Letter to the Editor

3D printing-assisted surgery for the treatment of proximal clavicle fracture with ipsilateral acromioclavicular joint dislocation: a case description

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Submitted May 22, 2023. Accepted for publication Oct 11, 2023. Published online Nov 16, 2023.
doi: 10.21037/qims-23-720
View this article at: https://dx.doi.org/10.21037/qims-23-720

Introduction

Shoulder injuries, such as clavicle fractures and acromioclavicular (AC) dislocations, are quite prevalent. A study revealed that each year, around 29–64 individuals out of every 100,000 experience clavicle fractures (1). Among the cases reported, people aged 13–20 years are more susceptible to this kind of shoulder injury. Additionally, men are 2.6 times more likely to sustain clavicle fractures than women. These injuries are commonly observed in sports-related activities (2). AC joint dislocation is a prevalent type of shoulder injury, contributing approximately 9% of all AC joint injuries (3). However, instances of this dislocation combined with proximal clavicle fractures are rare (4). This occurs when both ends of the clavicle are not securely attached to the shoulder, resulting in a floating clavicle state. It is important to note that this is different from the typical floating clavicle injury, in which the ipsilateral sternoclavicular and AC joints are dislocated, causing the clavicle to float (5). In the case of this type of fracture and dislocation, the sternoclavicular joint remains unaffected.

The development of 3-dimensional (3D) printing technology has revolutionized the field of surgical planning and medical training models, leading to the creation of highly customized tools (6). 3D printing technology can play a crucial role in the diagnosis, preoperative planning, and doctor-patient communication of complex and rare fractures and dislocations (7,8). By utilizing this technology, medical professionals can achieve a better understanding of the patient's unique case and create a more effective surgical plan. This can lead to improved patient outcomes and a more positive experience for the patient, as they are better informed about their condition and the proposed treatment (9). Several studies have demonstrated the applications of 3D printing technology in aiding the surgical management of a singular midshaft clavicle fracture (10,11). Additionally, there have been reports of utilizing 3D printed models to preoperatively customize the bending of hook plates in the treatment of isolated AC joint dislocation (12,13). Nevertheless, there is currently a lack of literature discussing the utilization of 3D printing technology in cases involving combined AC joint dislocations and proximal clavicle fractures. Here, we report a case of 3D printing-assisted surgical treatment of proximal clavicle fracture with ipsilateral AC joint dislocation.

Patient information

A 53-year-old woman presented to the emergency department with an injury to her left shoulder following a fall from an electric bicycle 4 hours previously. The patient reported persistent dull pain that was aggravated when moving the shoulder, and the numerical rating scale (NRS) was 5. The patient did not present any history of other notable diseases.

Clinical findings

The physical examination revealed swelling and significant deformity of the left shoulder. The distal end of the left

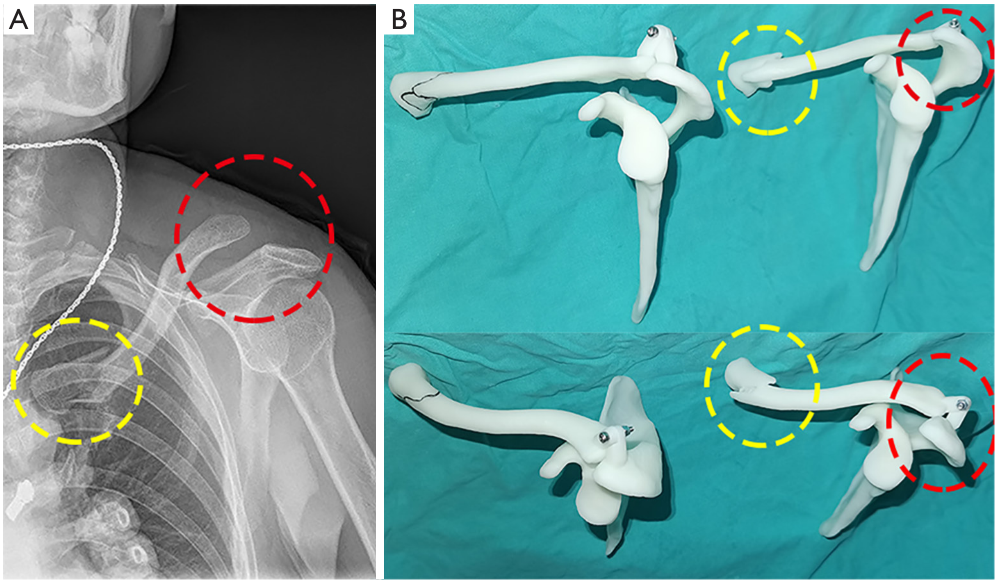

Figure 1 The postoperative evaluation. (A) The preoperative X-ray revealed a shattered fracture (yellow dotted circle) in the left proximal clavicle coupled with an ipsilateral dislocation of the acromioclavicular joint (red dotted circle) and a transverse process fracture in C7 on the left side. (B) A precisely scaled 3D solid model was produced, followed by an exact 1:1 replica of the reduced version, which were then examined from various perspectives. The upper right picture displayed the front view of the 3D printed model before reduction, whereas the lower right picture provides a top view of the same model. The yellow dotted circles showed the proximal clavicle fractures (AO/OTA type 15-A1) and the red circles displayed the dislocation of the acromioclavicular joint (Rockwood type IV). The upper left picture revealed the 3D printed model after reduction, as seen from the front view. The lower left picture showed the model after reduction from the top view. The black lines on the model represented the fracture line, which aided in determining the location of fragments. The 3D printed model after reduction facilitated the pre-bending of the plates. 3D, 3-dimensional; AO/OTA, Arbeitsgemeinschaft fur Osteosynthesefragen/Orthopaedic Trauma Association.

clavicle was observed to protrude upwards and the proximal end protruded forward. Both ends of the left clavicle were tender and the “piano key” sign (14) was positive. In addition, the movement of the left shoulder joint was restricted, exhibiting active range of motion (ROM) limitations of 0–30° in flexion, 0–10° in adduction, 0–45° in abduction, 0–25° in external rotation, and 0–20° in internal rotation. The neurological examination did not reveal any abnormalities.

Diagnostic assessment

The X-ray films revealed multiple fractures and dislocations, including a dislocation in the left AC joint, an increase in the coracoclavicular distance, a comminuted fracture in the proximal left clavicle, and a fracture in the transverse process of the left seventh cervical vertebra (*Figure 1A*). The preoperative computed tomography (CT) scan revealed that the distal clavicle was displaced in an upward and backward direction, along with the presence of a free fragment located in front of the proximal clavicle. Based on these results, the patient was diagnosed with a comminuted fracture of the left proximal clavicle [classified as Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) type 15-A1] (15) in addition to an ipsilateral AC joint dislocation (Rockwood Type IV) (16) and a left transverse process fracture in C7.

Therapeutic intervention

After the patient was admitted, pertinent examinations were conducted, including preoperative blood tests, an electrocardiograph (ECG), a chest CT scan, and a bone mineral density (BMD) test. The left clavicle CT scan’s Digital Imaging and Communications in Medicine (DICOM) format data was uploaded into Mimics software (Materialise Magics, Leuven, Belgium) for a 3D reconstruction. With the help of slicing software

(Materialise Magics), a highly accurate 3D photopolymer solid model was subsequently printed using a 3D printer (3DSL-600; Digitalmanu, Shanghai, China). Using this model, the surgical team planned and simulated the procedure to reduce and coaptation the bone, and subsequently printed a 1:1 3D solid model after the reduction procedure (*Figure 1B*). Based on this model, the team designed plates that were pre-bent and screw lengths that were customized for the patient's anatomy. All implanted plates underwent pressure steam sterilization before the surgery.

During the operation, the patient was positioned in a supine position and the left shoulder was elevated using a silicone pad. Following routine disinfection and draping, an incision was made along the entire length of the clavicle through the skin and subcutaneous tissue. With the assistance of a 3D printing model, the bone fragments were properly reduced and fixed above the clavicle with a pre-bent reconstruction plate (Synthes, Oberdorf, Switzerland). Additionally, a pre-bent clavicle hook plate (Wego Ortho, Weihai, China) was utilized at the distal end to correct the dislocated AC joint, and the surrounding soft tissue was strengthened through suturing. A microplate (Wego Ortho) was employed to fix the proximal anterior free fragment. Intraoperative fluoroscopy confirmed the satisfactory reduction of the fracture, and the internal fixation was accurately aligned with the preoperative design (*Figure 2A,2B*). The surgical site was irrigated with copious amounts of normal saline and meticulous hemostasis was achieved before the incision was sutured. The total surgical duration was 45 minutes, and the blood loss was 50 mL.

Follow-up and outcomes

After the surgery, the patient's left upper limb was kept suspended for a period of 4 weeks, and the fracture in the cervical transverse process was immobilized with a cervical collar for the same length of time. After 4 weeks, the X-ray results were reviewed, and it was observed that the internal fixation of the clavicle was intact, the fracture line had become fuzzy, and the formation of calluses was visible (*Figure 2C*). Additionally, the left AC joint showed no displacement. The patient reported experiencing mild pain (NRS =1) in the left shoulder joint. Consequently, Codman pendulum exercises were initiated after a 4-week follow-up. These exercises involve the patient standing with a flexed trunk, with the affected arm hanging downwards. By utilizing the momentum from trunk movement, the arm is moved without engaging the muscles of the shoulder girdle (17). The exercises were performed for a duration of 30 seconds initially, gradually extending the time until the patients were able to complete 3–5 minutes per session. This was repeated 5 times daily. At 6 weeks after the operation, active exercises such as wall climbing were incorporated. The patient was instructed to position herself sideways or face a wall, and gradually walk her fingers up the wall until experiencing pain limit (18); 8–10 times wall climbing made one cycle, and five cycles were performed each day. At 12 weeks after the surgery, the X-ray films were re-evaluated. The internal fixation of the clavicle remained stable, and the fracture had disappeared completely (*Figure 2D*). Furthermore, the left AC joint showed no signs of displacement. The patient's Constant-Murley shoulder score (19) and Disabilities of the Arm, Shoulder, and Hand (DASH) score (20) had both remarkably improved. Hence, the patient was advised to continue with the exercises and attend the hospital for further follow-ups. After 1 year, the patient underwent examination and the scores for both Constant-Murley and DASH had significantly improved (*Figure 2E,2F*) (*Table 1*). The patient expressed satisfaction with the functioning of her shoulder but wished to adhere to local cultural norms by having the plate removed. Consequently, the plate was successfully removed 1 year after the initial surgery, and a CT scan confirmed that the clavicle had healed well (*Figure 2G,2H*). All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was provided by the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal.

Discussion

The first report of "floating clavicle" could be traced back to 1831, but it was not until 1982 that additional relevant reports began to surface (21). To date, there have been roughly 40 documented cases (22). Furthermore, archaeological research has uncovered evidence of AC and sternoclavicular joint dislocations in remains dating back to the 17th century (22). The typical "floating clavicle" condition is mostly attributed to the dislocation of the AC and sternoclavicular joints, which causes the two ends of the clavicle to remain unfixed and creates an unstable floating state. Sopu *et al.* (23) reported a similar case involving a

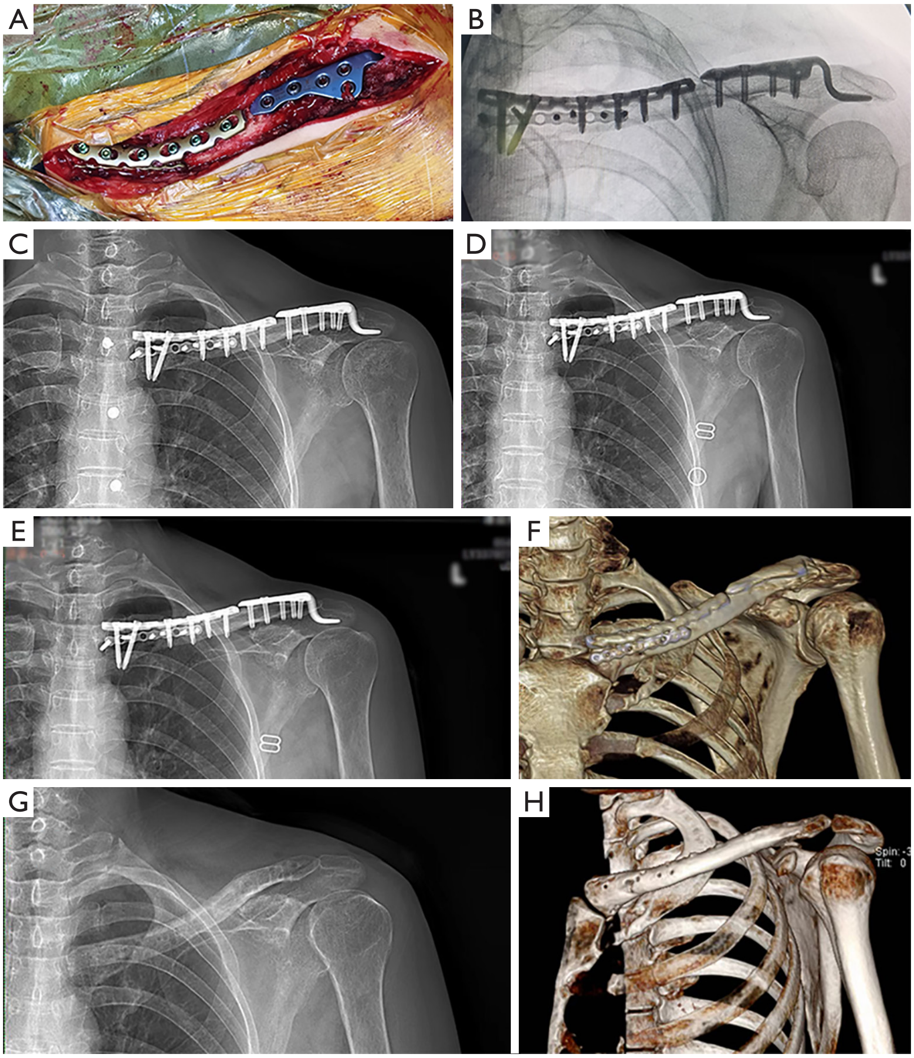

Figure 2 Intraoperative and postoperative evaluation. (A) After all bone fragments were reduced and fixed using three plates and screws, an overall observation was conducted. (B) During the surgery, the utilization of C-arm fluoroscopy presented a successful reduction and fixation of the affected area. (C) After a 4-week follow-up, it was found that the internal fixation was still in place and there was evidence of callus formation. (D) After a 12-week follow-up, it was revealed that the internal fixation is in place and the clavicle is almost completely healed. (E,F) After a 1-year follow-up, the X-ray and CT scans revealed that the clavicle fracture had fully healed. Additionally, the acromioclavicular joint was intact and the internal fixation remained stable. (G,H) After undergoing internal fixation removal surgery, X-rays and CT scans revealed that the clavicle fracture had completely healed and the acromioclavicular joint remained intact. CT, computed tomography.

proximal clavicle fracture combined with a distal clavicle fracture, which was also classified as "floating clavicle".

"Floating clavicle" is a rare condition, with only a few sporadic clinical cases reported (24). Literature on this condition is limited, making it challenging to determine a standardized treatment approach. Moreno-Fenoll *et al.* reported a similar case of dislocation of the ipsilateral AC joint of the proximal clavicle fracture, which was classified as "floating clavicle". However, different surgical methods were used, including the use of locking plates to fix the distal and proximal ends of the fracture, and double-button type with high-strength fibers to repair the distal AC joint dislocation, ultimately achieving good clinical results (4).

Recent work by Bakir *et al.* has proposed a classification of clavicle fractures and ligament complex injuries, with Type II being bilateral complex injuries, accounting for

Table 1 The preoperative scores and follow-up scores

Clinical score	Preoperative	4 weeks	12 weeks	1 year
Constant-Murley shoulder score				
Pain score	0	5	15	15
Functional assessment	2	9	14	19
Range of motion	2	12	22	34
Strength measures	0	6	11	22
Overall	4	32	62	90
DASH score				
Overall	87.9	59.5	40.5	15.5

The Constant-Murley shoulder score was developed to assess the functionality following treatment for a shoulder injury. This test includes four subscales, namely pain (15 points), activities of daily living (20 points), range of motion (40 points, including forward elevation, external rotation, abduction, and internal rotation of the shoulder), and strength (25 points). A higher score indicates better functional ability. On the other hand, the DASH score is used to evaluate upper extremity disabilities. To calculate the score, at least 27 out of 30 items need to be completed. The assigned values for all completed responses are summed and averaged, resulting in a score out of 5. This value is then transformed to a score out of 100 by subtracting one and multiplying by 25. The purpose of this transformation is to facilitate comparison with other measures scaled on a 0–100 scale. A higher score indicates a higher level of disability. In this case, the Constant-Murley shoulder score demonstrated improvement over time, suggesting increased functionality with the passage of follow-up time. Similarly, the DASH score decreased, indicating reduced disability. DASH, Disabilities of the Arm, Shoulder, and Hand.

approximately 7.7% of cases. Within this classification, subtype IIa includes proximal fracture with distal AC dislocation—a category that encompasses the present case. Subtype IIb involves dislocation of the sternoclavicular joint with distal fractures, referred to as a “floating clavicle”, whereas subtype IIc includes sternoclavicular and AC dislocations, defined as a “true floating clavicle”. To address Type II fractures, fixation with a clavicle locking plate or the contralateral distal clavicle anatomical plate is recommended to stabilize the proximal clavicle, coupled with fixation with a clavicle hook plate or double-button type with high-strength fibers for the distal clavicle (25).

In the field of orthopedic surgery, 3D printing technology has been effectively utilized for various purposes. It has shown great success in producing tissue engineering scaffolds, aiding in surgical planning for complex cases, and helping design patient-specific instruments (PSIs) (26). Fillat-Gomà *et al.* demonstrated the potential of 3D printing technology in revolutionizing the treatment of upper extremity trauma through their exploration of 8 diverse cases. Their findings illuminate the advantages provided by this innovation, including the ability to precisely select the optimal implant prior to surgery, effectively preempting potential complications, and significantly reducing surgical duration (27). Furthermore, 3D printing can enhance the complex clavicle fracture surgical proficiency of inexperienced surgeons (28). For the treatment of AC joint dislocation, the use of 3D printing had been reported to assist in selecting and pre-bending clavicle hook plates, thereby enabling precise reduction (12,13). Additionally, the utilization of 3D printing navigation templates showed promise in enhancing the accuracy and reliability of AC joint dislocation surgery (29).

In this particular case, the proximal clavicle fracture was comminuted, and as a result, the fixation position was limited. Therefore, meticulous preoperative planning and precise plate and screw placement design were imperative to ensure adequate holding force prior to surgery. By utilizing 3D printing technology, we were able to create clavicle models for both before and after reduction, and pre-bend the plates accordingly, predicting the necessary screw length, which effectively reduced operation time. Furthermore, the surgical design could be visually assessed prior to the procedure, allowing for easy comprehension of the patient’s condition and corresponding surgical treatment. This model also helped the team to explain the surgery plan to the patient and their family members, to help them better understand the surgical procedure preoperatively. The surgical duration and blood loss were even less than those of simple clavicle fracture surgery performed by the same surgical team.

Recent research has demonstrated that pre-bending the steel plate with the aid of 3D printed models can notably enhance compliance of the steel plate, reduce foreign body sensation, and decrease the need for plate removal (11). A major limitation in the utilization of such planning tools is the cost and time required to produce the models. In this situation, the cost was approximately US$220 and was provided within 24 hours. However, depending on the availability at a particular care facility, the cost of such modelling can be many thousands of US$ and take days to weeks. To make this technology more accessible, both these issues will need to be addressed. However, our case demonstrated the potential benefits of the time and cost expenditure. This instance highlights a good utilization of 3D printing technology, culminating in the attainment of optimum clinical outcomes. More similar cases utilizing 3D printing on complex clavicle fractures and dislocations should be collected for further studies.

In conclusion, proximal clavicle fracture with ipsilateral AC joint dislocation is a rare clavicle injury and is a type of "floating clavicle". Utilizing 3D printing technology in conjunction with proximal clavicle internal fixation and AC joint clavicle hook internal fixation, presents itself as a viable treatment option that yields positive clinical outcomes.

Acknowledgments

Funding: None.

Footnote

Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-23-720/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was provided by the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal.

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Cite this article as: Gu Y, Zhuang Y. 3D printing-assisted surgery for the treatment of proximal clavicle fracture with ipsilateral acromioclavicular joint dislocation: a case description. Quant Imaging Med Surg 2024;14(1):1234-1240. doi: 10.21037/qims-23-720

