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3D-printing assisted clavicle osteotomy for scapulothoracic abnormal motion: a case report

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Fractures of the clavicle are common, representing approximately 3% of all fractures and more than 40% of fractures of the shoulder girdle.[13] Fractures of the midshaft account for more than 80% of clavicle fractures, and midshaft clavicle fractures can be treated either operatively or nonoperatively on an individualized basis.[13,21] While clavicle malunion is common after conservative treatment, symptomatic malunions of the clavicle causing pain, limitations in motion, and dysfunction are rare.[8] Patients with symptoms from clavicle malunion often have problems with shoulder motion and overhead activities. These symptoms might be related to scapulothoracic abnormal motion (STAM), which is often not recognized. Symptomatic clavicle malunions can be treated with corrective osteotomy with patient satisfaction, pain relief, and return to function.[9]

STAM is a descriptive term to indicate abnormality of the position of the scapula and its motion on the chest, resulting in pain and dysfunction.[5,7] Causes of STAM could be related to muscular reasons or bony reasons. Muscular reasons include periscapular muscle paralysis, pectoralis minor hyperactivity, upper trapezius hyperactivation, and serratus anterior hypoactivity. Bony etiologies could include clavicle or scapula fracture malunion, acromioclavicular and sternoclavicular bony deficiency, and rib and chest wall bony deficiency.

If the cause of STAM is muscular, then manual reduction of the scapula on the chest is possible in most cases. However, if STAM results from a bony abnormality like clavicle malunion and shortening, then manual reduction of the scapula on the chest wall may not be possible. Although bony shortening of the clavicle can be noted on clinical inspection, in many instances, it is challenging without the aid of advanced imaging. Three-dimensional (3D)-printing technology is a novel tool that can help address the 3-D deficits characteristic of STAM.[17,20] We present a case of a symptomatic midshaft clavicle malunion causing STAM, treated with 3D-printing assisted corrective osteotomy to restore native clavicular anatomy and normal scapulothoracic motion.

Case report

A 26-year-old male laborer presented to our multi-institutional referral clinic for more than 1 year of right shoulder pain following a workplace injury. The patient sustained a right displaced midshaft clavicle fracture when a trench wall collapsed on his right shoulder (Fig. 1, *A*). The clavicle fracture was treated conservatively with osseous union (Fig. 1, *B*); however, the patient continued to complain of severe right shoulder pain with activities, limitations in shoulder motion, and inability to return to work. On examination, the patient had tenderness in the trapezius, acromioclavicular joint, and long head of biceps. The patient had decreased active forward elevation (right: 130°, left: 160°) and external rotation in an adducted position (right: 20°, left: 45°) of the affected shoulder. The patient exhibited

Mass General Brigham Institutional Review Board approved this study (protocol number 2010P002462/PHS). The patient provided informed consent for case reporting.

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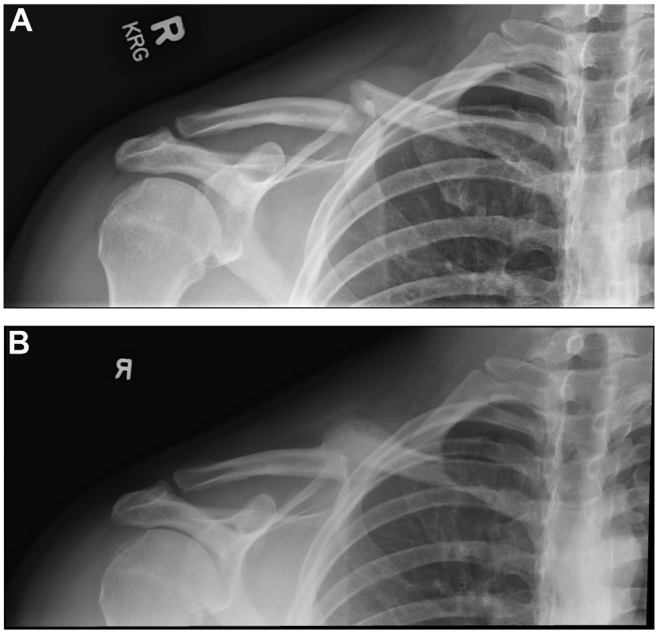

Figure 1 (**A**) Initial injury plain radiographs depicting a displaced midshaft clavicle fracture and (**B**) subsequent malunion.

subtle weakness of the supraspinatus and infraspinatus on strength testing. Inspection of the back showed depression, retraction, and downward rotation of the inferior tip of the affected scapula. The scapula was unable to be brought back to anatomic position with the scapular assist maneuver in the office due to the rigid clavicle deformity. Electromyography showed no periscapular muscle paralysis, magnetic resonance imaging showed a structurally intact rotator cuff, and computed tomography further characterized the osseous malunion. The patient failed to symptomatically improve with conservative treatment, consisting of physiotherapy and an ultrasound-guided corticosteroid injection to the biceps sheath, and the shared decision was made to pursue corrective osteotomy of the clavicle for the indication of STAM.

Due to the 3-dimensional nature of the problem of STAM and the need to restore native anatomy of the clavicle such that the scapula tracks normally along the posterior ribcage, the decision was made to use 3D-printed patient-specific intraoperative aids for the osteotomy and fixation (Materialise, Leuven, Belgium). CT of bilateral clavicles and scapulae were obtained, allowing uninjured contralateral clavicle to be mirrored onto the deformed clavicle to serve as a template for restoration of preinjury anatomy. A closing wedge osteotomy was planned, based on the uninjured contralateral clavicle, to correct the clavicle deformity and the resultant rigid malposition of the scapula (Fig. 2).

The surgery was performed under general anesthesia and a regional nerve block in the semi-inclined position. A standard anterior approach was utilized. The clavicle malunion was identified, and the patient-specific 3D-printed drill guide was applied to the bone and held with parallel K-wires. The clavicle was predrilled for subsequent fixation. The drill guide was removed, and the patient-specific 3D-printed cutting guide was applied to the bone using the same parallel K-wires. The closing wedge osteotomy was performed using a microsagittal saw with copious irrigation (Fig. 3). A lag screw by technique was inserted freehand, and the precontoured anterior clavicle plate was applied to complete the fixation of the osteotomy. The origin of the clavicular head of the pectoralis major was closed as able over the plate to prevent prominence.

Postoperative, the patient was immobilized in a sling with early pendulum exercises. In physiotherapy, active assisted overhead motion was initiated at 6 weeks after surgery, active motion at 8 weeks after surgery, and strengthening at 3 months after surgery. At 5 months after surgery, the patient had no further complaints, resolution of pain, and return to full-time gainful employment. On examination, the patient had symmetric active forward elevation (160°) and external rotation in an adducted position (45°) of shoulders, full strength, and correction of scapular posture. Plain radiographs at 5 months after surgery showed a healed osteotomy (Fig. 4), and the patient was discharged from care. The patient provided informed consent for case reporting.

Discussion

Midshaft clavicle fractures are common shoulder girdle injuries[13]; when there is no open injury, skin tenting, or neurovascular compromise, most cases of midshaft clavicle fractures can be treated either operative or nonoperatively, based on a shared decision-making discussion with the patient.[11,19,21,22] Malunions are common after conservative treatment of midshaft clavicle fractures, but symptomatic malunions are rare.[8] A clavicle malunion causing pain, motion deficits, and dysfunction can be treated with a corrective osteotomy with patient satisfaction, pain relief, and return to function.[9]

In this article, we have reported a case of a patient with a symptomatic midshaft clavicle malunion causing STAM. In this case, inferior displacement and angulation of the clavicle caused depression, retraction, and downward rotation of the inferior tip of the affected scapula. Importantly, because of the bony shortening of the clavicle and displacement of the scapula position, it was not possible on manual exam to reposition the scapula to its anatomic position. This aspect of bony STAM is very important to recognize so that the patient is not erroneously diagnosed with a muscular cause of STAM. Recognition of this diagnosis and surgical correction of the osseous deformity can lead to correction of the secondary STAM, pain relief, and restoration of function.

STAM is an inherently 3-dimensional disorder, and the advent of 3D-printing technology in the last decade affords an innovative tool to assist surgeons in the correction of bony deformities causing STAM. 3D-printing uses additive manufacturing by the sequential deposition of materials in thin 2-dimensional layers and has recently been used to create custom patient-specific models and intraoperative guides.[17,20] The applications of 3D-printing for deformity correction in the upper extremity has mainly focused on the correction of scaphoid, distal radius, diaphyseal forearm, and distal humerus deformities,[1,2,6,12,14-16,18,23] and few applications of 3D-printing has been reported for clavicle deformities. Cheah et al[3] and Consigliere et al[4] reported on the use of 3D-printed models mirrored from the uninjured contralateral clavicle as an intraoperative visual aid during corrective osteotomy for symptomatic midshaft clavicle malunions. Fusaro et al reported the use of patient-specific 3D-printed drill guide and cutting guide based on the uninjured contralateral clavicle during the corrective osteotomy for symptomatic midshaft clavicle malunion.[10] To the authors' knowledge, we report the first case of the use of 3D-printing technology for clavicle corrective osteotomy to address STAM. For this indication, we recommend mirroring the uninjured contralateral clavicle to plan the corrective osteotomy, and we also recommend mirroring the entire contralateral shoulder girdle to ensure correction of scapular position. Preoperative planning in 3

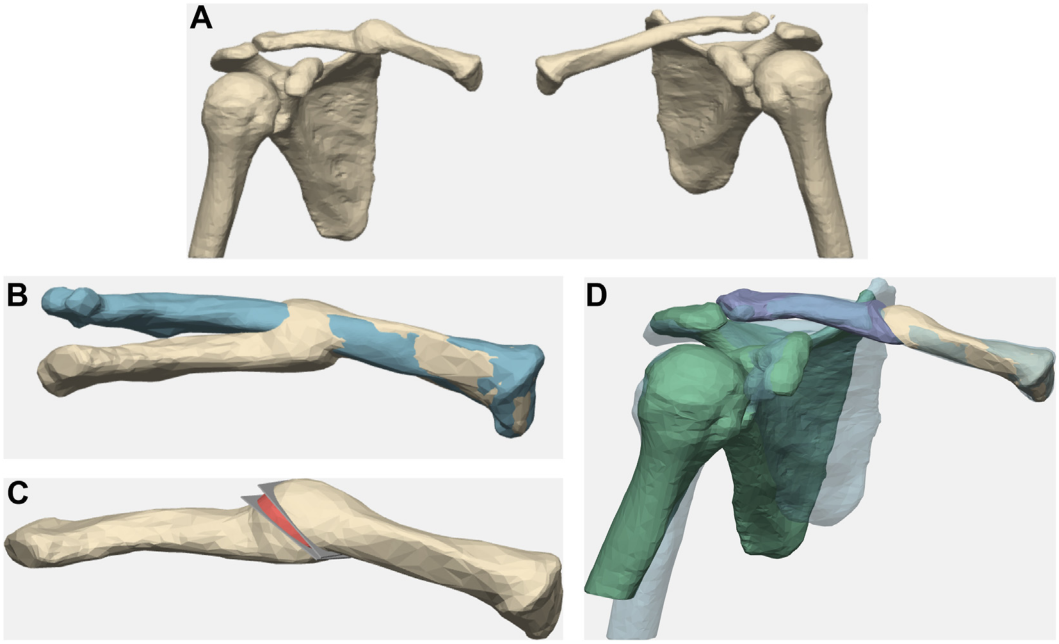

Figure 2 (**A**) CT of bilateral clavicles and scapulae, depicting an angular malunion of the *Right* midshaft clavicle (figure *Left*) and a normal *Left* clavicle for comparison (figure *Right*). (**B**) The uninjured contralateral clavicle was 3 dimensionally mirrored onto the deformed clavicle to restore preinjury anatomy. The deformed right clavicle is shown in white, and the mirror contralateral uninjured clavicle is shown in blue. (**C**) The closing wedge osteotomy was planned based on the uninjured contralateral clavicle. The planned osteotomy cuts are shown in gray and the closing wedge segment is shown in red. (**D**) The osteotomy was planned to correct the angular clavicle malunion and the resultant rigid malposition of the scapula. The scapula and proximal humerus shown in green represents the final planned position of the shoulder girdle after corrective osteotomy. *CT*, computed tomography.

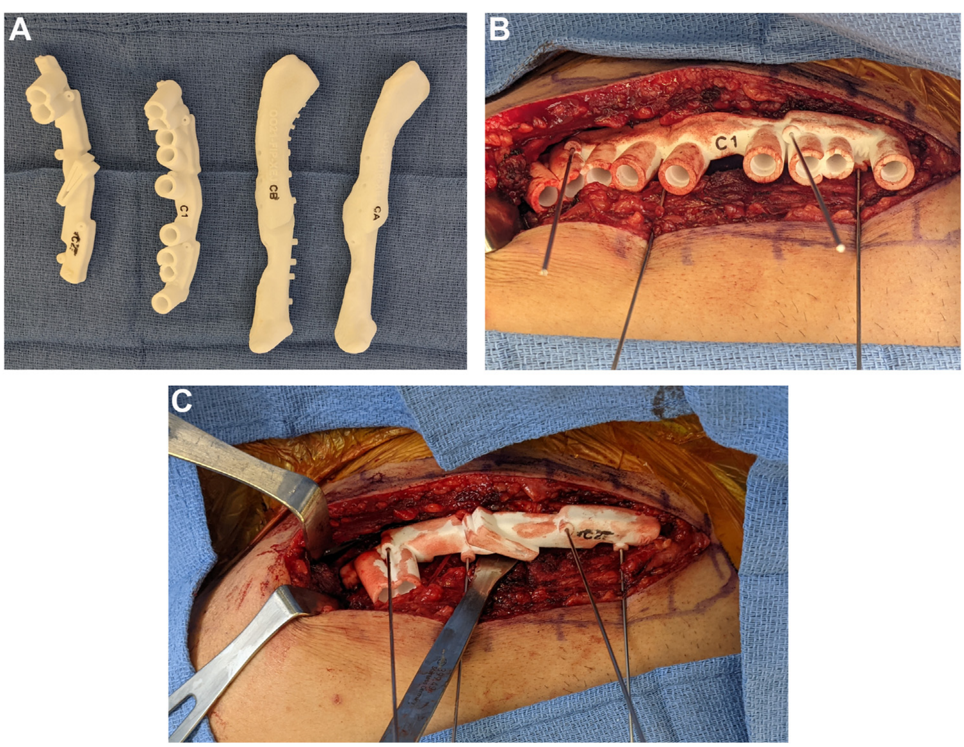

Figure 3 (**A**) Sterile 3D-printed models of the affected clavicle before (CA) and after (CB) correction were made for intraoperative use. Patient-specific drill guide (C1) and cutting guide (C2) are shown. (**B**) The drill guide (C1) is precontoured to the clavicle deformity and held with parallel K-wires, allowing the clavicle to be predrilled for subsequent fixation. C1 is then removed while maintaining parallel K-wires. (**C**) The cutting guide (C2) is slid on through the parallel K-wires in order to perform the osteotomy through the cutting guides with copious irrigation. Following the osteotomy, a lag screw by technique was inserted freehand, and the clavicle plate was applied to complete fixation.

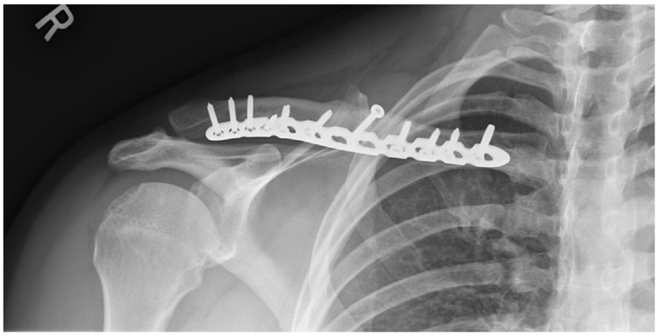

Figure 4 Postoperative plain radiographs 5 months following surgery depict a healed clavicle osteotomy with restoration of anatomy.

dimensions and patient-specific intraoperative guides can be helpful in the execution of this deformity correction.

Conclusion

To the authors' knowledge, we report the first case of the use of patient-specific 3D-printed intraoperative guides for clavicle malunion corrective osteotomy to address STAM. In patients with symptomatic midshaft clavicle malunions, surgeons should be suspicious for and assess for STAM caused by a rigid osseous deformity of the shoulder girdle. Recognition of this diagnosis and surgical correction of the clavicle deformity can lead to correction of the secondary STAM, patient satisfaction, pain relief, and restoration of function. Preoperative planning in 3 dimensions and patient-specific intraoperative guides can be helpful in the execution of this complex deformity correction.

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