Carpal dislocations

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Summary
Carpal dislocations represent a group of injuries for which an accurate diagnosis, prompt treatment and attention to detail are important to a successful outcome. It is possible to gain a functioning wrist and return patients to heavy manual work despite a severe injury. There is some evidence that the purely ligamentous injuries do less well than those combined with bony injuries perhaps due to the more frequent open reduction and anatomical restoration achieved in the latter. Salvage procedures include partial or total arthrodesis or proximal row carpectomy. Individual carpal bone excision appears to produce a poorer functional outcome.

Introduction
Carpal dislocations are an important group of injuries in terms of their clinical and economic impact on the patient who is generally young. These injuries are easily missed and can be difficult to treat, with potential devastating effects on the patient if mismanaged. This article outlines the important aspects of diagnosis and management of these injuries, and provides an understanding of their classification.

History
In 1855, prior to the introduction of radiography, Malgaigne\textsuperscript{1} and, slightly later, De Quervain,\textsuperscript{2} were the first to publish a description of perilunate fracture dislocations. The first true series was reported in 1906 by Tavernier in France,\textsuperscript{3} and in 1918, Destot studied the wrist more carefully and described these injuries in greater anatomical detail.\textsuperscript{4} Unfortunately, enthusiasm for the study of wrist dislocations was lost until 1968, when Fisk presented the Royal College of Surgeons Hunterian Lecture on the concept of the intercalated segment. In 1972, Linscheid and Dobyns further modified the intercalated segment concept by introducing the terms volar intercalated segment instability (VISI) and dorsal intercalated segment instability (DISI). In 1980, Mayfield illustrated the mechanism of perilunar wrist instability as a series of four stages, resulting in perilunate dislocations or lunate dislocations.\textsuperscript{5} Recently much progress has been made in classifying these injuries, and further studies of the kinematics of the wrist have enabled more detailed insights into the mechanisms of injury and the rationale of reconstruction.

Epidemiology
The true incidence and prevalence of these injuries are difficult to define precisely, and there are few studies that...
give a clear picture of the epidemiology. However, there is a belief that perilunate injuries in general are under-diagnosed. The peak incidence is in the third decade with a predominance of males. The perilunate dislocation, the lunate dislocation and the perilunate fracture dislocation variants have been estimated to comprise less than 10% of all wrist injuries. In a study of 166 carpal dislocations by Herzberg in 1993, it was noted that perilunate fracture-dislocations were more frequent than the perilunate dislocations at a ratio of two to one. The initial diagnosis was missed in 25% of cases.6

Anatomy

Biomechanics

The wrist has been thought of functionally in terms of either rows or columns, or even more recently, as a combination of the two. In reality, it is likely that individuals differ depending on anatomical variation in ligamentous laxity and the osseous configuration of the carpus, the distal radius and ulna. The object of carpal kinematics is to maintain joint congruency throughout all ranges of motion.

The forces transmitted through the radius and ulna do vary and it has been calculated that the radius transmits 100% of the axial force with an ulna negative wrist but 30% of the force will go through the ulna if there is a ulna positive variance.7 Clearly the position of the wrist will also significantly alter the kinetics and therefore the forces through the wrist at the time of injury which will influence the injury pattern.

Johnson8 divided the wrist into arcs which are named the greater and lesser arcs. These give rise to the terminology of greater and lesser arc injuries. The lesser arc injuries are those confined to ligamentous injuries around the lunate and greater arc injuries are fractures involving bones around the lunate. These are not to be confused with Gilula’s lines which are drawn along the borders of the carpal bones (Fig. 1) and are akin to Shentons’ line of the hip. Gilula’s lines guide the eye looking for relational incongruity between the carpal bones.

Kinematics

The lunate is the keystone in terms of comprehending the kinematics of the wrist and it is important to identify the factors influencing its position to help understand the various dislocation patterns. A compressive force across the wrist will exert a palmar-flexion force on the scaphoid. The triquetrum, due to its articular relationship to the hamate, will tend to dorsi-flex under compressive load. The triquetrum and scaphoid therefore influence the position of the lunate via their respective ligaments producing equilibrium of forces on the lunate with the default position of the lunate being slight dorsi-flexion. An imbalance in the forces secondary to trauma and disruption to the scapho-lunate or luno-triquetral ligaments will thus cause deformation in the normal relations within the carpus and lead to carpal instability. If the scapho-lunate ligament is ruptured the lunate rotates dorsally due to the reaction of the triquetrum creating the DISI pattern. If the luno-triquetral ligament is ruptured the lunate rotates volarwards with the scaphoid producing the VSI pattern.

In terms of total flexion and extension, the midcarpal and radio-carpal joints roughly contribute an equal amount although there is individual variation. The midcarpal joint tends to provide more extension and the radio-carpal joint more flexion. In radial deviation the proximal carpal row moves from extension to flexion and the distal row dorsi-flexes to compensate.

As alluded to earlier, the more accurate the reduction of the carpus after injury, the better the outcome. It is therefore important to understand the normal carpal relationships and to restore them with appropriate treatment.

The scapho-lunate angle, measured on a true lateral radiograph in neutral, normally lies between 30° and 60° and there is said to be scapho-lunate dissociation when this angle exceeds 70°. The capitate and lunate should be almost collinear (±15°). The carpal height ratio, which is the ratio of the carpus to the third metacarpal, should be approximately 0.54. Fig. 2 shows how to use a lateral radiograph to measure the axes of the various bones. In addition, translocation of the carpus in the ulna direction needs to be recognized. This measurement was made by comparing the distal radial articular width with the distance from radial styloid to the ulnar edge of the lunate. This ratio should be 0.87 ± 0.04 (Fig. 3).9 There are other measurements which can be made but these provide a useful minimum set to assess whether a satisfactory reduction has been obtained.

Ligaments

The carpal ligaments are pivotal in the stability and kinematics of the wrist joint and an understanding of their anatomy is important for wrist injury reconstruction.

The carpal ligaments are divided into extrinsic and intrinsic, dorsal and volar. The intrinsic ligaments attach the carpal bones one to another. The dorsal and volar
extrinsic ligaments are extra-articular and are often best appreciated from within the joint at arthroscopy.

The important **intrinsic** ligaments include the scapholunate and the lunotriquetral ligaments of the proximal row, and the intrinsic ligaments of the distal row. The distal interosseous ligaments allow almost no movement at the distal row but the scapho-lunate and the lunotriquetral ligaments provide a complex link in proximal carpal interrelationship.

The extrinsic ligaments are different histologically from the intrinsic ligaments and have also been shown to fail in a different way due to their differing yield strengths. The intrinsic ligaments tend to fail at the bone-ligament interface whereas the extrinsic ligaments tend to fail mid-substance. This clearly has implications in terms of repair particularly of the scapho-lunate ligament.

The main **extrinsic** dorsal ligament complex comprises the dorsal radio carpal ligament (DRCL) which runs from the radius to the triquetrum (radio-triquetral ligament). The dorsal intercarpal ligament reinforces the intrinsic ligament. There is no extrinsic dorsal ulno-carpal ligament. The deep and superficial volar ligaments form in such a way that creates a theoretical space and an actual area of weakness termed the “Space of Poirier” at the capito-lunate interval—between 4, 3 and 2 (Fig. 4). This is the “space” through which the lunate will dislocate in a lunate dislocation—the path of least resistance. The proximal radio carpal ligament links the radius and the proximal row, and the larger distal inverted “V” links proximal and distal rows while the radioscapo-capitate ligament links all three. The important ligaments are the radioscapoid, radioscapo-capitate and short and long radio-lunate ligaments. The radioscapo-capitate ligament is a fulcrum for the scaphoid and it flexes and extends around this. Incidentally, the much quoted ligament of Testut is, in actual fact, not a true ligament and although it is termed the radioscapo-lunate ligament, it has no structural integrity and is thought to be a vascular supply for the scapho-lunate ligament and carpus. The palmar side comprises the radio-carpal and ulno-carpal ligaments.

In 1980 Mayfield et al. performed a cadaver study which gave an insight into the probable sequence of injury in the perilunate spectrum of injury. On impact from a fall on the forward outstretched hand, the force through the wrist produces a supination injury and begins radially then either passes through the body of the scaphoid with a fracture, or through the scapho-lunate interval with ligamentous disruption. The four stages he described provide a spectrum of carpal injuries relating to lunate and perilunate dislocations. These are illustrated in Fig. 5 and are defined as: stage 1, progressive rupture of the scapho-lunate ligament from volar to dorsal, followed by stage 2, dorsal dislocation of the capitate with dissociation.
at the luno-capitate joint with tearing at the space of Poirier, then stage 3, luno-triquetral ligament disruption, with the rest of the carpus being displaced, usually dorsally, and finally, stage 4 is complete ligament disruption with the lunate forced volarwards by the proximal portion of the capitate resulting in dislocation of the lunate through the space of Poirier. A fall on the hand placed behind the body results in the reactive force through the ulna side of the wrist producing a pronation type injury. The ligament disruption then starts with the luno-triquetral and propagates in the reverse direction—sometimes called a “reverse Mayfield injury”.

**Diagnosis**

As noted in the study by Herzberg and Garcia-Elias, carpal dislocations are often missed on initial evaluation. What is required is a good history of the mechanism of injury, a high index of suspicion and adequate assessment, both clinically and radiographically. A reason for misdiagnosis can be the fact that these injuries are high energy causing multiple injuries, resulting in the less obvious wrist injuries being overlooked. It is also important to remember that a missed chronic dislocation can fool the unwary, as the amount of wrist movement can be deceptively good in some cases. Neurological sequelae are not uncommon and in particular the median nerve is at risk from perilunate dislocations and volar lunate dislocations.

In the assessment of acute injuries the following radiological images are mandatory: a postero-anterior (PA) in neutral rotation, a lateral and an oblique view (45° pronated). The lateral view is pivotal and if there is any concern that the radius, lunate and the capitate are not in alignment then a carpal disruption must be suspected. Figs. 6a and b show a volar lunate dislocation on the lateral not seen so well on the PA where there is, however, overlapping of the scaphoid, lunate and capitate. The radiographic sign is the “spilled teacup” sign of the lunate when it rotates anteriorly around the radio-lunate ligament.

This frank dislocation of the lunate is, however, the extreme end of a spectrum of injuries.

**Mechanism of injury**

Most carpal dislocations result from a staged disruption of the ligamentous structures as described by Mayfield. Forces may be directed through the carpal bones themselves resulting in a fracture. Less commonly the forces are transmitted through the ulnar side of the wrist as a result of falling backwards producing a pronation of the carpus. This can result in a trans-triquetral perilunate injury.

The capitate–hamate diastasis injury is rather different in that it is caused by an anterior–posterior crush type force which forces the intrinsic ligaments apart and, because this is radiographically quite subtle, is easily missed.

**Classification**

These injuries may be acute or chronic.

(i) **Perilunate injury**

(A) Lesser arc

1. Dorsal or volar perilunate dislocation or isolated lunate dislocation (end stage perilunate dislocation).

(B) Greater arc

1. Dorsal or volar fracture/dislocations.

(ii) **Axial dislocations**

(iii) **Isolated carpal dislocations**

(l) **Perilunate injuries**

A. **Lesser arc injuries**

Scapho-lunate ligament rupture

The lesser arc injuries are a spectrum of disorders and this first stage is described by Mayfield as stage 1.
Dorsal perilunate dislocations
After scapho-lunate injuries these are the most common injuries seen—the lunate remains within the lunate fossa of the radius whilst the remainder of the carpus displaces dorsally (Fig. 7).

Lunate dislocations
The lunate is most commonly dislocated in a palmar direction leaving the volar and ulno-lunate ligaments intact.

Palmar perilunate injuries
These are rare injuries being only 3% of all perilunate injuries and are most likely to represent a hyperflexion and supination force at the time of injury. It is not uncommon for the scaphoid to have been fractured and, unlike the trans-scaphoid perilunate injury, the fracture is usually more vertical and unstable. It is characterized by the "crowded carpus" sign similar to Fig. 6 on the PA view, although it is more easily diagnosed on the lateral radiograph. These are extremely unstable injuries.

Luno-triquetral ligament rupture
These are a variation of the Mayfield injuries and can be thought of as a reverse stage 1 with forces opposite of those producing the scapho-lunate ligament injury.
(B) Greater arc injuries

Perilunate fracture dislocations
These can occur in a variety of configurations (Fig. 8a and b). By far the most commonly encountered is the trans-scaphoid perilunate injury which accounts for 60% of carpal dislocations. These usually involve a transverse fracture of the scaphoid waist with the proximal portion remaining with the lunate, although according to Herzberg, 3.6% will also have an SL ligament injury.

Trans-scaphoid, trans-capitate perilunate dislocations—described by Fenton—are caused by hyperextension during which the capitate is forced against the dorsal distal radius and result in a transverse fracture of the capitate, the proximal part of which is then forced into a volar tilt by the eventually normally aligned distal fragment.

Transtriquetral perilunate dislocations
This represents a reverse Mayfield’s injury and most commonly this is a ligamentous injury (75%) only. In this case the luno-triquetral ligaments are torn while the distal row pivots around the lunate making it a lesser arc injury. The radio-lunate ligaments, presumably being stronger, keep the lunate in position, while the weaker luno-triquetral ligament ruptures. Only in about a quarter of cases a trans-triquetral injury occurs instead of a rupture of the luno-triquetral ligament resulting in a greater arc injury.

(II) Axial fracture/dislocations of the carpus
These are caused by crush injuries resulting in splitting of the column of the carpus where there is an axial division leaving the radial carpus aligned normally with the radius, and the ulna side displaced, or the ulna portion normally aligned with the radius and the radial portion of the carpus displaced. The injury may also split the corresponding metacarpals with their respective carpus and clearly this can also result in a severe soft tissue injury and a high level of suspicion should exist for compartment syndrome and neurovascular injury (Fig. 9).

(III) Isolated carpal dislocations
All the carpal bones have been reported to dislocate in an isolated fashion and probably represent a localized injury directed over the bone concerned.

The scaphoid has been shown to dislocate anteriorly (type 1) or in association with a capitale–hamate injury (type 2). These injuries are too rare for the exact mechanism of injury to be identified but a violent force is presumed to be required with a sudden pronation with the wrist in ulna deviation and extended wrist probable for the type 1 injury.11

The pisiform can be avulsed from its ligamentous attachments by forced and violent contraction of the flexor carpi ulnaris, and may dislocate proximally or distally, if, for example, the tendon itself ruptures.12

The trapezium and the trapezoid have also been reported as isolated dislocations.13,14

Isolated triquetral dislocations have been described only four times in the literature. A crushing injury was described in two, the others being of uncertain aetiology.15

The capitate has been reported to have been dislocated three times with two volar and one dorsal displacement. All were reduced by open reduction apparently successfully.16

The hamate has also reported to have been dislocated by high energy injuries or penetration of the carpus causing direct displacement. Either removal, open reduction or closed reduction appears to have been satisfactory in the few cases.17

Treatment

Carpal dislocations require urgent identification and reduction to avoid a poor outcome. There are three main categories of treatment, namely, closed reduction and cast, closed reduction and percutaneous Kirschner-wire (k-wire) fixation and open reduction with fixation.

It is important to reduce the dislocation as soon as possible. This is best achieved in the operating theatre; however, if there is no immediate access to theatre it may be necessary to perform a closed reduction in the emergency room if there is neuro-vascular compromise. Either regional or general anaesthetic is required. Longitudinal traction is applied to the wrist for several minutes
before attempting the reduction manoeuvre. An effective way of achieving traction is to use Chinese finger traps attached to the index and middle fingers. The fingers may be suspended vertically or horizontally with the elbow at right angles. Weights can be added to the arm or fingers to increase the traction which can be left for several minutes to take advantage of the visco-elasticity of the tissues before the reduction is attempted. In order to identify the injury pattern more effectively, it is useful to obtain radiographic images in traction.

Closed reduction is then attempted and the manoeuvre for a lunate dislocation is one method which was originally described by Tavernier in the early 1900s. This involves applying a counterforce to the volar lunate while simultaneously flexing the wrist (capitate) over the lunate with axial traction. Reduction should be accompanied by a definite click as the capitate engages with the lunate.

Although closed reduction is used for initial treatment, further stabilization is usually necessary to maintain an accurate reduction. In particular, a trans-scaphoid injury has a high incidence of non-union without internal fixation of the scaphoid fracture despite a good initial reduction of the fracture.

Closed reduction and percutaneous fixation

Closed reduction and percutaneous fixation are acceptable if the reduction can be achieved with accuracy. The temptation to compromise must be avoided. In cases where the acute injury is being managed by a surgeon with less experience it is preferable to perform closed reduction, apply a cast and refer for more specialist management. Inappropriate initial surgery can compromise the definitive repair. The priority in closed reduction is to maintain a satisfactory position of all carpal bones and this can often be achieved using k-wires. temporary k-wires inserted dorsally into the lunate and scaphoid can be used as joysticks to achieve correct relative orientation. Definitive wires can be placed from the scaphoid into the lunate to maintain reduction. If a satisfactory reduction is achieved on image, a second wire is placed from the scaphoid into the capitate once traction has been relieved and a third wire placed across the luno-triquetral articulation. Generally, the wires are removed after 6–8 weeks and the wrist splinted for a further 6 weeks to allow the ligamentous disruption to heal.

If the scaphoid fracture is adequately reduced, it is possible to fix this percutaneously with a cannulated differential pitch screw using the technique described by
There is, however, a risk of causing fracture displacement if there is instability and this may necessitate open reduction. K-wires fixation for stabilizing the scaphoid fracture may be possible but is not ideal.

An image intensifier is generally used to reduce and fix the carpal bones; however, arthroscopy is also useful although comparative studies have not been undertaken to compare the two methods.

Open reduction

Studies would suggest that open reduction and internal fixation give the most satisfactory results in terms of anatomical restoration and outcomes. Subtle injuries may be found such as small osteochondral fractures, which were not initially seen on plain films. These may well require reattachment and other ligamentous injuries can be more accurately repaired and intra-articular soft tissue removed. This infers, but does not prove, a better outcome.

If a displaced scaphoid fracture is present then open reduction is required. If the injury is a purely ligamentous one then the decision whether to perform an open repair needs to be made according to the type of injury, the degree of instability and the likelihood of anatomical reduction with more conservative techniques. Patient factors such as age and occupation will also influence the decision as to whether open reduction is preferable.

Approach

What approach is best to use? Dorsal, volar or a combined approach? The fear has always been that a dorsal approach would lead to lunate and scaphoid avascular necrosis due to interference with their blood supply. This has so far remained a theoretical rather than a real complication. Campbell et al. reported on nine patients with a dorsal perilunate dislocation reduced via a dorsal approach with no avascular complications. The lunate or proximal pole of the scaphoid will sometimes exhibit signs of increased radio density in the ensuing post-operative period but this does not generally lead to collapse but resolves as revascularization occurs. The dorsal approach allows greater accuracy in reduction of the scapho-lunate interval and repair of the ligament while, with a volar lunate dislocation a volar approach allows the important volar ligaments to be repaired and the carpal tunnel to be decompressed. The scapho-lunate and luno-triquetral ligaments may avulse from the bone-ligament interface and reattachment of the ligament may require intraosseous sutures or bone anchor fixation to provide adequate reconstruction.

The dorsal approach is made via a longitudinal incision over the wrist centered on Lister’s tubercle. The third dorsal compartment is entered and extensor pollicis longus retracted. The fourth compartment is then subperiosteally elevated in an ulna direction to aid exposure of the dorsal capsule. Alternatively the fifth dorsal compartment may be incised and the distal half of the extensor retinaculum reflected to Lister’s tubercle. The capsule may be found to be avulsed from the radius and require repair.

The palmar approach is via an extended carpal tunnel incision retracting the median nerve radially. The lunate and volar capsular rent will be visible in a palmar lunate dislocation and it can be reduced through this and the capsule repaired (Fig. 10). Several authors recommend utilizing a palmar approach in addition to the dorsal one and Sotereanos used combined approaches in 11 perilunate fractures and fracture-dislocations and obtained good clinical results at a mean follow-up of 30 months.

Ligament repair

There is a trend for direct ligamentous repair in carpal dislocations in an attempt to improve long-term stability. Several studies have shown the superiority of this method but it is not clear whether this is due to a greater accuracy of reduction or due to the repair of the ligaments. Adkinson treated cases via a dorsal approach and direct visualization of reduction and percutaneous pinning without repair of the ligaments with good results. In the absence of data to answer this question, it is recommended that significant ligamentous injuries should be repaired during open reduction which will most often require a combined dorsal and palmar approach. The dorsal approach will provide access to the scapho-lunate ligament and dorsal luno-triquetral ligament, and the palmar approach will allow repair of the volar luno-triquetral ligament and the extrinsic radioscapohamate ligament (Fig. 11).

Fracture fixation

The greater arc injuries involving a fracture of the scaphoid require fixation even if undisplaced, as non-operative
treatment leads to a non-union rate of about 50%. These are extensive injuries and the amount of energy imparted to the tissues is much greater than for an isolated undisplaced scaphoid fracture. In order to fix the scaphoid, various types of screw fixation can be used. There are no direct studies comparing acute fixation methods in such injuries, but a study from Derby (UK) looked at healing rates and adequacy of fixation in scaphoid non-unions. Double k-wire fixation, Herbert screw and AO mini fragment screw fixations were compared in terms of union rates and time in the cast. The two screw fixations achieved similar rates of union (85% and 77%, respectively) but the wire fixation resulted in much reduced union rates (55%) with prolonged immobilization. k-wire fixation provides inadequate compression and it may indeed result in distraction at the fracture site. If there is significant comminution of the scaphoid, primary bone grafting may be required to prevent malunion in a “humpback” deformity (Fig. 12).

Treatment of late injuries

There are a significant number of injuries which are missed on initial presentation. It is well established that delayed treatment as well as the adequacy of reduction influences the final outcome. Reduction of a perilunate dislocation has been undertaken by the authors at 35 weeks with a good result at one year. Even at this stage attempt at reduction should be made as the results are better than expected. Reduction may be facilitated by external fixator application prior to definitive treatment by open reduction. If good anatomical reduction is not achieved then the results tend to be poor. If reduction is not possible and the patient is symptomatic, then a proximal row carpectomy may be helpful for a lunate dislocation. An arthrodesis, especially for an old perilunate dislocation, is considered a useful salvage procedure. Excision of the lunate or scaphoid in isolation gives a poor result.

Prognosis

Herzberg et al. looked at the outcomes of trans-scaphoid perilunate injuries. Of 14 treated with acute open reduction and internal fixation, the mean Mayo wrist score was 86 for the Mayfield stages ii or iii and 79 for stage iv (normal 100). Aspergis et al. looked at 28 cases of perilunate dislocations and fracture/dislocations and eight of these were treated with closed reduction alone and 19 with internal fixation. It was suggested that the poorer outcome in the closed treatment group was related to the instability of the injury with lack of direct anatomical reduction and ligament repair. The scoring system used, however, was not validated and the groups were somewhat heterogeneous.

Minami et al. treated 13 patients with lunate and perilunate dislocations and correlated the anatomical reduction from post-operative radiographs with the follow-up clinical outcome at an average of 2 years. They suggested that a scapho-lunate gap of greater than 3 mm leads to a poorer functional outcome. Two of their patients failed to obtain normal carpal architecture and both went on to have wrist arthrodesis and proximal row carpectomy.

In both greater and lesser arc injuries, the best radiological results were observed after open reduction, internal fixation and direct ligament repair. In the greater arc group, the fixation of the scaphoid alone was not always sufficient and occasionally a scapholunate dissociation, lunotriquetral dissociation, ulnar translation of the carpus or other carpal collapse pattern remained at follow up. The initial appraisal of both the osseous and ligamentous pathology was felt to be very important and best performed at operation.

Weir described the outcomes of late perilunate reductions. The radiographic assessment and the range of movement were relatively poor at a mean follow up of two years although the functional results were surprisingly good despite radiographic evidence of arthrosis in 57%.

In a study by Garcia-Elias, however, delayed treatment of dorsal perilunate dislocations had a significant correlation with poorer outcome. Poorer outcomes were also correlated with accuracy of reduction and maintenance of reduction.
For trans-scaphoid perilunate injuries the average Mayo clinic score at eight years was 79 (normal 100) with recovery of 110° of movement and 75% grip strength. The poorer results have been associated with poor anatomic restoration e.g., ulna translocation or a higher energy injury with a stage iv Mayfield injury.

Although traditionally many of these injuries, whether treated by open or closed means, have been treated with prolonged immobilization, there is increasing evidence that earlier mobilization is better and does not seem to compromise the ligamentous repair. Inoue et al. treated 28 trans-scaphoid perilunate injuries with open reduction, ligament repair and Herbert screw fixation of the scaphoid and noted that those treated by 4 weeks of cast immobilization had a significantly better range of movement than those with greater than 5 weeks.

References