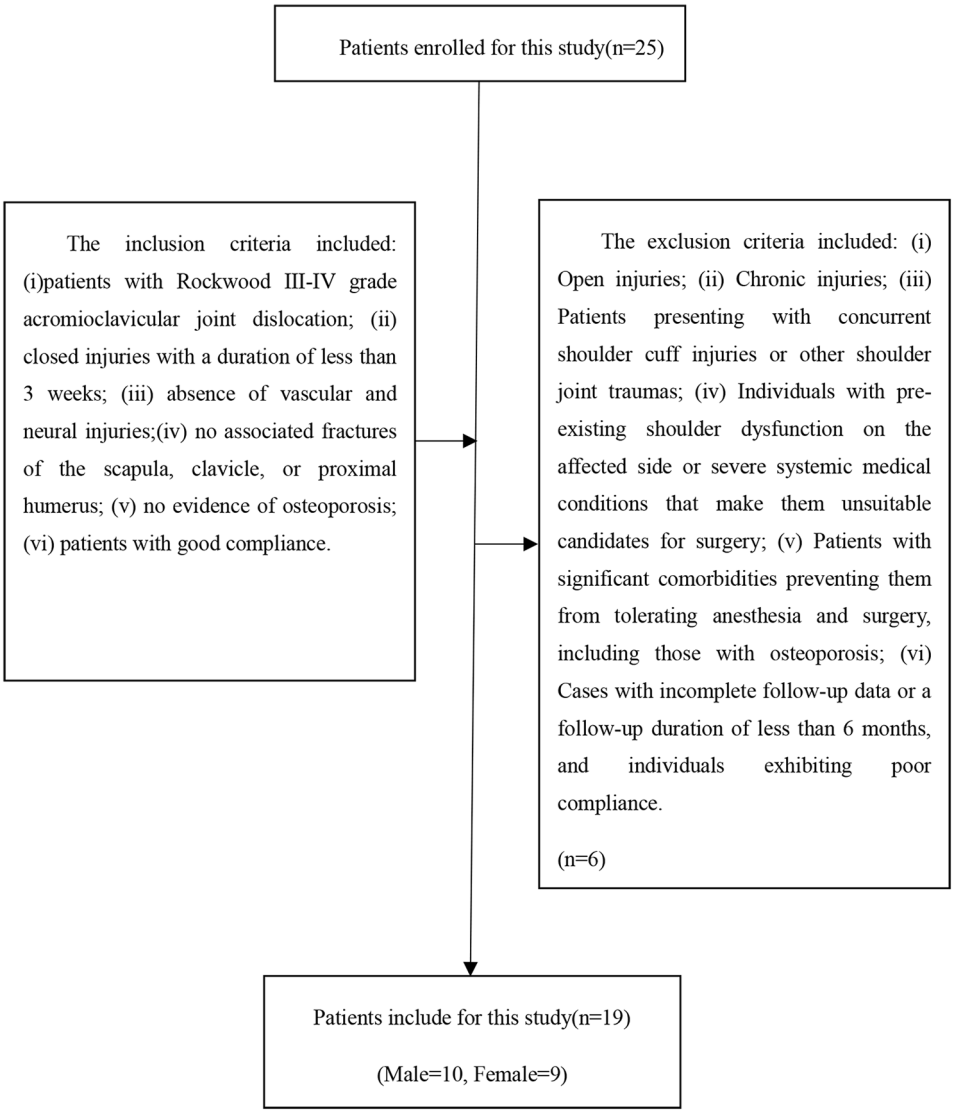


**Fig. 1** Flow chart of patient inclusion

study was approved by the ethics committee of our hospital, all patients signed informed consent for surgery.

### Operative procedure

**Patient preparation.** The patient was positioned supine on a radiolucent operating table, with brachial plexus anesthesia administered. The affected shoulder was slightly elevated, and the head and neck were oriented toward the contralateral side. Restraining straps were utilized to secure the affected upper limb and torso. Radiation protection lead caps and aprons were applied to the head, face, neck, trunk, and perineum. Standard disinfection procedures were employed, including the placement of sterile drapes.

**Dislocation reduction and maintenance.** The dislocation reduction was achieved through manipulative techniques. A Kirschner wire (K-wire) with a diameter of 2.0 mm was employed to maintain the reduction. In cases where maintaining reduction proved challenging, a cross-pin fixation method was implemented using 2 K-wires.

**Navigation image acquisition, registration, and Surgical path planning**. A patient tracker was inserted at the acromion to ensure continuous visibility within the optical tracking system of the mechanical arm. The C-arm in three-dimensional mode is employed to acquire intraoperative fluoroscopy images by rotating 180° around shoulder and transmitting them to the navigation system for three-dimensional imaging and registration calculation. The location of the guide needle was then planned on the reconstructed three planes (anteroposterior, lateral, and coronal plane). The clavicular tunnel was positioned centrally within the anterior and posterior cortical aspects of the clavicle, while the coracoid tunnel was

situated centrally within the medial and lateral aspects of the coracoid base.

**Precise bone tunnel drilling**. A transverse incision, approximately 1.5 cm in length, was made above the clavicle along the predetermined pathway, traversing the skin, and subcutaneous tissues, and reaching the cortical layer of the clavicle. Following the planned trajectory, a 2.5 mm-diameter guide pin was vertically inserted from the superior aspect of the clavicle (with the entry point precisely situated at the central aspect of the anterior or posterior clavicular cortex) towards the inferior aspect of the coracoid (exit point precisely located at the central aspect of the medial or lateral coracoid cortex at its base). Confirmation of the guide pin placement involved ensuring its precise penetration through the cortical margin of the coracoid. C-arm X-ray machine fluoroscopy confirms that the guide pin was placed in a good position, upon confirming the satisfactory location, the guide pin was withdrawn.

**Threading and knotting**. A longitudinal incision, approximately 1.5 cm in length, was made below the coracoid process. Blunt dissection was performed, extending down to the base of the coracoid. A 2.0 mm passage wire was introduced through the clavicular tunnel from above, guiding a four-strand non-absorbable high-strength suture (Johnson & Johnson, USA) loaded on an endobutton titanium plate (Smith & Nephew, UK) down to the base of the coracoid through the incision below the coracoid. Above the clavicle, the four strands of high-strength suture were threaded through the endobutton titanium plate, and a "Nice" knot was executed on the endobutton titanium plate above the clavicle to secure and tighten the fixation.

**Reduction and fixation confirmation.** The 2.0 mm K-wire temporarily stabilizing the acromioclavicular joint was removed. Subsequently, a fluoroscopic assessment using aC-arm X-ray machine fluoroscopy was performed to confirm the reduction of the AC joint and verify the positions of the bone tunnels and the endobutton titanium plate. Layer-by-layer suturing was then carried out, followed by subcutaneous closure of the incision. All surgeries were performed by the same senior surgeon (Doctor Yang) who received formal operational training and followed standardized operational procedures during surgery. Figure 2. The operative procedure.

### Postoperative management and observation indicators

Within the first 24 h postoperatively, antibiotic therapy with first or second-generation cephalosporins was administered to prevent infection. Concurrently, analgesia, anti-swelling measures, and symptomatic treatment were employed. Postoperatively, routine shoulder

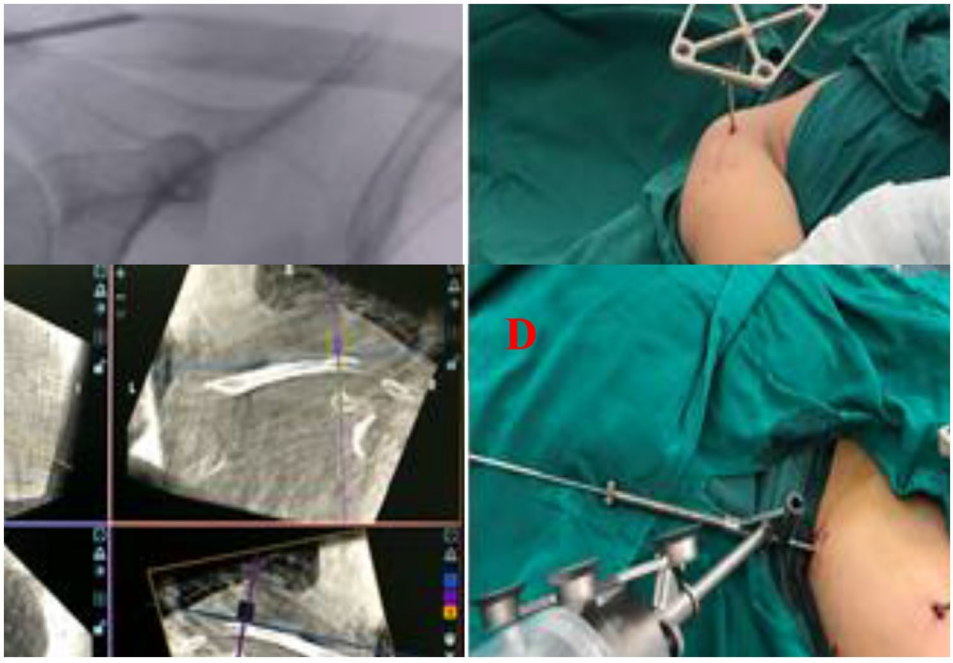


**Fig. 2** The operative procedure. (**A**) Closed reduction of the acromioclavicular joint dislocation was performed, and while a single Kirschner wire fixation proved challenging to maintain, a dual Kirschner wire configuration was employed for cross-fixation of the acromioclavicular joint to ensure sustained reduction. (**B**) A patient tracker was inserted at the proximal end of the humerus. The tracker support structure was secured as close as possible to the proximal end, with careful attention paid to intraoperative maneuvers to prevent damage to the biceps tendon, axillary nerve, and humeral head cartilage. Simultaneously, fixation of the affected limb and trunk was performed to prevent displacement of the limb during the procedure, thus avoiding any positioning discrepancies. (**C**) Preoperatively, the pathways for the clavicular and coracoid tunnels were meticulously planned. (**D**) Following the planned trajectory, a 2.5 mm-diameter bone tunnel guide pin was inserted

X-rays and CT scans were conducted to assess the quality of reduction and the position of internal fixation. Passive shoulder joint functional exercises commenced on the third postoperative day, performed three times daily, each session lasting 20–30 min. Subsequently, outpatient follow-up visits were scheduled at 1, 2, 3, 6, and 12 months postoperatively. The affected limb was suspended for 6 weeks postoperatively after which active shoulder joint exercises were introduced. However, heavy lifting and strenuous activities were to be avoided for the subsequent 3 months. Permission for a gradual transition to full weight-bearing status was granted after 6 months postoperatively.

Before the surgery, on the second day postoperatively, and at the last follow-up, each affected limb underwent assessments using the Visual Analogue Scale (VAS) for pain, the Constant-Murley score (CMS), and an evaluation of shoulder joint abduction. Concurrently, CT imaging parameters of the AC joint were collected at 1 month and 1 year postoperatively. These parameters encompassed the acromioclavicular distance (ACD), the distance between the upper and lower endobutton titanium plates (DED), the horizontal span between the anterior edge of the distal clavicle and the anterior edge of the acromion (DACC), the diameter of the conoid tubercle tunnel (DC), the diameter of the clavicle tunnel (DCT), along with monitoring complications during and post-surgery.

During postoperative follow-ups, a seasoned musculoskeletal ultrasound specialist conducted ultrasound examinations on both the affected and unaffected sides of the AC joint. Ultrasound was utilized to discern the continuity and width of the acromioclavicular ligament and coracoclavicular ligament. Color ultrasound images and data were meticulously acquired and measured to assess the healing status of the ligaments on the affected side, drawing comparisons with the unaffected side. Three independent sonographers performed measurements twice in order to assess the inter- and intraobserver reliability of the method.

### Statistical analysis

Statistical analysis was conducted using SPSS 27.0 software (IBM SPSS 27.0, SPSS Inc). Continuous data, including age, Visual Analogue Scale (VAS) scores, Constant-Murley scores (CMS), shoulder joint abduction range, acromioclavicular distance (ACD), the distance between endobuttons (DED), horizontal distance between the anterior edges of the distal clavicle and acromion (DACC), diameter of the conoid tubercle tunnel (DC), diameter of the clavicle tunnel (DCT), as well as widths of the acromioclavicular ligament and coracoclavicular ligament, were expressed as means ± standard deviations. Continuous variables were presented as means and standard deviation (SD) and compared using a Student's *t*-test when the data were normally distributed, whereas characteristics with non-normal distributions are were presented as median (Quartiles), and the Mann-Whitney *U* test was performed. Categorical data, such as gender, type of injury, and incidence rates of complications, were presented as counts and percentages (%), and inter-group comparisons were performed using the chi-square test. *p*-values less than 0.05 ($P<0.05$) were considered significant. For the analysis of the reliability in an intra- and interobserver setup, the intraclass correlation coefficients (ICC) and their 95% confidence intervals were calculated. The ICC ranges from 0.00 (no agreement) to 1.00 (perfect agreement). Data from both readings were used for the assessment of the reliability in the interobserver setup. ICC values > 0.8 were considered to show excellent reliability.

## Results

### Perioperative patient profile

19 cases were completed with robot-assisted closed-loop double endobutton internal fixation surgery. Among them, 1 patient exhibited preoperative CT evidence of cartilage disc injury and subsequent dislocation, observed as a free-floating disc outside the acromioclavicular(AC) joint. This particular patient underwent AC joint open reduction, entailing the removal of the damaged cartilage disc, and direct repair of the acromioclavicular ligament under direct visualization. The remaining 18 patients did not undergo open reduction for the AC joint. Intraoperatively, no complications such as axillary vascular or nerve injuries were encountered in any of the patients. Postoperatively, no adverse events, including fever, incision infection, incision fat liquefaction, or numbness in the skin around the incision site, were reported. The follow-up period spanned from 12 to 24 months, with an average duration of 14.8 months. Typical cases are shown in Fig. 3.

### Pre- and postoperative pain and function of the shoulder

At the final follow-up, a significant improvement was observed in VAS scores, Constant-Murley scores (CMS), and shoulder abduction range of motion when compared to preoperative values (all, $P<0.05$). Details are shown in Table 1.

### CT imaging parameters

On the second day and 1 month after surgery, there were no statistically significant differences in the measured indicators of the acromioclavicular distance(ACD), the distance between the upper and lower Endobutton titanium plates (DED), the horizontal span between the anterior edge of the distal clavicle and the anterior edge of the acromion (DACC), the diameter of the conoid

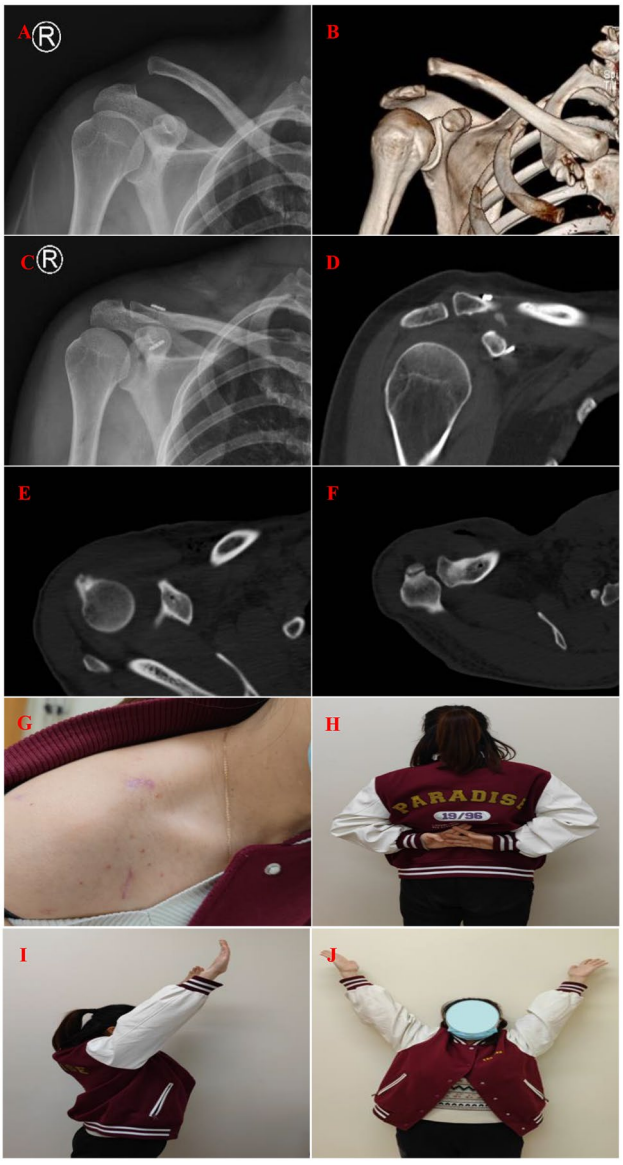


**Fig. 3** Typical case. (**A** and **B**) Pre-operative X-ray and CT scans showed dislocation of the acromioclavicular joint. (**C** and **D**) Post-operative X-ray and CT scans showed that the acromioclavicular joint was well repositioned and the internal fixation position was good. (**E** and **F**) Post-operative CT scans showed the location of the bone tunnels were good. (**G**) With few scars on the body surface after the operation and more cosmetic effect. (**H**, **I** and **J**) Shoulder function at the end of the follow-up was good

tubercle tunnel (DC), the diameter of the clavicle tunnel (DCT). However, at the final follow-up, significant statistical differences were observed in DCT and DC compared to 1 month postoperatively. Specifically, there was a pronounced lower canal expansion compared to the upper canal, presenting a "flask" shape; the suprascapular canal expansion was more noticeable than the infrascapular canal, exhibiting an "inverted flask" shape; and the clavicular canal expansion was more apparent than the coracoid canal(Figure 4), with statistically significant differences ($P<0.05$). On the other hand, no statistically significant differences were found in ACD, DED, and DACC indicators ($P>0.05$). At the final follow-up, the reduction loss of ACDwas less than 1 mm in 17 cases, with 2 cases experiencing a loss of 1–2 mm. According to the definition of reduction loss based on ACD>5 mm postoperatively [12], no cases experienced reduction loss, resulting in a reduction loss rate of 0% (0/19) for ACD expansion greater than 5 mm.

### Healing of the ligament

Preoperatively, color Doppler ultrasound revealed 10 cases of coracoclavicular ligament rupture located at the coracoid attachment point, 5 cases at the clavicular attachment point, and 4 cases in the middle part of the ligament. Postoperatively, ultrasound examinations of the coracoclavicular and acromioclavicular ligaments were conducted at 1, 2, and 3 months, as well as at the final follow-up. At the 3-month postoperative mark, a musculoskeletal ultrasound demonstrated imaging indicative of ligament healing. At the final follow-up, ultrasound examinations in 17 patients displayed good continuity of the affected side's acromioclavicular and coracoclavicular ligaments. There was no reduction in echogenicity at the ligament ends, and no surrounding fluid accumulation, except for 2 cases where the coracoclavicular ligament presentation was unclear(Figure 5). At the final follow-up, the thickness of the affected side's acromioclavicular ligament in 17 patients ranged from 2.1 to 3.6±1.1 mm (average 2.6±0.4 mm), while the thickness of the healthy side's acromioclavicular ligament ranged from 2.2 to 3.8 mm (average 2.8±0.3 mm). The comparison between the two sides showed no statistically significant difference ($P=0.08$). On the affected side, the coracoclavicular ligament thickness ranged from 8.1 to 9.7 mm (average 8.1±1.4 mm), while on the healthy side, it ranged from 9.2 to 11.4 mm (average 10.2±1.1 mm). The comparison between the two sides revealed a statistically significant difference ($P=0.04$). The inter- and intraoberver reliability was very high. The ICC values were >0.95 in all cases with minimally higher values for the intraobserver setup.

### The occurrence of complications

Among the 19 cases, cortical bone resorption on the superior surface of the clavicle was observed in 2 cases, resulting in a slight 2 mm depression of the endobutton on the clavicle. However, no complications such as incision infection, incision fat liquefaction, vascular or nerve damage, dull sensation around the incision, migration of the internal implant, periprosthetic fractures, heterotopic ossification, traumatic arthritis, or shoulder joint stiffness were observed.

**Table 1** The clinical efficacy and CT imaging parameters

| | Preoperative | 2 days after surgery | 1 month after surgery | The last follow-up | t value | *P* value |
|---|---|---|---|---|---|---|
| VAS score | 5.3 ± 1.1 | 8.4 ± 2.6 | 2.2 ± 0.8 | 0.5 ± 0.1 | $t_a$=10.46<br>$t_b$=5.241 | $P_a$=0.01<br>$P_b$=0.03 |
| Constant-Murley score | 55.6 ± 4.2 | / | / | 92 ± 3.4 | $t_a$=7.28 | $P_a$=0.012 |
| Shoulder abduction (degrees) | 42.2 ± 5.2 | / | / | 172.6 ± 7.4 | $t_a$=17.24 | $P_a$<0.001 |
| ACD (mm) | / | 0.61 ± 0.02 | 0.62 ± 0.02 | 0.76 ± 0.04 | $t_b$=1.26 | $P_b$=0.14 |
| DED (mm) | / | 25.1 ± 2.4 | 26.2 ± 2.4 | 27.6 ± 2.8 | $t_b$=0.75 | $P_b$=0.45 |
| DACC (mm) | / | 1.4 ± 0.6 | 1.6 ± 0.2 | 1.8 ± 0.3 | $t_b$=1.01 | $P_b$=0.24 |
| DC (mm) | / | 2.5(2.5, 2.5) | 2.74 ± 0.16 | 4.7 ± 1.2 | $t_b$=1.67 | $P_b$=0.08 |
| DCT (mm) | / | 2.5(2.5, 2.5) | 2.62 ± 0.12 | 3.6 ± 1.1 | $t_b$=6.43 | $P_b$=0.04 |

VAS: Visual Analogue Scale, ACD: acromioclavicular distance, DED: the distance between the upper and lower endobutton titanium plates, DACC: the horizontal span between the anterior edge of the distal clavicle and the anterior edge of the acromion, DC: the diameter of the conoid tubercle tunnel, DCT: the diameter of the clavicle tunnel, a: Comparison between preoperative and final follow-up, b: Comparison between 1 month after surgery and final follow-up

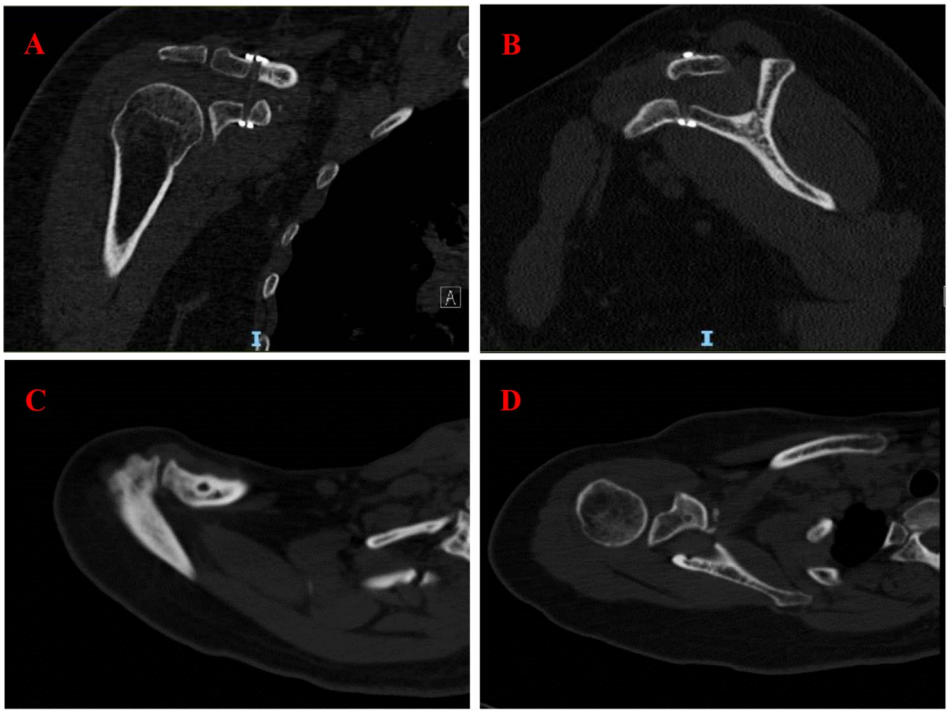


**Fig. 4** Follow-up CT scans showed tunnel enlargement. (**A** and **B**) The clavicle bone tunnel exhibited a "funnel" shape expansion, while the coracoid bone tunnel demonstrated an "inverted funnel" shape expansion. (**C** and **D**) The clavicular tunnel has widened, with the diameter increasing from 2.5 mm to 5.96 mm, the coracoid tunnel has widened, with the diameter increasing from 2.5 mm to 4.37 mm

## Discussion

With the continuous advancement of technology, the field of artificial intelligence has entered a new era, the planning of surgical treatment in orthopedics, with the help of three-dimensional (3D) technologies, has been widely used in the field of trauma orthopedics [13] and the utilization of medical robots in orthopedic surgery is becoming increasingly prevalent. This robotic system adopts a universal, compact, and modular design. Operators employ imaging devices to scan the patient's injury site and acquire medical images. Subsequently, the images are transmitted to the control console, where, upon recognition, the operators can design the surgical parameters such as the direction, entry point, and depth of internal fixation screws. During the surgical execution phase, the robotic arm achieves precise positioning based on the physician's planning, assisting in the surgery. The optical tracking system conducts real-time position monitoring, and in the event of positioning errors, it guides the robotic arm to automatically track and adjust. In comparison to traditional surgery, TiRobot offers advantages in terms of precise positioning, high accuracy, intelligence, safety, and efficiency.

Acromioclavicular joint dislocation using three-dimensional navigation robotic-assisted loop double endobutton placement is undertaken in this study, and good

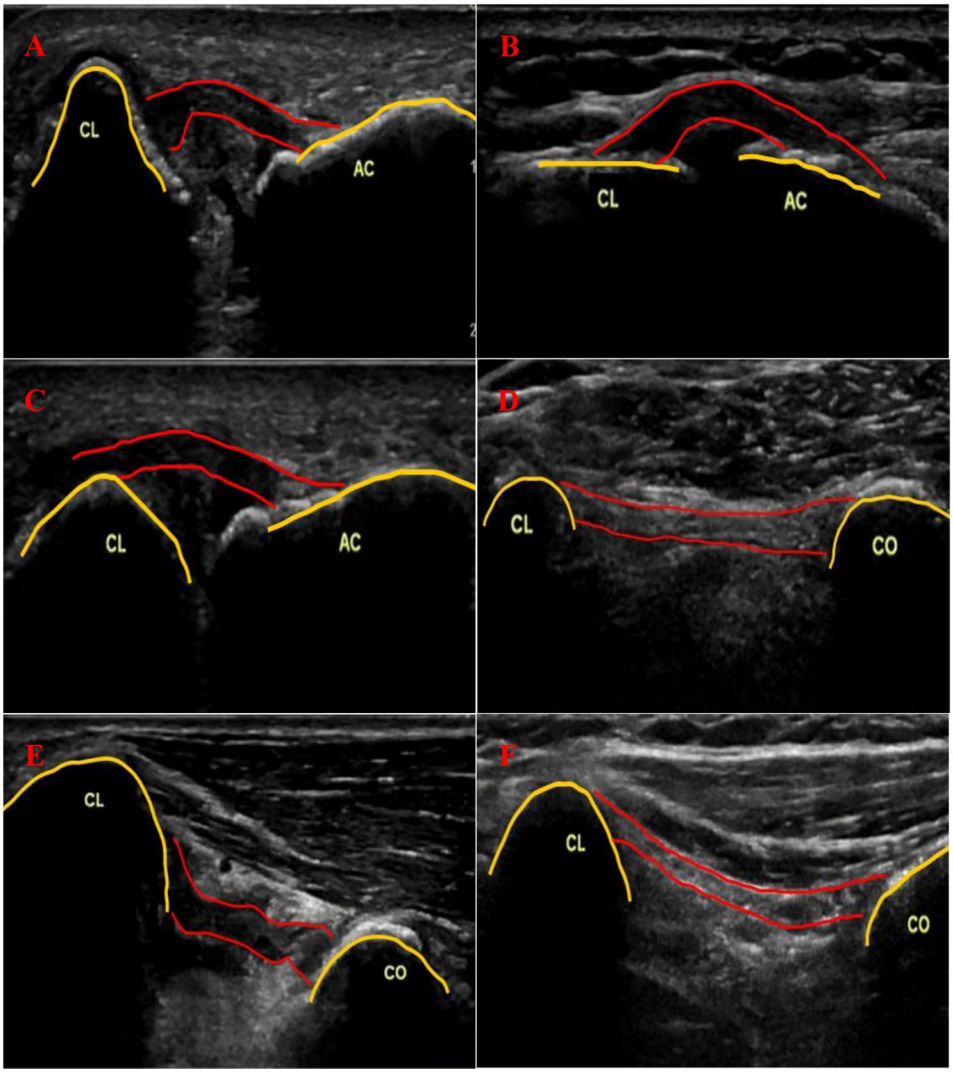


**Fig. 5** Musculoskeletal ultrasound imaging. (**A**) Preoperative ultrasound examination shown continuous disruption of the acromioclavicular ligament. (**B**) The continuity of the acromioclavicular ligament was good at the last follow-up time, with a slight elevation compared to the normal side, suggesting healing through scar tissue formation after injury. (**C** and **D**) Healthy side acromioclavicular ligament and coracoclavicular ligament ultrasound images. (**E**) Preoperative ultrasound examination shown continuous disruption of the coracoclavicular ligament, the broken end was located on the coracoid side. (**F**) The continuity of the coracoclavicular ligament was good at the last follow-up time. CL: clavicle, AC: acromion, CO: coracoid. The imaging between the two red lines corresponds to the acromioclavicular ligament and the coracoclavicular ligament

clinical results have been achieved. In this study, we employed robot assistance to create clavicle and coracoid bone tunnels, ensuring that the tunnels were centrally located within the anterior and posterior cortices of the clavicle and the inner and outer cortices of the coracoid. The enlargement of the bone tunnel can still be observed in later follow-up. A study [14] asserted that the reason for the more susceptible enlargement of the clavicular end tunnel was its proximity to the metaphyseal end of the clavicle, which contained a greater amount of cancellous bone. The extent of tunnel enlargement for the clavicle and coracoid process tended to be lower in tunnels oriented more vertically compared to oblique tunnels. This was attributed to the fact that, during shoulder movement, vertically oriented tunnels could reduce cutting forces, thereby mitigating the extent of tunnel enlargement. This study employed 2.5 mm Kirschner wires to create bone tunnels, and four strands of Ultrabraid high-strength suture were tightly packed within the tunnels. In comparison to 4.5 mm bone tunnels, the resulting "windshield wiper" effect was minimized. During the final follow-up, varying degrees of enlargement were observed in the coracoid and clavicle bone tunnel diameters. The clavicle bone tunnel exhibited a "funnel" shape expansion, while the coracoid bone tunnel demonstrated an "inverted funnel" shape expansion, with the enlargement of the clavicle bone tunnel significantly surpassing that of the coracoid bone tunnel.

We hypothesized that the position of the acromion was relatively stable, with a greater range of motion observed at the distal end of the clavicle. During shoulder movement, a "windshield wiper" effect was generated within the tunnel by the cables, resulting in a propensity for the clavicular tunnel to be more susceptible to cable cutting compared to the coracoid tunnel. These factors may have contributed to the observed characteristics of bone tunnel enlargement mentioned above.

The endobutton technique has demonstrated outstanding biomechanical performance and clinical efficacy in the treatment of acute AC joint dislocation. However, some scholars have reported complications, including bone resorption at the contact site between the clavicle and the endobutton. This phenomenon results in a partial displacement of the endobutton and reduction loss postoperatively [15]. To address these complications, we employed a robot-assisted approach, utilizing 2.5 mm diameter Kirschner wires to establish bone tunnels instead of using a 4.5 mm diameter hollow drill. The smaller diameter bone tunnels result in a more uniform pressure distribution on the titanium plate contact surface. In theory, this helps prevent plate displacement caused by bone resorption. In addition, if the arm that places the tracer moves during the operation or the influence of respiratory motion, the positioned tunnel may not be centered. These factors may cause internal fixation failure. Although there were no fixation failures in this study, the possibility of type II error still exists due to the limited cases and the minimum follow-up, the sample size should be expanded and the follow-up time should be extended in further research.

Based on the results of the biomechanical study [16], double endobutton provided approximately twice the mechanical stability compared to the coracoclavicular ligament. Consequently, the double endobutton effectively maintained the elasticity and toughness of the coracoclavicular ligament, preventing the recurrence of dislocation. The endobutton was manufactured using titanium alloy, and the Ultrabraid high-strength suture was composed of ultra-high-molecular-weight polyethylene (UHMWPE) and polypropylene monofilament, demonstrating excellent biocompatibility. These materials were non-degradable and could remain in the body for an extended period, eliminating the need for secondary surgery for removal. In surgery using the double endobutton, there was no need for conventional incisions to expose the acromioclavicular joint, and implantation beneath the acromion was not required. The surgical procedure did not involve the rotator cuff tissues or the glenohumeral joint space, thereby avoiding postoperative pain caused by acromial impingement and preventing shoulder joint adhesions. Patients could engage in better postoperative shoulder joint abduction, elevation, internal rotation, and external rotation, facilitating early functional exercises.

Musculoskeletal ultrasound has been deemed a reliable diagnostic tool for assessing injuries and healing in tissues such as the rotator cuff, acromioclavicular ligament, coracoclavicular ligament, and Achilles tendon. Compared to methods such as magnetic resonance imaging and spiral computed tomography, musculoskeletal ultrasound offered the advantages of low cost, absence of ionizing radiation, convenience, speed, and the ability to provide dynamic observations of ligaments at specific locations or in multiple planes [17]. Therefore, in clinical diagnosis and follow-up processes, we preferred utilizing ultrasound imaging to assess ligament injuries and healing status. In this study, we conducted color Doppler ultrasound examinations at 1, 2, and 3 months postoperatively. By the 3-month postoperative mark, the ligaments displayed imaging indicative of healing. Ultrasound imaging was used to assess ligament healing status. In two cases, the ultrasound images of the coracoclavicular ligament were not sufficiently clear, while 89.5% (17/19) of patients exhibited good continuity of the acromioclavicular and coracoclavicular ligaments. At the final follow-up of this study, the thickness of the injured-side coracoclavicular ligament ranged from 8.1 to 9.7 millimeters (average $8.1 \pm 1.4$ millimeters), while the healthy side ranged from 9.2 to 11.4 millimeters (average $10.2 \pm 1.1$ millimeters). The statistically significant difference between the two sides indicated slightly reduced thickness on the injured side. This could be attributed to the transient overstretching of the ligament's muscle fiber bundles during injury and the subsequent result of scar tissue healing post-injury.

The application of an orthopaedic surgery robot positioning system in minimally invasive trauma orthopedic treatments undoubtedly brought revolutionary changes to this field. However, we cannot overlook the fact that as large medical equipment, artificial intelligence systems require clinicians to undergo rigorous training and assessment before operation. Physicians had to strictly adhere to surgical indications and follow standardized operating procedures to ensure the smooth progress of subsequent surgeries. At that time, orthopedic robot systems were expensive and demanded well-established supporting facilities. Therefore, it was challenging for grassroots hospitals to implement such systems. During surgery, 3D X-ray scans were necessary, and doctors had to pay special attention to providing effective protection against ionizing radiation for patients. Many issues may need to be addressed before it can be widely used in health care. Seek innovation and improvements in technology to reduce manufacturing costs of orthopedic robotic systems. This may include using cheaper materials and optimizing designs to reduce the number of

components. Design user interfaces and operational procedures to be more intuitive and easier to learn. This can be achieved by simplifying surgical processes and providing real-time guidance. Develop online training modules and simulation training platforms to allow physicians to undergo virtual training and simulated surgeries before actual operations. Adopt an open platform design that allows integration with equipment and systems from different manufacturers to increase the system's flexibility and applicability.

Nevertheless, there were several limitations in this study: There was a potential risk of selection, confounding, and expertise bias due to the single-institution, retrospective study design. Shortness of the follow-up period and the low number of cases. Moreover, we did not compare this surgical technique with others, such as open surgery or arthroscopic surgery.

In summary, This study applied the orthopaedic surgery robot positioning system in the treatment of acromioclavicular joint dislocation, the TiRobot demonstrated significant practical value in the surgical treatment of fresh acromioclavicular joint dislocation using endobutton fixation. This orthopedic robot established bone tunnels with precision, minimally invasive techniques, intelligence, and safety, offering an ideal new approach for the minimally invasive treatment of acromioclavicular joint dislocation. Furthermore, the procedural, standardized, and stable nature of the robot's surgical operations, coupled with a relatively short learning curve, enhanced its applicability in clinical settings. In the next phase of our research, our research team conducted long-term follow-ups with a large sample of cases to comprehensively assess the clinical effectiveness of TiRobot in the treatment of acromioclavicular joint dislocation surgeries.

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**Author contributions**
Gang Liu and Chengzhi Yang: study design, data collection, and interpretation, figures, and article writing. Renchong Wang and Wanjie Lan: study design, article editing. Jingli Tang and Lu Li: statistical analysis, data collection. Hao Wu: data collection. Juzheng Hu: study design, article editing, and checking the final version. The author(s) read and approved the final manuscript.

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**Data availability**
The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

## Declarations

**Ethics approval and consent to participate**
All of the following procedures followed the ethical standards of the National Committees on Human Experimentation and the Helsinki Declaration of 1964 and later versions and were approved by the Medical Ethics Committee of Liuzhou Worker's Hospital. Informed consent was waived because of the retrospective nature of this study according to the Medical Ethics Committee of Liuzhou Worker's Hospital.

**Consent for publication**
Consent was obtained from all participants for publication of this result and the accompanying images.

**Competing interests**
The authors declare no competing interests.

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