Fractures of the Clavicle

L.A. Kashif Khan, Timothy J. Bradnock, Caroline Scott and C. Michael Robinson
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Current Concepts Review
Fractures of the Clavicle

By L.A. Kashif Khan, BSc(Hons), MRCSEd, Timothy J. Bradnock, BSc(Hons), MRCSEd, Caroline Scott, MBChB, and C. Michael Robinson, BMedSci, FRCSEd(Orth)

- Undisplaced fractures of both the diaphysis and the lateral end of the clavicle have a high rate of union, and the functional outcomes are good after nonoperative treatment.
- Nonoperative treatment of displaced shaft fractures may be associated with a higher rate of nonunion and functional deficits than previously reported. However, it remains difficult to predict which patients will have these complications.
- Since a satisfactory functional outcome may be obtained after operative treatment of a clavicular nonunion or malunion, there is currently considerable debate about the benefits of primary operative treatment of these injuries.
- Displaced lateral-end fractures have a higher risk of nonunion after nonoperative treatment than do shaft fractures. However, nonunion is difficult to predict and may be asymptomatic in elderly individuals. The results of operative treatment are more unpredictable than they are for shaft fractures.

The traditional view that the vast majority of clavicular fractures heal with good functional outcomes following nonoperative treatment is no longer valid. Recent studies have identified a higher rate of nonunion and specific deficits of shoulder function in subgroups of patients with these injuries. These fractures should therefore be viewed as a spectrum of injuries with diverse functional outcomes, each requiring careful assessment and individualized treatment. This article provides an overview of the current knowledge regarding the epidemiology, classification, clinical assessment, and treatment of clavicular fractures in adults.

Epidemiology

Fractures of the clavicle are common, accounting for 2.6% (533 of 20,501 patients) to 4% (number of study patients, 2035) of adult fractures and 35% (1666 of 4772 fractures) of injuries to the shoulder girdle[1-3]. The annual incidence of clavicular fractures is estimated to be between twenty-nine and sixty-four per 100,000 population per year[1,2,4]. Fractures of the shaft account for between 69% (692 of 1000) and 82% (435 of 533) of all fractures, lateral-end injuries account for 21% (427 of 2035) to 28% (280 of 1000), and medial-end injuries account for 2% (four of 187) to 3% (twenty-eight of 1000)[1,3,5,6].

The first and largest peak incidence is in males less than thirty years of age (Fig. 1). These fractures tend to be of the shaft, sustained when a direct force is applied to the point of the shoulder during sports activity[6]. They occur commonly in equestrian sports and cycling, when, as a result of inertia when the horse or bicycle stops suddenly, the rider is thrown forward and lands on the unprotected shoulder. The second, smaller peak of incidence occurs in elderly patients (over eighty years of age), with a slight female predominance (Fig. 1). These fractures tend to be related to osteoporosis, sustained during low-energy domestic falls.

Shaft fractures occur most commonly in young adults, whereas lateral and medial-end fractures are more common in elderly individuals[1,2,4]. Most shaft fractures are displaced, whereas the majority of lateral-end fractures are undisplaced[1].

Classification

Allman[5] proposed a classification based solely on the anatomic location of the fracture, and Neer classified lateral-end fractures according to whether they were undisplaced (Type I) or displaced (Type II)[7]. Displaced lateral-end fractures were then subclassified according to the integrity of the coronoid and trapezoid ligaments. In Type-IIA injuries the ligaments remain

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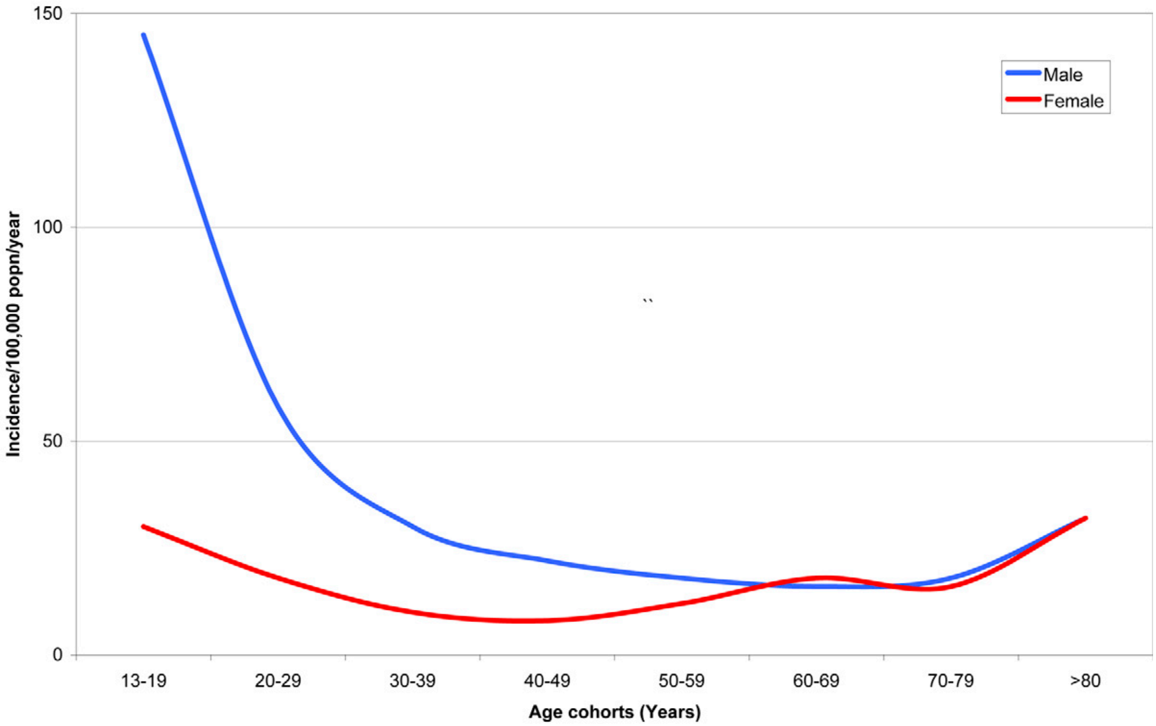

Fig. 1
The incidence of clavicular fractures in relation to age and sex cohorts. (Reproduced, with modification, from: Robinson CM. Fractures of the clavicle in the adult. Epidemiology and classification. J Bone Joint Surg Br. 1998;80:480. Reprinted with permission and copyright © of the British Editorial Society of Bone and Joint Surgery.)

intact, whereas in Type-IIB injuries the coracoclavicular ligaments are partially or completely detached[7]. Craig further modified the Neer and Allman systems by the inclusion of the additional subdivisions of medial and lateral-end fractures[8].

The Edinburgh classification[1], based on an analysis of 1000 clavicular fractures, was the first to subclassify shaft fractures according to their displacement and degree of comminution (Fig. 2). Another study demonstrated that these parameters were independently predictive of nonunion after nonoperative treatment[9]. The classification has been shown to have acceptable levels of interobserver and intraobserver variation[1]. Medial and lateral-end fractures are also subclassified with this system, according to their displacement and articular involvement[1].

Clinical and Radiographic Assessment

Clavicular fractures typically produce an obvious painful deformity, with tenderness localized over the site of the fracture. There is often downward displacement of the lateral fragment under the weight of the shoulder and elevation of the medial fragment from the unopposed pull of the sternocleidomastoid muscle[8]. Prominence of displaced fracture fragments, which "button-hole" subcutaneously through the platysma muscle, is not uncommon, especially with severely angulated or comminuted fractures (Edinburgh Types 2A2 and 2B2). However, open fractures or soft-tissue tenting sufficient to produce skin necrosis is uncommon[1].

Medial-end fractures may be difficult to distinguish clinically from medial physeal separations (which may occur up to the age of twenty-five); sternoclavicular joint dislocations; osteoarthritis; or, if the degree of trauma was minimal, septic arthritis of the sternoclavicular joint[10,11]. Posterior displacement of a medial-end fracture can cause compression of the mediastinum and major vessels, requiring urgent operative intervention, but this is very rare[12-14].

The whole arm distal to the fracture should be assessed to exclude brachial plexus or vascular injury. These injuries are rare, but high-energy trauma and marked fracture displacement or comminution are associated with an increased risk of their occurrence[15-17]. Neurovascular injury may be produced either directly by displaced fracture fragments or by stretch or blunt injuries associated with the overall injury of the limb. A difference in blood pressure between the two upper extremities is suggestive of vascular injury, but duplex scanning and arteriography should be undertaken if the diagnosis is suspected[18,19].

The radiographic diagnosis is usually made on the basis of a single anteroposterior view. Some authors advocate the use of a 15° posteroanterior radiograph to assess the degree of shortening[20], but spiral computed tomography with three-dimensional reformatted views allows the best assessment of displacement and may also be useful for the evaluation of fracture union (Fig. 3). Computed tomography is usually required for adequate visualization of medial-end fractures, particularly those extending into the sternoclavicular joint[13]. Stress radiographs are occasionally used to assess the integrity of the coracoclavicular ligaments in association with lateral-end fractures[21]. A careful clinical and

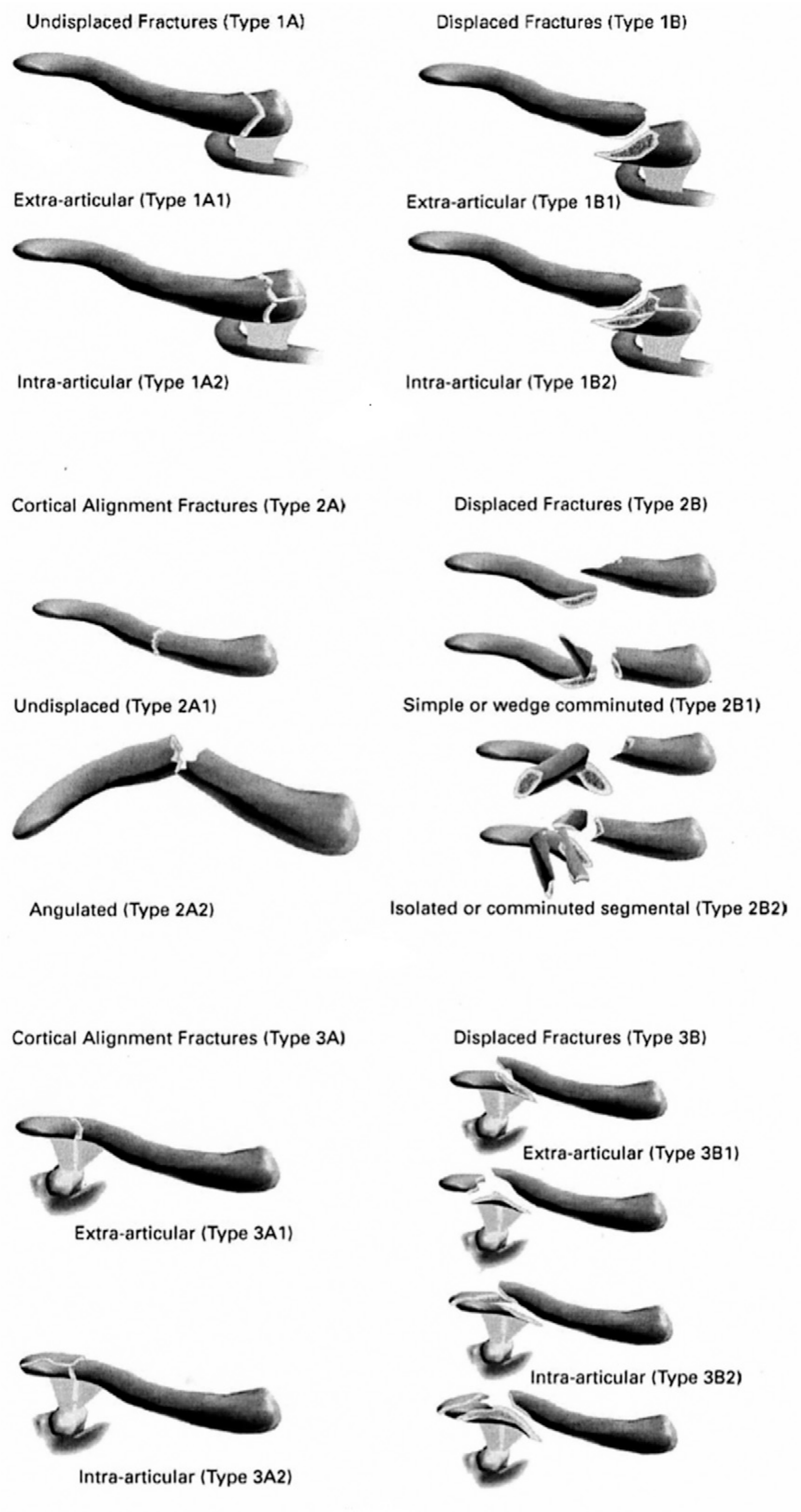

Fig. 2

The Edinburgh classification of clavicular fractures. (Reprinted, with permission and copyright © of the British Editorial Society of Bone and Joint Surgery, from: Robinson CM. Fractures of the clavicle in the adult. Epidemiology and classification. J Bone Joint Surg Br. 1998;80:477.)

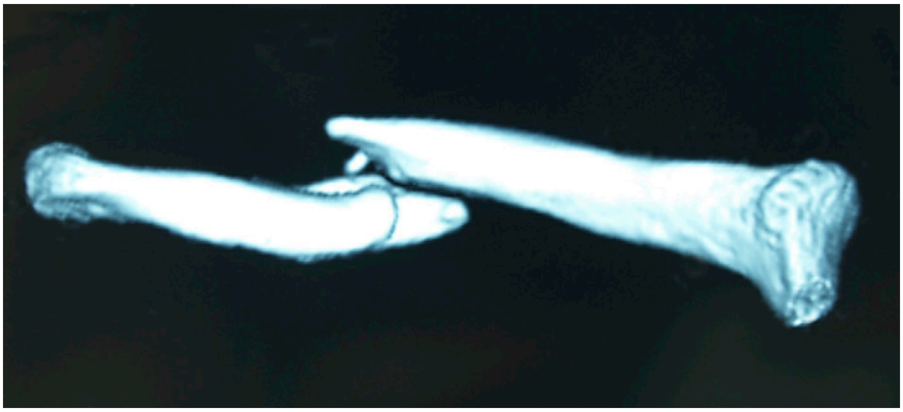

Fig. 3

A three-dimensional computed tomography reconstruction of a diaphyseal clavicle fracture (Edinburgh Type 2B1) in a forty-year-old woman who sustained the injury in a fall down stairs. The scans were obtained fourteen weeks after the injury because there was uncertainty about whether the fracture had united. The lack of callus formation and the clear fracture gap suggest a delayed union.

radiographic survey is also needed to exclude an associated chest injury, such as a pneumothorax or hemothorax[22], which occurs in 3% of patients (twenty-one of 690[21]) and is almost always associated with multiple ipsilateral rib fractures. Evidence of an ipsilateral shoulder girdle injury, such as a double disruption of the superior shoulder suspensory complex[23], should also be specifically sought on the initial trauma series radiographs.

Treatment of Shaft Fractures (Edinburgh Type 2)

Acute Injuries: Operative or Nonoperative Management?

There is general agreement that undisplaced (Edinburgh Type-2A) fractures should be treated nonoperatively. The traditional view of the treatment of displaced fractures has been that they rarely require operative stabilization. The rationale for this is threefold. First, in most studies, the rate of nonunion has been <1%[6,21,24-27]. Second, two large retrospective studies performed in the 1960s by Neer[26] and Rowe[21] showed that the rate of nonunion after primary open reduction and internal fixation was higher than that after nonoperative treatment. However, both studies included fractures in children, which nearly always unite. The final reason is that a number of studies in the past have shown a high level of patient satisfaction after nonoperative treatment of these fractures[24,25,28]. However, more recent studies, over the last ten years, have demonstrated higher rates of nonunion and poorer functional outcomes after nonoperative treatment, while the results of primary operative reduction and fixation have improved considerably[29-31]. Currently, there is considerable debate about whether acute displaced fractures should be treated operatively or nonoperatively.

Nonoperative Treatment

Many conservative treatment methods have been described[32], but the simple sling and the so-called figure-of-eight bandage have been used most widely. A comparative study demonstrated better patient satisfaction with the simple sling, and the functional and cosmetic results of the two treatment methods were identical[24]. Neither technique reduces a displaced fracture[24], but the risk of axillary pressure sores, compression of the neurovascular bundle, and nonunion are higher in patients treated with the figure-of-eight bandage[13,20,24,27,33-35]. For this reason, the simple sling is most commonly used. Use of the sling can normally be discontinued once the acute pain has subsided, and patients are encouraged to undertake normal activities as pain allows. Recovery of the range of motion and function of the shoulder is usually swift if the fracture unites, and supervised physiotherapy is only rarely required. Most patients respond well to a simple self-administered program of range-of-motion and muscle-strengthening exercises.

Primary Operative Treatment

Until recently, there was no evidence to suggest that early operative treatment of displaced clavicular shaft fractures conferred a functional benefit when compared with the results of initial nonoperative treatment[7,9,21,36-38]. Pertinent to this issue is the fact that the reported results of operative treatment of clavicular nonunions are excellent[39-44]. However, in a retrospective clinical series of fifty-two nonoperatively treated displaced fractures, initial shortening of ≥20 mm was associated with a greater risk of nonunion and a poor clinical outcome[45]. A later study in which patient-based outcome measures were used revealed deficits in shoulder strength and endurance after displaced fractures[31].

A recent multicenter trial comparing nonoperative treatment with primary plate fixation for displaced fractures in 138 patients demonstrated better functional outcomes, lower rates of malunion and nonunion, and a shorter time to union in the latter group[29]. However, the operative group had a complication rate of 34% and a reoperation rate of 18%, although most reoperations were for hardware removal. The two validated functional scores that were reported showed a small but significant benefit from plate fixation ($p = 0.001$ for the Constant score[46] and $p < 0.01$ for the Disabilities of the Arm, Shoulder and Hand [DASH] score[47]). However, the poorer overall scores in the nonoperative group may have been due to a minority of outlying patients with poor scores due to nonunion. It was unclear whether any distinct functional benefit was gained from the operative treatment in the patients with a healed fracture as compared with the outcome in those in whom the fracture healed after nonoperative treatment. The authors stated that their results supported the use of primary plate fixation of displaced fractures in active adults. However, this interpretation may lead to overtreatment, as a number-needed-to-treat analysis revealed that operative fixation of nine fractures would be required to prevent one nonunion, and fixation of 3.3 fractures would be required to prevent one symptomatic malunion or nonunion[48]. Other randomized controlled trials are currently ongoing in this area, and it will be important to determine if those results support the findings of the multicenter study.

A recent study[49] comparing acute operative treatment of midshaft fractures with delayed treatment of established nonunions and malunions showed no significant difference in the DASH score and a significant difference ($p = 0.05$) in only one of six strength and endurance variables that were tested. There was a significant difference ($p = 0.02$) of 6 points in the Constant score, but all patients reported a high level of satisfaction.

As yet, there is no firm consensus regarding which displaced fractures should be treated operatively. Many younger patients now seek operative treatment in the hope of obtaining a better functional outcome and an earlier return to contact sports. It is our opinion that these patients should be offered the option of operative treatment, after they have been adequately counseled regarding the risks involved and the likely outcome of that treatment.

Operative Techniques

A wide variety of methods have been described for operative fixation of shaft fractures (see Appendix)[21,29,36,38,50-67].

Plate Fixation

This technique provides immediate rigid stabilization and pain relief and facilitates early mobilization[7,39,42,44,45,68]. Most commonly, the plate is implanted on the superior aspect of the clavicle, and biomechanical studies have shown this to be advantageous, especially in the presence of inferior cortical comminution[69]. However, the approach is associated with a greater risk of injury to the underlying neurovascular structures during fracture manipulation and drilling, and subsequent prominence of the plate may necessitate its removal. In an attempt to address these problems, an anterior-inferior approach to allow inferior implantation of the plate was developed. This technique was associated with a low complication rate in a series of fifty-eight patients[65], although biomechanical testing has suggested that a superior position of the plate provides more secure fixation[69,70].

Currently, the implants most commonly used are either dynamic compression or locking plates. Reconstruction plates have fallen into disfavor, since they are susceptible to deformation at the fracture site, leading to malunion. Site-specific precontoured locking plates have recently been introduced, and they may be less prominent after healing, leading to lower rates of hardware removal after union[29,71]. There is now also the option of locking screws into these plates, to improve the fixation of fractures that extend into the lateral end of the clavicle and of those in elderly patients with osteoporotic bone. The efficacy of these implants has not yet been fully tested in comparative clinical studies. The complications related to the use of plate fixation are infection[36], plate failure[36], hypertrophic or dysesthetic scars[72], implant loosening[36,73], nonunion[63], refracture after plate removal[36,63,73], and very rarely intraoperative vascular injury[74].

Intramedullary Fixation

The sigmoid shape of the clavicle poses specific problems in the design and insertion of intramedullary devices, and static locking is not possible with the implants that are currently available. The nail must be narrow and flexible enough to pass through the narrow medullary canal and sigmoid curvature of the clavicle, yet strong enough to withstand the forces acting on the fracture until it unites[21,75,76]. There is biomechanical evidence to suggest that plate fixation provides a stronger construct than intramedullary fixation[77]. A variety of devices, including Knowles pins[38,57], Hagie pins, Rockwood pins, and minimally invasive titanium nails, have been used[54]. Two methods of implant insertion have been described: antegrade, through an anteromedial entry point in the medial fragment, and retrograde, through a posterolateral entry portal in the lateral fragment. As a result of the narrow medullary canal, the fracture site must usually be opened through a separate incision to expose the proximal and distal parts of the canal for implant insertion.

The reported results have been more mixed than those after plate fixation[38,53,57], and the inability to statically lock these implants may lead to shortening, especially if there is comminution. High rates of implant breakage, temporary brachial plexus palsy, and skin breakdown over the entry portal have also been reported with the use of these techniques[78,79]. Intramedullary fixation is therefore used less widely than plate fixation, although proponents of the technique suggest that the more minimally invasive approach offers advantages for patients with multiple injuries or other shoulder girdle injuries[54].

Other Techniques

External fixators have been used to treat clavicular fractures, although this technique is most commonly recommended only for open fractures or septic nonunions[80]. Kirschner wires have been advocated to maintain reduction, but numerous reports have described complications arising as a result of wire breakage and migration to a variety of anatomic locations, with potentially catastrophic consequences[42,81]. The use of these implants in the management of clavicular fractures is therefore strongly discouraged.

Treatment of Lateral-End Fractures

Undisplaced Lateral-End Fractures (Neer Type I, Edinburgh Type 3A)

Most lateral-end fractures are minimally displaced and extra-articular. The intact periosteum and the coronoid and trapezoid ligaments bind the fragments together and prevent displacement[7]. Nonoperative management is the treatment of choice, and the protocol is similar to that for shaft fractures[7,28,82,83]. Neer recognized that fractures extending into the acromioclavicular joint may be associated with persistent symptoms due to a step defect in the articular surface[7]. Late excision of the distal segment (through either an arthroscopic or an open approach) may be used in this group of patients if the fragment is small[7,82].

Displaced Lateral-End Fractures (Neer Type II, Edinburgh Type 3B)

A number of influential retrospective studies[1,7,26,82,84,85] have revealed high rates of nonunion after nonoperative treatment of these fractures. This led to the recommendation that primary reduction and internal fixation should be used to prevent the adverse consequences of nonunion, which include pain[7,57,86-88] and loss of shoulder function[42]. However, the rate of nonunion after nonoperative treatment was lower (11.4%; thirty of 263) in a recent series[9], and high rates of postoperative complications have also been reported in previous studies[26,84,89].

Since the majority of these injuries occur in middle-aged and elderly individuals[90], nonunion may be associated with minimal symptoms and a high degree of patient satisfaction[9,82,89,91,92], with few requiring delayed operative intervention[82,89-92]. In one series, delayed operative intervention was reserved for patients who had a symptomatic nonunion or degenerative joint disease of the acromioclavicular joint at six months after the injury[90]. The outcomes of nonoperative treatment were comparable with those reported after primary operative treatment[84,86,90,93].

Older patients with a displaced lateral-end fracture should be informed that nonoperative treatment is associated with a higher risk of nonunion, which may be accompanied by cosmetic deformity or osteoarthritis of the acromioclavicular joint. However, in the small number of patients in whom substantial arthritis develops, resection of the lateral segment may result in a functional shoulder[7,82,94]. A randomized controlled trial is needed to determine whether immediate operative intervention in younger patients with a displaced lateral-end fracture results in better rates of fracture union and better functional outcomes compared with those after nonoperative treatment.

Operative Treatment for Displaced Lateral-End Fractures (Neer Type II, Edinburgh Type 3B)

Many operative techniques have been described for the treatment of these fractures (see Appendix)[84-86,89,92,93,95-115], although no single approach is generally accepted and each has a relatively high rate of complications. Many of the operative techniques used to treat displaced lateral-end fractures have been adapted from those used to treat acromioclavicular separations. Although both injuries are double disruptions of the superior shoulder suspensory complex[23], a ligament repair or substitution is often not required in the treatment of lateral-end fractures. This is because healing of the lateral-end fracture will usually restore stability to the complex. The indications for operative treatment of displaced lateral-end fractures can be divided into early and late categories: early indications include compromise of the soft-tissue envelope, double disruption of the ipsilateral shoulder suspensory complex, and a fracture in a young active individual, athlete, or manual laborer requiring a rapid return to full function. Late indications include persistent symptomatic malunion or nonunion and acromioclavicular osteoarthritis.

Coracoclavicular Screw (Fig. 4)

The use of a coracoclavicular screw was first described in the treatment of acromioclavicular joint subluxation (Fig. 4)[116]. It is technically demanding as a result of the fairly narrow area within the coracoid that is available for screw fixation. This leads to an appreciable rate of fixation failure due to screw cutout or loosening (reported in six of seventy-six cases in the six series summarized in the Appendix). The technique has been used with some success in small case series, and it is still widely employed[84,85,95,101,106,117]. The screw often limits shoulder movement and often needs to be removed once the fracture has united[95,106].

Plate and Hook-Plate Fixation

Adequate plate fixation can be achieved only if the distal fragment is large enough to hold a minimum of two, and ideally three, bicortical screws[93]. Recently, site-specific precontoured plates with a locking option were introduced. These plates allow the insertion of a greater number of locking screws into the distal fragment, which may improve the stability of the reconstruction[113].

The clavicular hook plate was developed for treatment of fractures in which the distal fragment is too small to allow conventional plate fixation (Fig. 5). The plate has an offset lateral hook, designed to engage distal to the posterior aspect of the acromion[118]. It has been used with some success for displaced lateral-end clavicular fractures, but there are concerns that the plate may induce shoulder stiffness and osteoarthritis of the acromioclavicular joint[97,103,109], and there is also a risk of skin slough and infection. Improper positioning of the hook may lead to inadequate fixation. Osteolysis has been noted around the hole for the hook as shoulder movement increases[103], and most surgeons advise routine plate removal at three months after implantation, which necessitates a second operation. The timing of plate removal is critical, as early removal may result in nonunion or refracture due to instability at the fracture site, whereas delayed removal can lead to shoulder stiffness or even fracture medial to the plate[119].

Kirschner Wire Fixation

This technique was first popularized by Neer[104], but it has been largely superseded by more modern implants. The major problem with this technique is the inherent risk of wire breakage and migration[97], with unpredictable and potentially serious complications. Other authors have described high nonunion and infection rates[89] and have recommended that this method of fixation not be used[81,97].

Suture and Sling Techniques

Coracoclavicular sling and Dacron graft ligaments have been used to reconstruct the coracoclavicular ligaments, both as the primary mode of stabilization and as reinforcement of other fixation techniques, with good functional results[93,98,100,105]. The

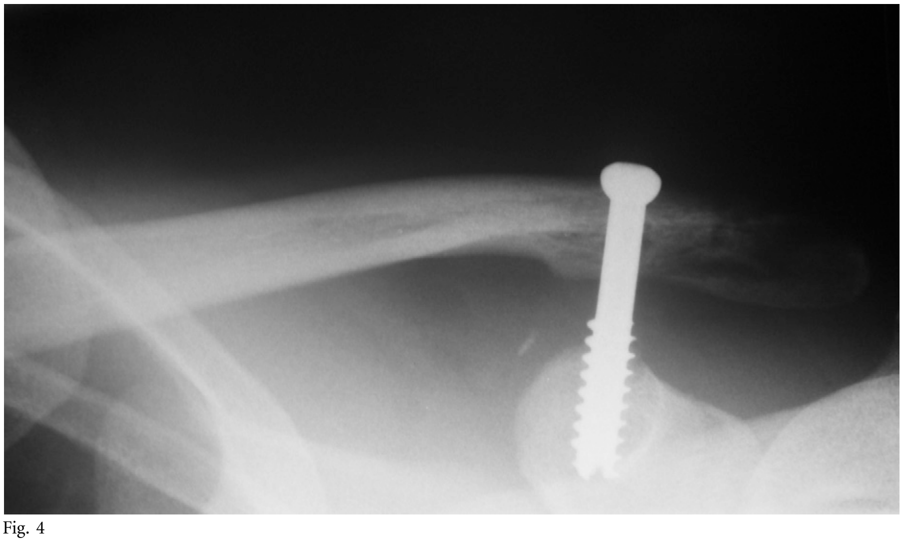

Fig. 4
Anteroposterior radiograph of a forty-five-year-old woman who sustained a lateral-end clavicular fracture (Edinburgh Type 3B1) when she fell on the shoulder. The fracture was treated with a coracoclavicular screw, which was removed at three months, at which time the advanced degree of fracture-healing had restored sufficient stability to prevent redisplacement.

graft either is looped around the coracoid and over the clavicle fragment to form a sling[105] or is passed through drill-holes[98]. The use of two EndoButtons, toggled through drill-holes in the clavicle and coracoid to link a continuous loop of one of the new generation of robust nonabsorbable suture materials, has also been described and has been referred to as the *tightrope technique* (Fig. 6)[120].

Transarticular PDS (polydioxanone) banding has been used to reconstruct ruptured coracoclavicular and/or acromioclavicular ligaments with a small peripheral fragment or an associated disruption of the acromioclavicular joint[93,100]. Proponents of these techniques claim that they provide stable, although not rigid, fixation of the fracture, thereby allowing early mobilization and not requiring a second operation to remove metalwork[93,98,100,105]. Arthroscopic ligament reconstruction techniques to treat displaced lateral-end fractures have recently been described[114,121,122]. Full clinical evaluation of these techniques has not been performed, to our knowledge.

Intra-Articular Lateral-End Fractures (Neer Type III, Edinburgh Types 3A2 and 3B2)

These uncommon fractures have a reported prevalence of between 2.4% (twenty-one of 868)[9] and 3.3% (thirty-three of 1000)[1]. They are usually treated initially in the same manner as

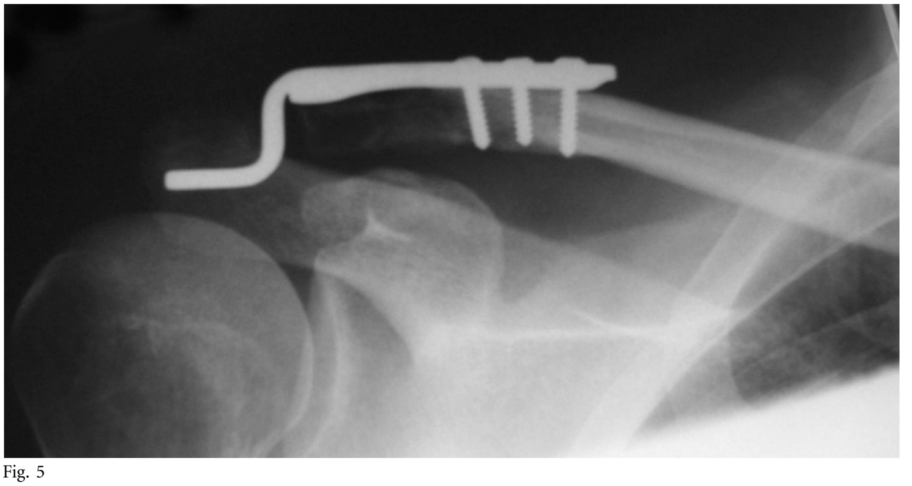

Fig. 5
Anteroposterior radiograph of a twenty-four-year-old man who sustained a lateral-end clavicular fracture (Edinburgh Type 3B1) when he fell from a bicycle. The fracture was treated with a hook plate. The plate was removed at three months after the injury, at which time the advanced degree of fracture-healing had restored sufficient stability to prevent redisplacement.

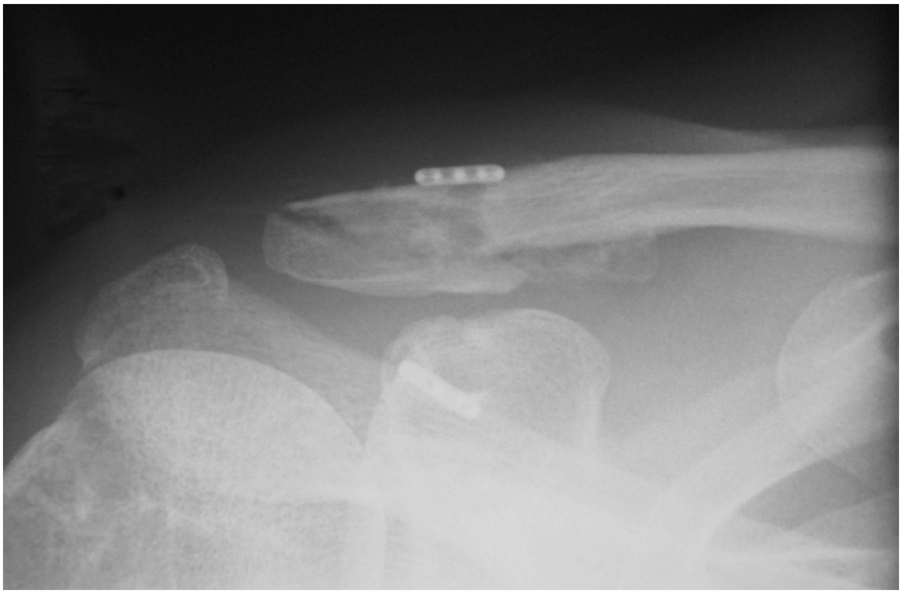

Fig. 6

Anteroposterior radiograph of a twenty-nine-year-old man who sustained a lateral-end clavicular fracture (Edinburgh Type 3B1) when he fell on the shoulder while skiing. The fracture was treated with the so-called tightrope technique (see text).

extra-articular injuries, depending on their degree of displacement. These fractures carry an increased risk of later acromioclavicular osteoarthritis, which may require further treatment. The authors of one study reported that two of nineteen patients with a type-3A2 fracture and three of fourteen patients with a type-3B2 fracture had this complication[1]. The investigation and treatment of this condition are discussed in a later section.

Treatment of Medial-End Clavicular Fractures (Edinburgh Type 1)

These fractures are rare, and most are extra-articular and minimally displaced[1,2]. Stability depends on the integrity of the costoclavicular ligament[5] because, if that ligament is ruptured, the lateral fragment displaces anteriorly and may overlap the medial fragment[11]. These fractures are usually managed nonoperatively, unless fracture displacement produces superior mediastinal compromise. In these circumstances, an emergent attempt at closed reduction should be made[10,13], with open reduction performed next if this is unsuccessful. Internal fixation with any form of implant carries the risk of migration of the implant into the adjacent mediastinal structures. Kirschner wires in particular have an unacceptably high rate of migration and should not be used[81]. A variety of other internal fixation techniques, including use of the modified Balser plate and use of Mersilene or other strong braided interosseous suture, have been described[10,13,123]. The use of sutures obviates the requirement for a second operation to remove implants and avoids the potential complications that might arise from migration of those implants[13]. Supporting evidence is limited for each technique, and there is currently a lack of consensus regarding the optimal treatment for fractures that require operative intervention.

Open reduction and stabilization is occasionally required for treatment of a symptomatic nonunion or delayed-onset obstruction of the superior mediastinum by fracture callus[12-14,124]. Excision arthroplasty of the medial end of the clavicle is an alternative if the medial fragment is small.

Complications of Clavicular Fractures

Nonunion of Shaft Fractures

Nonunion was previously considered to be rare after nonoperative treatment, with a reported prevalence of <1%[21]. Contemporary studies have suggested that adults with a displaced fracture have a higher rate of nonunion (up to 15%; eight of fifty-two)[1,9,21,25,26,35,37,38,40,45]. The risk factors for nonunion include increasing age, female sex, fracture displacement, and comminution[1,9]. However, the majority of fractures occur in a younger, predominantly male population[1-3,9], and most nonunions are therefore encountered in this population. Accurate prediction of which patients will have nonunion therefore remains difficult, although an estimate can be made on the basis of the known risk factors that are independently predictive of nonunion (Table I)[9,125]. This may be useful in patient counseling.

Shaft nonunions in active individuals are usually symptomatic, causing pain[26,35,42,126,127] and a clicking sensation on movement[26,35]. Restriction of shoulder movement[35,42,127], weakness[26,35,127], cosmetic deformity[26,35,126], neurological symptoms[42,126,128], thoracic outlet syndrome[35,42,126,129], and subclavian vein compression have also been reported. Patients may also report disturbed sleep, an inability to perform manual work, difficulty driving, enforced absence from normal sporting activities, and a reduction in sexual activities due to pain[126]. Clinical and radiographic signs of nonunion include mobility or pain on stressing of the fracture and an absence of bridging callus on radiographs[9,130]. In equivocal cases,

TABLE I Calculated Probability of a Nonunion at Twenty-four Weeks After a Clavicular Shaft Fracture, Based on Age, Sex, Comminution, and Displacement*

	Probability of a Nonunion							
	Not Displaced, Not Comminuted		Displaced, Not Comminuted		Comminuted, Not Displaced		Displaced and Comminuted	
Age *(yr)*	Males	Females	Males	Females	Males	Females	Males	Females
20	<1%	2%	8%	16%	2%	7%	18%	30%
30	<1%	3%	10%	20%	4%	9%	20%	35%
40	1%	5%	13%	26%	5%	12%	25%	38%
50	2%	6%	18%	28%	6%	13%	29%	40%
60	2%	7%	19%	30%	8%	15%	31%	44%
70	4%	10%	21%	37%	9%	18%	35%	49%

*The values are based on studies including a total of 581 fractures[9,125].

computed tomography scans may be helpful by demonstrating whether bridging callus is present across the fracture site. A number of operative techniques have been described to treat shaft nonunions (see Appendix)[35,39-44,51,68,126,131-146].

Plate Fixation

Plate fixation permits early mobilization of the shoulder while providing secure fixation, with a predictably high rate of union and a low risk of complications[41,42,135,139,141-143,147,148], and most authors have advocated this technique[39-42,44,135,139,141-143,147,148]. A variety of implants have been used, including reconstruction[40,41,140], wave[39,139], dynamic compression[41,43,68,135], and low-contact dynamic compression plates[44,68]. It has been suggested that low-contact dynamic compression plates are superior as their structured undersurface optimally preserves the blood supply to the underlying bone fragments[44,68]. Reconstruction and semitubular plates are generally considered to be too weak and prone to deformation or breakage when used to treat nonunions. Wave-plate osteosynthesis was introduced to treat femoral and humeral nonunions[149,150], and it has also been described for clavicular nonunions to reduce hypertrophic callus formation, which may cause brachial plexus and subclavian vein compression[141]. Site-specific precontoured locking plates may also be employed for nonunions, but their use for this indication has not yet been reported, to our knowledge.

Supplementary autologous bone-grafting is commonly used and may shorten the time to union[68,135,141]. When nonunion is associated with clinically important shortening, an intercalary iliac crest bone graft can be used to restore length[42]. Vascularized fibular[151-153] and medial femoral condyle[154,155] grafts have also been used successfully, although they are probably indicated only in revision cases in which the initial operative treatment of the nonunion has failed.

Other Methods

Intramedullary fixation[126,127,132,134,136,144,156] and external fixation[80,147] have been used in small series. Although these techniques produce more cosmetically acceptable incisions and disturb the soft-tissue envelope less[132,134], they provide less rigid fixation and thus are not commonly used[38,42,135]. External fixation with use of Papineau's technique[157] has been utilized to treat infected pseudarthroses[158], but it is not widely used.

Nonunion of Lateral-End Fractures

The rate of nonunion after nonoperative treatment of lateral-end fractures is higher than the rate after nonoperative treatment of shaft fractures, but there is some debate regarding its exact prevalence, with some authors reporting higher rates than others. In some small case series, the rate was reported to be between 18% and 40%[1,7,26,82,84,85], whereas more recently a larger prospective study of 263 lateral-end fractures demonstrated a nonunion rate of 11.5%[9]. The independent risk factors for this complication include age and displacement of the fracture, and these factors can be used to calculate a probability of nonunion (Table II)[9,125]. The symptoms of nonunion in this area include pain[7,57,86-88] and loss of shoulder function[42]. However, in many older patients with lower functional demands, the nonunion is asymptomatic[82,90].

TABLE II Calculated Probability of a Nonunion at Twenty-four Weeks After a Lateral-End Clavicular Fracture, Based on Age and Displacement in a Series of 263 Patients[9]

	Probability of a Nonunion	
Age *(yr)*	Not Displaced	Displaced
20	1%	16%
30	3%	21%
40	5%	27%
50	6%	37%
60	10%	44%
70	17%	52%

The treatment options for an established symptomatic nonunion include excision of the lateral end of the clavicle, or fracture fixation with or without bone graft. Excision is usually preferred if the lateral fragment is small and the coracoclavicular ligaments are intact, whereas fixation is used when there is a larger fragment, with good bone stock, and there is a reasonable chance of the procedure successfully promoting union. The methods of internal fixation that have been used are similar to those described previously for acute fractures. The results of treatment have been assessed only in small numbers of patients, in studies mainly focusing on the treatment of midshaft nonunions[26,41,42,126,127].

Malunion

All displaced fractures that are treated nonoperatively heal with some degree of malunion due to angulation or shortening[159], but often with few or no symptoms[160]. However, malunion may be associated with intrusive symptoms in some patients[31,47,145] as a result of anteroposterior angulation and overlapping of bone ends[159]. The effect of shortening on the functional outcome is controversial. Some authors have reported that shortening of >15 mm is associated with shoulder discomfort and dysfunction[25,37,45], and it has been suggested that the angular deformity and shortening change the orientation of the glenoid, altering the shoulder dynamics[161]. Others have suggested that, although permanent shortening after fracture is common, it has no clinical relevance[162,163]. The authors of a prospective study examining the risk factors for long-term functional problems found that, although comminution, initial displacement, and increasing age were predictive of symptomatic malunion[130], the degree of shortening was not.

Corrective osteotomy and plate fixation can improve function in patients in whom symptomatic malunion has produced neurovascular compression, discomfort and weakness with use of the shoulder, or cosmetic deformity[30,145,160,161,164]. It is typically possible to recreate the original fracture line, distract the proximal and distal fragments, and correct length. The corrective osteotomy may be supplemented with adjuvant autologous bone-grafting, although this is often not required. Since many clavicular malunions are asymptomatic, careful patient selection and counseling before surgery, with its inherent risk of complications, is recommended. There is only limited available information on the treatment of posttraumatic shortening without angulation that causes functional impairment of the shoulder in the absence of neurovascular compression, although restoration of the normal shoulder contour and function has been reported[44,161,164-166].

Neurological Complications

Nerve compression can be caused acutely by displacement of the fracture fragments, or it can be caused by chronic malunion or nonunion associated with hypertrophic callus formation, subclavian pseudoaneurysm, or scar constriction (delayed type)[15,16,128,129,167-173]. Brachial plexus palsy may also occur as a complication of operative treatment with use of intramedullary fixation[79]. A number of synonyms have been applied to this condition, including *thoracic outlet syndrome, costoclavicular syndrome,* and *fractured clavicle-rib syndrome*[129,174]. Entrapment of the medial cord of the brachial plexus by callus superiorly and by the first rib inferiorly in the costoclavicular space (between the first rib and the clavicle) is typical, producing predominantly ulnar nerve symptoms. This situation is more likely in the presence of a hypertrophic nonunion or malunion[15,42,128,169]. The precise prevalence is poorly defined because of the element of subjectivity in the diagnosis. Rowe reported late neurovascular sequelae after 0.3% (two) of 690 fractures[21], although higher rates have been reported in more recent studies, with prevalences of between 20% and 47% in series of between fifteen and fifty-two patients[29,45,126,168].

TABLE III Recommendations for Care

Type of Fracture/Technique	Grade of Recommendation*
Acute displaced diaphyseal (Edinburgh Type-2B) fracture	
Plate fixation	C
Intramedullary fixation	C
Nonunion after diaphyseal (Edinburgh Type-2) fracture	
Plate fixation with bone graft	B
Intramedullary fixation with bone graft	C
Acute lateral-end (Edinburgh Type-3B) fracture	
Coracoclavicular screw fixation	C
Plate fixation	C

*A = good evidence (Level-I studies with consistent findings) for or against recommending intervention, B = fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention, C = poor-quality evidence (Level-IV or V studies with consistent findings) for or against recommending intervention, and I = there is insufficient or conflicting evidence not allowing a recommendation for or against intervention.

The clinical tests for these syndromes are nonspecific, and the diagnosis should be made only when a patient has a suggestive clinical history with supportive evidence on electrophysiological testing[16], arteriography or venography[17,19], and specialized imaging. The treatment should be directed toward correction of the malunion or nonunion[15,16,128,169,173].

Refracture

Refracture can occur after nonoperative or operative treatment, with risk factors including epilepsy and alcohol abuse[109] and an early return to contact sports. Reinjury shortly after operative treatment may cause breakage or bending of the fixation device, or fracture around the implant[51,97,109,126,134], whereas a reinjury after implant removal may produce further fracture at the site of the previous injury. Nonunion is relatively common after refracture, and internal fixation is often required.

Osteoarthritis of the Acromioclavicular Joint

This complication occurs most frequently following an intra-articular fracture, although occasionally it is seen after an extra-articular fracture. In a medium-term study of 101 lateral-end clavicular fractures, three of eleven intra-articular (Edinburgh Type-3B2) fractures and six of ninety extra-articular (Edinburgh Type-3B1) fractures were associated with radiographic signs of osteoarthritis[90]. The major symptom is activity-related pain, which characteristically is worsened by cross-arm adduction (the so-called scarf test[175]). Examination reveals local swelling and tenderness, with a positive active compression test as described by O'Brien et al.[176]. Plain radiographs may reveal signs of osteoarthritis, but this must be established as the cause of the problem, since complex regional pain syndrome, rotator cuff impingement, posttraumatic osteolysis, and instability of the acromioclavicular joint may produce similar symptoms. Resolution of symptoms after an ultrasound-guided injection of a local anesthetic into the joint is a useful diagnostic sign. Symptomatic osteoarthritis of the acromioclavicular joint should be treated with either arthroscopic or open excision of the lateral fragment[7,82,94]. In cases where there is concomitant ligamentous instability, this should be combined with a procedure to restore stability to the lateral end of the clavicle, such as the Weaver-Dunn coracoclavicular ligament transfer procedure[177].

Complications of Operative Treatment

The main potential intraoperative complication is injury to the subclavian artery or vein at the time of fracture mobilization or from drill penetration. The risk of this complication should be very low, but it may necessitate vascular or cardiothoracic surgical intervention. Postoperative wound complications, scar dysesthesia, infection, fixation failure, and nonunion are relatively common and may require revision surgery, as does any other failed osteosynthesis.

Overview and Recommendations

There is a general consensus that undisplaced clavicular fractures are best treated nonoperatively. The paucity of Level-I and II evidence makes it difficult to produce concrete guidelines for the treatment of displaced clavicular fractures (Table III). Operative reconstructions of diaphyseal nonunions have good outcomes, and the large number of case series documenting consistently satisfactory outcomes after plate fixation lends support to the use of this technique as the treatment of choice (Grade-B recommendation). Although good outcomes have been reported after operative treatment of acute diaphyseal and lateral-end fractures, it is difficult to predict which patients should be offered primary operative reconstruction and which technique should be used (Grade-C recommendation). Although the results of a recent multicenter study lend support to the use of primary operative intervention for diaphyseal fractures[29], the magnitude of the treatment effect may be insufficient to justify offering surgery to all patients with this injury. Independent validation from other multicenter studies is required before the widespread use of this technique can be recommended (Grade-C recommendation).

Appendix

eA Tables listing studies of surgical techniques for the fixation of clavicular fracture are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD/DVD (call our subscription department, at 781-449-9780, to order the CD or DVD). ■

L.A. Kashif Khan, BSc(Hons), MRCSEd
Timothy J. Bradnock, BSc(Hons), MRCSEd
Caroline Scott, MBChB
C. Michael Robinson, BMedSci, FRCSEd(Orth)
Edinburgh Shoulder Clinic,
Royal Infirmary of Edinburgh,
Little France,
Old Dalkeith Road, Edinburgh EH16 4SU,
United Kingdom.
E-mail address for C.M. Robinson:
c.mike.robinson@ed.ac.uk

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