Traumatic Instability of the Wrist

Diagnosis, Classification, and Pathomechanics*

BY RONALD L. LINSCHEID, M.D.†, JAMES H. DOBYNS, M.D.†, JOHN W. BEABOUT, M.D.†, AND RICHARD S. BRYAN, M.D.†, ROCHESTER, MINNESOTA

From the Mayo Clinic and Mayo Foundation, Rochester

Post-traumatic instability of the carpus and the zigzag or sink deformity of the intercarpal joint in rheumatoid arthritis have interested two of us (R. L. L. and J. H. D.) for several years [10, 18]. Recently, when we encountered several cases of post-traumatic instability of the intercarpal joints, we were stimulated to review our experience with this condition, especially with rotatory subluxation of the intercarpal joint and the associated changes in position of the scaphoid with respect to the radius and the other carpal bones.

The first reference to carpal instability in the literature is the article by Gilford and associates in 1943. They noted that a link joint, such as the one between the proximal and distal carpal rows, should be unstable in compression and should crumple unless stabilized by a stop mechanism. This mechanism, they pointed out, is supplied by the scaphoid which bridges the intercarpal joint as a connecting rod. In fractures of the scaphoid, the stabilizing effect may be lost. Fisk called the resulting deformity the concertina effect and described similar findings in other conditions, further elucidating the mechanism involved. Such instability of the scaphoid has

Fig. 1-A Fig. 1-B Fig. 1-C

Figs. 1-A through 1-C: Posteroanterior roentgenogram of a normal wrist in neutral, radial, and ulnar deviation. Note that the space between the scaphoid and lunate is less than two millimeters in width and does not change.

Fig. 1-A: Neutral deviation.
Fig. 1-B: Radial deviation.
Fig. 1-C: Ulnar deviation.

* Read at the Annual Meeting of the American Society for Surgery of the Hand, San Francisco, California, March 5, 1971.

† 200 First Street, S.W., Rochester, Minnesota 55901.

FIG. 2-A

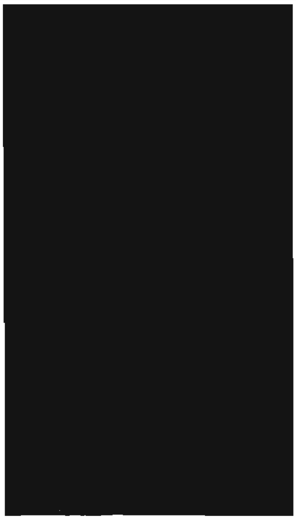

FIG. 2-B

FIG. 2-C

Figs. 2-A through 2-C: Scapholunate dissociation in a forty-eight-year-old man who had an acute dorsiflexion injury of his left wrist when he fell forward in an apple tree and checked his fall with the left hand.

Fig. 2-A: Posteroanterior roentgenogram with the left wrist in neutral position shows a three millimeter scapholunate gap and the scaphoid in a position of palmar flexion (vertical position). Note abnormal silhouette of scaphoid and the overlap of its distal pole and the capitate.

Fig. 2-B: Same view of wrist in radial deviation shows narrowing of scaphoid gap and persistent flexed position of scaphoid.

Fig. 2-C: Same view in full ulnar deviation shows widening of scapholunate gap and abnormal position of scaphoid.

been called subluxation of the scaphoid, rotational subluxation, and other names by several authors [2,6,7,11,23,28], and possible examples have been described in many articles [1,2,5,8,9,16,21,22,24-29].

It is the purpose of this article to describe the roentgenographic changes and clinical findings by which the diagnosis of carpal instability is made, to offer a classification of the carpal instabilities based on the roentgenographic findings, and to review existing knowledge of the pathomechanics of these lesions.

Significant Roentgenographic Relationships

On posteroanterior projections of the wrist, the space between the scaphoid and lunate (the scaphoid-lunate gap) in the normal wrist is the same as that between the other carpal bones. Also, on posteroanterior views made with the wrist in ulnar or radial deviation, the space in a normal wrist does not change (Figs. 1-A, 1-B, and 1-C). Widening of this space in the neutral position with further widening during ulnar deviation and narrowing during radial deviation is present in some forms of instability (Figs. 2-A, 2-B, and 2-C). In addition, forced radial deviation may cause the widening to reappear under these circumstances.

On the lateral projection the relationships of the scaphoid to the lunate and of the proximal carpal row to the radius and to the distal carpal row can be defined by drawing a series of axes as follows (Fig. 3):

1. The longitudinal axes of the long-finger metacarpal, the capitate, the lunate, and the radius (in the normal wrist in the neutral position these axes all fall on the same line) are drawn through the center of the head of the third metacarpal, the center of the head of the capitate, the mid-points of the convex proximal and the concave distal joint surfaces of the lunate, and through the mid-point of the distal articular surface of the radius.

2. The longitudinal axis of the scaphoid is drawn through the mid-points of its proximal and distal poles.

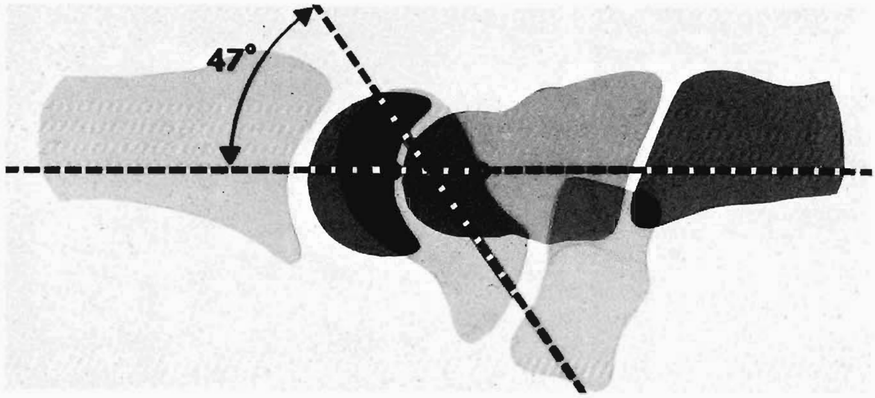

FIG. 3

Diagram of lateral roentgenogram of a normal wrist in neutral position showing longitudinal axes (colinear in this position) of capitate, lunate, and radius, and also longitudinal axis of scaphoid forming an angle of 47 degrees (scapholunate angle) with longitudinal axis of lunate. See text for points of reference for the axes.

Use of these axes makes it possible to measure angles that define the positions of the carpal bones. The scapholunate angle formed by the longitudinal axes of the scaphoid and of the lunate averages 46 degrees and ranges from 30 degrees to 60 degrees in normal wrists (Fig. 3). An angle greater than 70 degrees indicates carpal instability with the lunate dorsiflexed due to loss of the connecting-rod function of the scaphoid. However, similar intercarpal instability occasionally may be present when the scapholunate angle is smaller (Cases 19 and 20, Table I; Cases 3 to 5, Table II) while the angle is often less than normal when instability associated with palmar flexion of the lunate is present. The capitolunate angle formed by the longitudinal axes of the capitate and of the lunate is normally zero but may be either a dorsal or a palmar angle in the presence of carpal instability. The radiolunate angle formed by and longitudinal axes of the lunate and the radius is, of course, a measure of the amount of dorsal or palmar flexion of the proximal carpal row on the radius. By making a correction for flexion or extension of the wrist when the roentgenogram was made this angle in the unstable wrist can be compared to that in the opposite normal wrist. The radiolunate angle may be either dorsal or palmar depending on the type of instability.

If the distal link (lunate with respect to radius or capitate with respect to lunate) is dorsiflexed, the radiolunate or capitolunate angle is recorded as positive, while if the distal link is palmar flexed, the angle is recorded as negative.

Classification

A study of scapholunate dissociations under way for a decade was broadened to include all cases of carpal instability reviewed in the Hand Clinic of the Mayo Clinic over a two-year period. From this study a simple classification of carpal instability evolved.

In general, there are two types: dorsal and palmar. In the most common dorsal type, a lateral roentgenogram of the wrist shows the carpal lunate to be dorsiflexed and displaced ventrally with respect to the longitudinal axes of the radius and the capitate, which are no longer colinear (Fig. 4). In addition, there usually is some associated rotational displacement of the longitudinal axis of the scaphoid so that this axis is almost perpendicular to the radius, that is, the vertical position of Armstrong. This position appears to be indicative of a dissociation of the scaphoid and lunate caused either by fracture of the scaphoid or by disruption of the ligaments of the wrist.

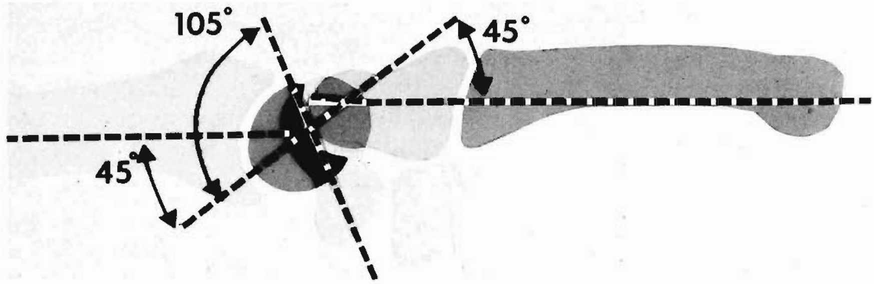

FIG. 4

Dorsiflexion instability. Diagram of lateral roentgenogram of the wrist showing dorsiflexion of the lunate relative to the radius, a scapholunate angle of 105 degrees, and palmar flexion of the capitate relative to the lunate of 45 degrees.

In the palmar type of carpal instability, there is palmar flexion of the lunate relative to the longitudinal axes of the radius and the capitate (Fig. 5), and there may be associated dorsal subluxation of the lunate on the radius as well. The scaphoid often appears foreshortened on the posteroanterior roentgenogram but there is no dissociation of the scaphoid and lunate (increase in the scapholunate gap).

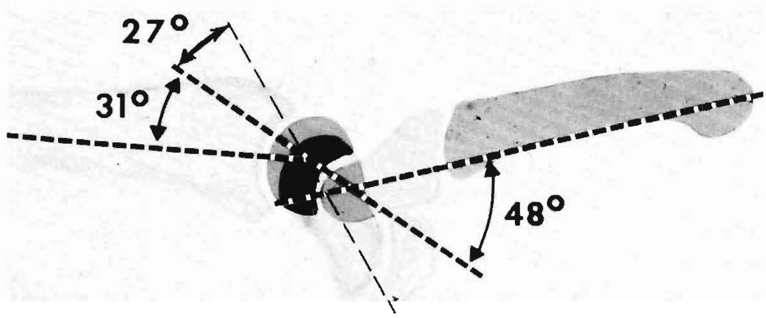

FIG. 5

Palmar flexion instability. Diagram of lateral roentgenogram showing palmar flexion of the lunate relative to the radius of 31 degrees, a scapholunate angle of 27 degrees (somewhat less than normal), and dorsiflexion of the capitate relative to the lunate of 48 degrees (see Figure 13).

Designation of these common patterns of deformity so as to cause minimum confusion is difficult. However, since the position of the proximal carpal row is usually easier to define on the roentgenograms and since the proximal carpal row is acting as an intercalated segment in these deformities, we suggest that the term dorsiflexed intercalated segment instability would best describe the crumpling deformity of Gilford and associates or the concertina deformity of Fisk and that the term palmar-flexed intercalated segment instability would be appropriate for the opposite change. Since these terms might be cumbersome for regular use, however, they could be shortened to dorsiflexion instability and palmar flexion instability.

These two types of instability are usually easily recognized on routine roentgenograms. However, the displacements of the carpal bones that occur in different positions of the wrist may lead to error in interpretation. For instance, in the normal adult the lunate palmar flexes approximately 20 degrees in relation to the radius during full radial deviation and dorsiflexes an average of 25 degrees in full ulnar deviation [4]. Thus, an error could be introduced by positioning the wrist improperly when the roentgenograms are made. Slight rotation of the wrist from the true lateral position also causes some variations in the appearance of the scaphoid and lunate on lateral roentgenograms. Although accurate positioning of the wrists in a neutral position for lateral views is routine, we wished to be certain that there was little likelihood that such rotation would be a cause of error in the interpretation of routine roentgenograms. A study of fifty roentgenograms of the wrist, which were removed from the files at random, showed less than 5 degrees of rotatory change in the position of the longitudinal axis of the lunate compared with the longitudinal axes of the capitate and radius after adjustment for wrist flexion or extension.

Both ulnar and radial deviations of the wrist cause overlap of the second and third metacarpal heads on the lateral roentgenogram. For adult males, the amount of overlap is approximately twelve millimeters in full ulnar deviation and seven millimeters in full radial deviation. When the wrist is well positioned for the lateral roentgenogram with neutral deviation there is an overlap of not more than two millimeters. An overlap of more than four millimeters is indicative of significant ulnar or radial deviation.

For the purpose of this study we were able to select roentgenograms that showed less than 20 degrees of dorsiflexion and less than 10 degrees of palmar flexion. The routine posteroanterior views selected for the study also appeared to show little radial or ulnar deviation. Roentgenograms showing the wrist in as nearly a neutral position as possible were selected to minimize error in the interpretation of the angulatory changes. A special effort was made to avoid radial deviation so that an assessment of the amount of flexion of the scaphoid could be made from the appearance of its end-on silhouette on the posteroanterior views.

The scaphoid, normally palmar, flexes during radial deviation and dorsiflexes during ulnar deviation. In the neutral position the scaphoid silhouette lies intermediately between these extreme positions. In both palmar flexion and dorsiflexion instability, the scaphoid tends to be in palmar flexion thus providing a smaller or end-on silhouette. Although it is the lateral roentgenogram that permits the palmar flexion of the scaphoid to be quantitated, the posteroanterior projection may suggest that instability is present.

Roentgenograms of wrists in multiple positions and cineroentgenograms demonstrated a synchronous motion of the scaphoid and lunate during movement of the normal wrist from radial to ulnar deviation.

Clinical Material

Of the patients reviewed who were found to have either dorsiflexion or palmar flexion carpal instability, twenty had scapholunate dissociation; three, perilunar dislocations with or without minor fractures; three, trans-scaphoid perilunar dislocations; thirteen, scaphoid fractures; three, changes in the radiocarpal and ulnocarpal joints with associated imbalance of muscle forces; and five, ligamentous injury or laxity. The pertinent findings in these wrists follow.

Scapholunate Dissociation

This condition found in twenty-three wrists (Table I) was the result of disruption of the scapholunate interosseous ligament and was manifest as a zigzag deformity of the intercarpal joint (Figs. 2-A, 2-B, 2-C, and 4). The clinical symptoms included pain in the wrist, particularly during dorsiflexion, and a snapping or clicking sensation with movement. The grip strength was usually diminished and wrist motions were impaired in some instances. Using image intensification, we could see that the scapholunate interosseous space opened during movement of the wrist and the normally synchronous movements of the scapholunate joint were disrupted, that is, the lunate did not move with the scaphoid but remained in the dorsiflexed position during most of the movement.

The diagnosis was made in twenty-three hands of twenty patients. A history of

TABLE I

SCAPHOLUNATE DISSOCIATION

Case No.	Age	Sex	Injury	Type of Instability	Scapholunate Gap (*millimeters*)	Angle (*degrees*) Scapholunate	Angle (*degrees*) Capitolunate	Angle (*degrees*) Radiolunate	Remarks
1	28	M	Auto accident	Dorsal	2	95	−23	16	Very stiff hand
2	48	M	Acute dorsiflexion	Dorsal	4	112	−43	45	Persistent clicking
3	41	M	Fell wrestling	Dorsal	7	115	−32	40	Weak wrist
4	59	M	Auto accident	Dorsal	4	80	−5	15	Old injury
5	35	M	Convulsion, fell 4.6 meters	Dorsal	2	73	−15	15	Surgical repair, scapholunate ligament
6	41	M	Traction injury	Dorsal	2	85	−15	20	
7	?	M	Ski instructor	Dorsal	4	100	−28	30	
8	67	M	Fell 15 years ago	Dorsal	5	80	−25	35	
9	52	M	Fell 3 meters	Dorsal	3	90	−22	22	
10	64	M	Fell 20 years ago	Dorsal	6	88	−33	40	
11	60	M	Fell mining	Dorsal	5	75	−30	32	Weak, painful, snapping wrist; ligament repair
12	77	M	Fell 1 year ago	Dorsal	3	80	−8	5	
13	74	M	Active life	Dorsal	5	120	−54	53	Daredevil stunts
14	75	M	Barber	Dorsal	3	80	−45	40	
15	65	M	Pain 1 year	Dorsal	4	75	−37	25	
16	80	M	Pain right wrist 6 months; left wrist, 3 months	Dorsal; dorsal	2; 6	110; 100	−60; −32	70; 30	Vigorous worker
17	51	F	Pain, right wrist	Dorsal	4	75	−8	15	
18	?	M	Swelling, crepitus, gave way climbing ladder right wrist; swelling, crepitus, gave way climbing ladder left wrist	Dorsal; dorsal	5; 3	90; 90	−25; −25	25; 25	Ligamentous reconstruction
19	?	M	Wrist pain, no known injury	Dorsal	5	55	5	0	Early degenerative changes; radial styloid
20	?	M	Pain, left wrist 1965; dropped weight on right wrist, 1968	Dorsal; dorsal	4; 5	75; 65	−10; 0	5; 0	Weak ligament

a specific dorsiflexion injury was elicited from ten patients. The other ten patients could not remember a specific injury, though at least four of them, by virtue of their occupation or previous avocation, had been subjected to trauma or stresses of significant degree. The others, including the three with bilateral dissociation, had no relevant history. Congenital ligamentous laxity or developmental ligamentous attenuation may have played a role in those cases.

A scapholunate gap greater than two millimeters was considered to be diagnostic. In three patients examined with image intensification the gap could be enlarged by motion, particularly dorsiflexion and ulnar or forced radial deviation. On the routine posteroanterior roentgenograms the gaps ranged from two to seven millimeters for an average of four millimeters. In twenty-one wrists (Cases 1 through 18, and left wrist of Case 20, Table I), dorsiflexion instability was evident. The capitolunate angle in these wrists ranged from −8 degrees to −60 degrees (average, −31 degrees) while the radiolunate angle, when corrected to place the wrist in the neutral position, was usually within 5 degrees of being the same as the capitolunate angle, although in the opposite direction. The scapholunate angle in these twenty-one wrists ranged from 70 degrees to 120 degrees with an average of 90 degrees. This average was 30 degrees above the upper limit of 60 degrees found in the normal wrists.

The two remaining patients with two wrists showing dorsiflexion instability (Case 19 and right wrist of Case 20, Table I) were atypical. They showed little evidence of intercarpal deformity at the capitolunate joint (they had normal capitolunate angles), but the gap between the scaphoid and lunate was five millimeters in each instance. The scapholunate angles were only 55 degrees and 65 degrees respectively (Figs. 6-A and 6-B), suggesting that the scaphoid was still performing its function as a connecting rod stabilizing the intercarpal joint in both of these wrists. In general, the end-on silhouette of the scaphoid as seen on the posteroanterior roentgenograms suggested that the degree of rotation of the scaphoid was roughly proportional to the size of the scapholunate angle as measured on the lateral roentgenograms.

FIG. 6-A

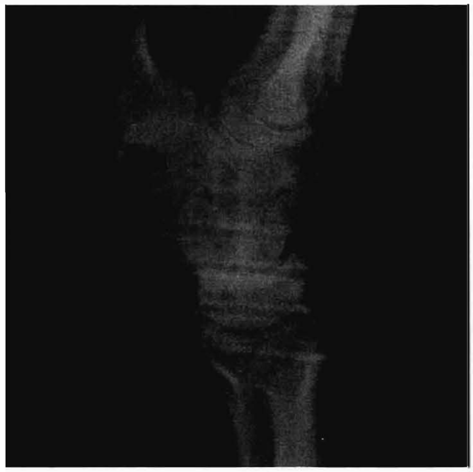

FIG. 6-B

Figs. 6-A and 6-B: Scapholunate dissociation with little associated intercarpal deformity.

Fig. 6-A: The posteroanterior roentgenogram shows a scapholunate gap five millimeters in width.

Fig. 6-B: The lateral roentgenogram shows a normal capitolunate angle, and a minimally increased scapholunate angle of 60 degrees, suggesting that the scaphoid is still stabilizing the intercarpal joint.

Perilunar Dislocations without Fracture

Three patients with perilunar dislocations were seen during the period covered by this study. A small fragment avulsed from the dorsal aspect of the lunate was the only visible fracture. Two of the three seen eight and eleven weeks, respectively, after injury had open reductions of their dislocations and ligament reconstructions. At operation, after reduction of the perilunar dislocation, the disruption of the scapholunate ligament was clearly visible and was associated with dorsal prominence of the proximal pole of the scaphoid and a large scapholunate gap (Figs. 7-A through 7-D). From the operative findings it was evident that both patients had unstable scapholunate joints, and, when tested by axial compression, one of them also had instability of the dorsiflexion type at the intercarpal joint. In both instances a loop of extensor tendon was used to reconstruct the scapholunate ligament. This loop appeared to hold the scaphoid and lunate in close proximity and improved scapholunate stability but in one instance it did not improve the intercarpal collapse.

The third patient was treated by closed reduction, which was successful. Subsequently this wrist was clinically stable with no capitolunate angulation, but there was persistent widening of the scapholunate gap amounting to three millimeters.

Perilunar Dislocations with Fractures of the Scaphoid and Other Bones

Three patients with these injuries were treated by immediate closed reduction and immobilization in a snug cast. In two of the three patients the initial reduction seemed stable (Figs. 8-A through 8-E), the scaphoid having been positioned under the image intensifier in one of them so that seemingly optimum reduction and stability were achieved. However, in both of these patients increasing dorsiflexion instability and non-union developed. Of these two patients one had no further treatment, while the other was treated with a bone graft using the Russe technique. Satisfactory healing seemed to have occurred nine months after grafting, but eighteen months after injury non-union was obvious. The third patient's scaphoid fracture united after closed reduction but the patient was left with a three-millimeter scapholunate gap and a persistent carpal deformity characteristic of dorsiflexion instability.

Scaphoid Fractures

There were thirteen patients who had scaphoid fractures complicated by insta-

FIG. 7-A

FIG. 7-B

Figs. 7-A through 7-D: A perilunar dislocation with dorsiflexion instability treated by open reduction and ligamentous reconstruction eight weeks after injury.

Fig. 7-A: Posteroanterior roentgenogram before reduction of dislocation.

Fig. 7-B: Lateral roentgenogram before reduction of the dislocation. No fracture is visible.

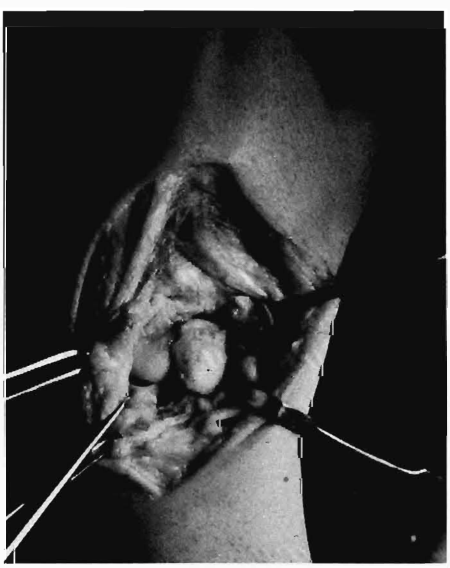

FIG. 7-C

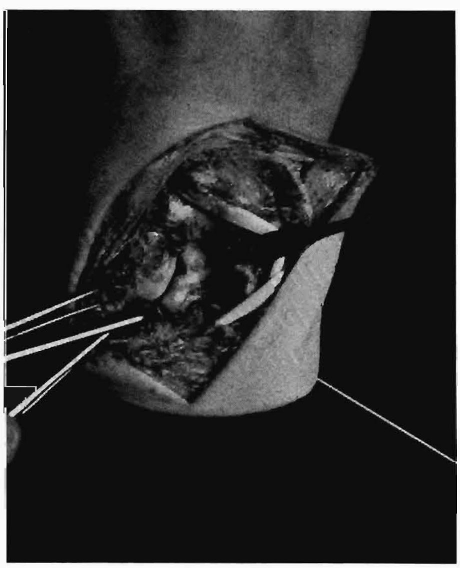

FIG. 7-D

Fig. 7-C: Scaphoid and adjacent bones exposed at operation prior to reduction. Note wide scapholunate gap, prominent proximal pole of displaced scaphoid, and capitate (visible to the left of the scapholunate gap) resting near the dorsal lip of the lunate. Rupture of the scapholunate ligament is evident. Exposure of such a large area of the articular surface of the capitate suggests flexion of the capitolunate joint. The lunate also appears dorsiflexed on the radius.

Fig. 7-D: After reduction and fixation with a Kirschner wire. Compare with Figure 7-C. Scapholunate ligament was repaired with tendon graft.

FIG. 8-A

FIG. 8-B

Figs. 8-A through 8-E: Perilunar dislocation with associated fractures through the radial styloid, scaphoid, and ulnar styloid process caused by a skiing accident.

Fig. 8-A: Posteroanterior roentgenogram before reduction.

Fig. 8-B: Lateral roentgenogram before reduction.

FIG. 8-C

FIG. 8-D

FIG. 8-E

Fig. 8-C: Satisfactory position after closed reduction on the posteroanterior roentgenogram.

Figs. 8-D and 8-E: Posteroanterior (Fig. 8-D) and oblique (Fig. 8-E) roentgenograms four weeks after reduction showing proximal migration of the head of the capitate into the widened scapholunate gap, ulnar displacement and dorsiflexion of the lunate, and malalignment of the scaphoid fracture.

TABLE II

SCAPHOID FRACTURES

Case No.	Age	Sex	History	Type of Instability	Angle (*degrees*) Scapholunate	Capitolunate	Radiolunate	Remarks
1	16	M	Fell 5 months previously	Dorsal	90	−25	30	Unrecognized fracture
2	15	M	Fell 2 years previously	Dorsal	75	−20	27	In cast, unrecognized fracture
3	34	M	Fall	Dorsal	60	−25	18	Non-union despite 6 months immobilization
4	34	F	Fell three years previously	Dorsal	90	−40	40	Non-union; intermittent immobilization
5	44	F	Fell 25 years previously; increasing pain	Dorsal	60	−18	18	
6	28	M	Fall; diagnosis made 1 year later	Dorsal	90	−38	40	Previous excision proximal fragment and radial styloid
7	40	M	Auto accident	Dorsal	80	−20	20	Failure, 9 months immobilization
8	25	M	Fall; treated as sprain for 6 weeks, then cast for 3 months	Palmar	15	45	−45	
9	51	M	Old scaphoid fracture, healed	Dorsal	90	−19	25	Severe degenerative changes
10	62	M	Old scaphoid fracture	Dorsal	85	−20	20	Non-union
11	48	M	Injury 32 years before	Dorsal	85	−30	28	Old non-union
12	70	F	Fell 1 year ago	Dorsal	73	−28	24	
13	55	M	Injury 32 years ago	Dorsal	85	−20	25	Pain for 2 months

bility at the intercarpal joint: twelve had dorsal and one palmar instability (Table II). Ten patients were male and three female. Their ages ranged from sixteen to seventy years. Four of these patients were treated soon after injury by immobilization in a plaster cast and the remainder had been untreated or undiagnosed for three months to twenty years after the fracture. Delayed union or non-union occurred in the four treated by immediate reduction and immobilization in a cast. Surgery for non-union of the scaphoid was carried out in eight patients. Seven had Russe procedures of which one failed. A scaphoid prosthesis was inserted in the remaining patient and in the one whose Russe procedure failed. The other five patients had non-union but insufficient symptoms to justify surgical treatment.

Roentgenographic examination showed evidence of dorsiflexion instability in twelve of the thirteen wrists, that is, dorsal angulation at the fracture site in the scaphoid (Figs. 9-A, 9-B, and 9-C). On these roentgenograms the scapholunate angle was measured using the axis running through the mid-point of the distal articular surface of the scaphoid and the mid-point of the fracture surface on the distal fragment because of the angulation at the fracture site. The scapholunate angles ranged from 60 to 90 degrees (average, 80 degrees). In this situation, however, these angles are of lesser importance since displacement at the fracture of the scaphoid rather than scapholunate ligamentous disruption allows intercarpal rotational instability to occur. The capitolunate angles ranged from −18 to −40 degrees with an average of −25 degrees, and the radiolunate angle showed a corresponding change, being roughly equal and opposite to the capitolunate angle.

The remaining patient had palmar flexion instability with a scapholunate angle of 15 degrees, a capitolunate angle of 45 degrees, and a radiolunate angle of −45 degrees (Figs. 10-A through 10-D).

Carpal Instability Secondary to Changes in Alignment of the Radiocarpal and Ulnocarpal Joints

Alteration of the alignment of the proximal and distal carpal rows is common

FIG. 9-A FIG. 9-B

Figs. 9-A through 9-C: A two-year-old ununited fracture of the scaphoid with dorsiflexion instability.

Fig. 9-A: Posteroanterior roentgenogram showing the prominent silhouette of the palmar pole of the lunate overlayed by the capitate.

Fig. 9-B: Lateral roentgenogram showing dorsiflexion of the lunate and angulation of the scaphoid at the fracture site.

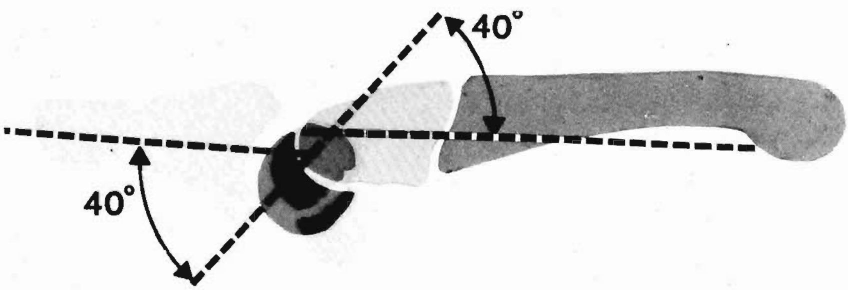

FIG. 9-C

Diagram of lateral roentgenogram showing longitudinal axes of the capitate, lunate and radius. Note marked dorsiflexion instability.

after fractures near the distal end of the radius when there is malunion with angulation and displacement of the radial articular surface. A few examples will illustrate this type of change in carpal alignment. A twenty-year-old woman had a weak, painful wrist and a malunited fracture of the distal end of the radius which resulted in radial and dorsal angulation of the articular surface of the radius (Figs. 11-A and 11-B). Associated with this angulation was a carpal deformity typical of dorsiflexion instability (scapholunate angle 70 degrees, capitolunate angle −35 degrees, and radiolunate angle 8 degrees). Study of intercarpal motion in the lateral projection under the image intensifier showed the deformity was not fixed. Correction of the alignment of the distal radial articular surface by osteotomy of the radius, before the carpal deformity had become fixed, improved the carpal alignment (Figs. 11-C and 11-D); nineteen months later she was symptom free.

A fifty-five-year-old woman, institutionalized for mental deficiency, had bilat-

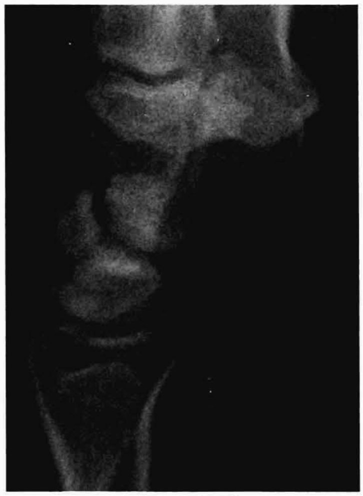

FIG. 10-A FIG. 10-B

Figs. 10-A through 10-D: Palmar flexion instability with scaphoid fracture.
Fig. 10-A: Posteroanterior roentgenogram at time of fracture.
Fig. 10-B: Lateral roentgenogram at time of fracture. Note palmar-flexed position of the lunate.

eral Colles' fractures with malunion. She had severe carpal deformities typical of dorsiflexion instability (scapholunate angles, 90 degrees and 100 degrees; capitolunate angles, −30 degrees and −35 degrees; and radiolunate angles, 15 degrees, and 20 degrees). In addition, she had claw-hand deformities apparently caused by her long-standing wrist deformity and the resulting muscle imbalance.

In these wrists the radiolunate angle was significantly less than the corresponding capitolunate angle. We believe that this difference from the wrists previously considered is explained by the fact that the scapholunate stability was maintained and the lunate was balanced but in an altered position on the displaced distal radial articular surface. This suggests compensatory realignments through balancing of the articular components rather than true instability.

FIG. 10-C FIG. 10-D

Figs. 10-C and 10-D: Posteroanterior (Fig. 10-C) and lateral roentgenograms (Fig. 10-D) showing persistence of palmar-flexed position after immobilization in a plaster cast.

FIG. 11-A

FIG. 11-B

Figs. 11-A through 11-D: Dorsiflexion instability secondary to deformity of the radius and absence of the distal end of the ulna in a twenty-year-old woman injured in an automobile accident.

Figs. 11-A and 11-B: Posteroanterior (Fig. 11-A) and lateral (Fig. 11-B) roentgenograms before operation showing radial angulation and dorsiflexion of the articular surface of the radius, absence of the distal end of the ulna, and dorsiflexion instability of the intercarpal joint.

FIG. 11-C

FIG. 11-D

Figs. 11-C and 11-D: Posteroanterior (Fig. 11-C) and lateral (Fig. 11-D) roentgenograms one week after osteotomy of the radius and resection of the distal end of the ulna show correction of carpal alignment as a result of correcting alignment of the distal articular surface of the radius.

An electrician, twenty-four years old, had lost the triquetrum, the distal end of the ulna, and the extensor tendons of all the fingers as the result of an electric burn which occurred while he was trimming tree limbs away from electric power lines. A carpal deformity, typical of palmar flexion instability, was evident one year after injury (Figs. 12-A and 12-B). At this time there was ulnar displacement of the carpus, radial deviation of the hand, and displacement of the scaphoid toward a vertical position relative to the longitudinal axis of the radius. The palmar flexion of the lunate results in a low scapholunate angle (30 degrees) characteristic of the palmar flexion deformity. The capitolunate angle was 45 degrees, and the radiolunate angle, −38 degrees.

FIG. 12-A

FIG. 12-B

Figs. 12-A and 12-B: Deformity of palmar flexion instability in a twenty-four-year-old man who sustained a severe electric burn with loss of the distal end of the ulna, the triangular fibrocartilage, triquetrum, and extensor carpi ulnaris tendon as well as the integument.

Fig. 12-A: Posteroanterior roentgenogram shows ulnar transposition of carpus and radial deviation of hand.

Fig. 12-B: Lateral roentgenogram shows palmar flexion and dorsal displacement of the lunate.

Ligamentous Injury or Laxity

Five patients had palmar flexion instability as the result of ligament injury or congenital laxity of the ligaments (Table III). Three of the five were thought to have had traumatic injuries of the carpal ligaments because symptoms began after the following incidents: an automobile accident during which the hands of a nineteen-year-old secretary were on the steering wheel; an attempt by a twenty-six-year-old fireman to open a stuck door by a blow with the heel of his hand (Fig. 13); and postoperative manipulation of a stiff wrist of a sixty-eight-year-old man.

The secretary had tenderness over the radiopalmar aspect of the left wrist for three weeks after the injury but thereafter was asymptomatic with no resultant weakness or loss of motion despite roentgenographic evidence of palmar flexion instability.

The fireman initially had tenderness over the hook of the hamate bone, but no evidence of fracture was visualized on a roentgenogram of the carpal tunnel. Tenderness and limitation of dorsiflexion to 20 degrees persisted for two weeks during which time a cock-up splint was worn. He returned to work three weeks after injury. One

TABLE III

LIGAMENTOUS INJURY WITH OR WITHOUT LAXITY

Case No.	Age	Sex	History	Palmar Instability, Wrist	Angle (*degrees*) Scapholunate	Capitolunate	Radiolunate	Remarks
1	19	F	Auto accident, hands on steering wheel; pain and weakness in left wrist	Right	50	22	−20	Only left wrist symptomatic
				Left	30	25	−30	
2	26	M	Struck door with heel of left hand	Right	18	50	−45	Only left wrist symptomatic
				Left	22	55	−40	
3	68	M	Audible painful crack in left wrist during manipulation	Left	35	60	−65	Volar capitolunate ligament probably torn
				Right	55	5	0	Normal wrist
4	43	M	"Trick" wrists	Right	45	23	−25	No disability
				Left	45	30	−20	No disability
5	24	M	Right wrist run over by truck; able to subluxate both wrists voluntarily	Right	15	35	−40	Ligament reconstruction, right wrist
				Left	?	?	?	

FIG. 13

Apparent severe palmar flexion instability in a twenty-six-year-old fireman who with the heel of his hand struck a door that would not open. Posteroanterior and lateral roentgenograms show marked palmar flexion of the lunate with normal scapholunate gap and angle. His other wrist showed same roentgenographic findings (note Figure 5).

year later he had a normal range of motion, normal grip strength, no pain or tenderness, and roentgenographic evidence of palmar flexion instability.

The sixty-eight-year-old man, prior to the injury to his left wrist, had had his median nerve avulsed at the level of the antecubital space and had had subsequent tendon transfers. After the wrist injury his hand was greatly weakened and he had considerable limitation of motion, but this disability was largely on the basis of his pre-existing condition.

The roentgenograms of the injured wrists of all three patients showed the typical changes of palmar flexion instability (Fig. 13). However, the opposite wrists of both the secretary and the fireman showed the same palmar flexion instability. It was assumed, therefore, that these two patients had congenital ligamentous laxity and that in the patient with the stiff wrist, tearing of the palmar capitolunate capsule had occurred during manipulation.

The two remaining patients could voluntarily subluxate their intercarpal joints producing the deformity of palmar flexion instability. One had trick wrists with no history of injury. He could voluntarily subluxate his wrist to the amusement of friends and the consternation of his doctors (Figs. 14-A through 14-D). The other

FIG. 14-A

FIG. 14-B

Figs. 14-A through 14-D: Voluntary subluxation of the wrist into position of palmar flexion instability. A forty-three-year-old man could assume this position by flexing his fingers at the interphalangeal joints, extending the metacarpophalangeal joints and the thumb, and then flexing and radially deviating the wrist, a combination of maneuvers that he would do almost instantaneously.

Fig. 14-A: Posteroanterior roentgenogram of wrist in normal position.

Fig. 14-B: Lateral roentgenogram of wrist in normal position.

FIG. 14-C

FIG. 14-D

Figs. 14-C and 14-D: Posteroanterior (Fig. 14-C) and lateral (Fig. 14-D) roentgenograms with the wrist subluxated. Note particularly the head of the capitate resting on the palmar part of the lunate concavity and the vertical position of the scaphoid relative to the radius.

patient reported that a truck had rolled over his hand while he was reaching to pick up his hat. However, he had been able to subluxate both wrists voluntarily before the injury and roentgenograms showed that both wrists subluxated into a position of palmar flexion instability.

Discussion

Dorsiflexion instability has been recognized for some time. In 1943, Gilford, Bolton, and Lambrinudi discussed the collapse of the carpal joints that occurs after certain scaphoid fractures, pointing out the importance of the scaphoid as a strut that prevents collapse or crumpling at the wrist. They noted that breaking this link allows angulation at the intercarpal joint with associated malalignment of the scaphoid fracture. They also noted that the lunate is dorsiflexed under these circumstances and suggested that the scaphoid functions as a double-stopped link allowing extension at the radiolunate joint and flexion at the capitolunate.

More recently, Fisk, in his Hunterian Lecture in 1968, described wrist-joint motion, the stabilizing effect of the various ligaments and tendons, and the importance of the scaphoid link in providing stability. On the basis of cadaver studies he concluded that the stability of the carpus depends largely on the integrity of the palmar radiocarpal ligament. Though radiocarpal dislocation was observed after division of the palmar radiocarpal ligament, the mid-carpal joint did not become unstable until the capsule between the capitate and lunate had been divided. Strong fibers were observed to run between the radial styloid process and the capitate. When these fibers were divided, the scaphoid could be flexed and extended independently within the carpus: Fisk also noted that the obliquity of the normal radiocarpal ligament prevents the carpus from "falling down hill" (ulnaward) on the inclined articular surface of the radius, a phenomenon that occurs particularly in rheumatoid arthritis, as already noted.

Studies of freshly amputated or cadaver specimens have also been carried out by others. Armstrong, England, and Dobyns and Perkins divided the dorsal radiocarpal ligament transversely over the scapholunate articulation and then severed the scapholunate interosseous ligament. Once these ligaments were divided the proximal pole of the scaphoid would subluxate dorsally, especially during palmar flexion or pronation. Tanz noted similar findings after all but the triquetral and pisiform attachments of the lunate had been severed.

We performed similar studies on four freshly amputated upper extremities. After removal of the skin and subcutaneous tissues, the forearm bones were fixed in a clamp and the different tendons of the forearm muscles were loaded before and after division of the ligaments of the wrist in varying combinations in an attempt to assess the roles of various muscle forces and of the ligaments in the production of wrist instability. Roentgenograms of the wrist in two planes were obtained for each position. In these experiments, it was found that after excision of both the dorsal radiocarpal ligament over the scapholunate joint and the scapholunate interosseous ligament, rotational subluxation of the scaphoid of moderate degree occurred. If, in addition, we partially or completely divided the thickened portion of the palmar radiocarpal ligament, which courses from the radial styloid process to the capitate anterior to the waist and tuberosity of the scaphoid, subluxation of the scaphoid was facilitated. Forced dorsiflexion, ulnar deviation, or radial deviation after division of these structures produced a gap between the scaphoid and the lunate as well.

The rotational instability of the lunate as seen in the clinical syndromes described was not easily reproduced in these experiments. This difficulty may be explained on the basis of gradual loosening of the lunate in the living state caused by continued use and motion or on the basis of inadequate freeing of the proximal carpal row in the fresh specimens.

Landsmeer described zigzag collapse, which occurs in a three-link system with only two controls. His description provides a basis for the understanding of the pathomechanics of wrist instability. In most parts of the body where there is an intercalated segment in a three-link system, control of this segment is provided by a third element. This may be a muscle inserted on the intercalated segment or, as in the case of the proximal phalanx of the fingers, it may be the lumbrical crossing the segment and moderating tension between the extensor apparatus and the flexor profundus. The unique contribution of the scaphoid to the stability of the intercarpal joint is analogous to this third-element control except that the scaphoid acts as a rigid connecting rod rather than as a dynamic muscular control. The interosseous scapholunate ligament provides a push-pull coupling to the lunate [15] and provides a viscoelastic damping effect to smooth out the interrelated motions.

MacConaill believed that during dorsiflexion there is a screw-clamp effect by which the lunate and the proximal carpal row are gripped so that they are carried into dorsiflexion synchronously with the rest of the carpus.

Several authors [2,7,10,11,21,23,24,28] noted that instability of the scapholunate joint may develop after scaphoid dislocation or subluxation, and emphasized the existence of intercarpal instability. We believe that the term scapholunate dissociation better describes dorsal flexion instability, the syndrome characterized by: (1) displacement of the scaphoid to a vertical position relative to the lunate and (2) a gap between the lunate and the proximal pole of the scaphoid. The intercarpal collapse resulting from this type of injury has not been sufficiently stressed and probably is much more common than the literature suggests. After any injury to the wrist the lateral roentgenogram should be examined carefully for evidence of intercarpal collapse. If it is present, closed reduction techniques should reduce it completely and maintain reduction; otherwise, open reduction and internal fixation should be considered. Persistence of intercarpal collapse would seem to predispose both to a high incidence of non-union of fractures of the carpal scaphoid and to late degenerative changes even in those instances where no fractures are present.

Palmar flexion instability is less commonly recognized. It may be seen in rheumatoid arthritis, in post-traumatic ulnar transposition of the carpus, possibly in the presence of congenital ligamentous laxity, and perhaps after tearing of the palmar radiocarpal ligament distal to the lunate. In this form of instability, the scapholunate ligament appears to be intact and the angle formed by the longitudinal axes of the scaphoid and lunate is decreased. The one example of this type of deformity in our series was observed after a scaphoid fracture (Case 8, Table II) but this deformity may have been present prior to the fracture as the result of congenital ligamentous laxity or previous injury. Therefore palmar flexion instability, manifest as palmar angulation of the proximal carpal row, seems to occur when the scapholunate ligament is intact, but presumably there is traumatic or congenital laxity of the palmar radiocarpal ligament.

From these considerations it is obvious that the kinematics of the wrist are complex and that to analyze them thoroughly will require sophisticated studies. However, certain basic motions are now understood. The proximal carpal row, excluding the scaphoid, is an intercalated segment whose position and motions are determined by the pressures exerted on it at the intercarpal and radioulnar articular surfaces. The proximal and distal carpal rows move synchronously during dorsal and palmar flexion but reciprocally during ulnar and radial deviation [16]. Synchronous angulation in the sagittal plane during dorsal and palmar flexion is accomplished primarily by the mechanical effect of the scaphoid linkage which spans the intercarpal joint. The complex arrangement of the dorsal and palmar radiocarpal ligaments serves to determine the arcs of motion.

During ulnar and radial deviation the reciprocal motions of the proximal and distal carpal rows appear to be produced by the pressure of the capitate as it moves on the concave distal articular surface of the lunate. During radial deviation the capitate exerts pressure anterior to the balance point of the convex surface of the lunate on the distal articular surface of the radius, and palmar flexion of the proximal carpal row occurs. During ulnar deviation, on the contrary, the pressure of the capitate shifts to the dorsal side of the balance point and dorsiflexion of the proximal row is the result.

Movement of the capitate during ulnar and radial deviation is a combination of conjugate rotation and gliding along an obliquely oriented course. This complex motion apparently is produced by the radial carpal extensors pulling in a dorsoradial direction during radial deviation and by the ulnar carpal flexors pulling in a palmar-ulnar direction during ulnar deviation. The directions of these muscle forces are undoubtedly altered by pronation and supination, notably by the change in the position of the extensor carpi ulnaris. The arc of movement of the capitate during ulnar and radial deviation, therefore, may vary with pronation and supination. The results of recent electromyographic and kinesiologic studies [3,20] are consistent with this description of the rotational and sliding motions of the capitate.

Traumatic instability of the wrist after injury occurs because of either disruption of the ligamentous restraints or changes in the geometry of the bone links. This type of disruption most commonly involves the scaphoid and its attachments which provide mechanical stability to the intercarpal joint. A lateral roentgenogram of the wrist shows that the longitudinal axis of the scaphoid lies on an oblique line extending from a proximal-dorsal to a distal-palmar position. With the wrist in neutral position this axis of the scaphoid neatly bisects the longitudinal line that joins the center of rotation of the proximal carpal row (located on the concave distal surface of the lunate) and the center of rotation of the distal carpal row (located in the neck of the capitate). The linkage in this location provided by the scaphoid is responsible for the synchronous motion of the two carpal rows in sagittal-plane motion and provides stability against rotational collapse. This mechanical system, which resembles a slider-crank arm, provides stability to the three-bar linkage by reason of its oblique placement [14] (Fig. 15). If the capsular restraints about either the distal or the proximal end of the scaphoid are lengthened or torn, the scaphoid does not provide as much stability for the intercarpal joint. A fracture of the scaphoid, of course, would produce the same effect.

Dorsiflexion instability occurred in most of the scapholunate dissociations and in all but one of the scaphoid fractures with displacement. The first observation strongly suggests that rupture of the scapholunate interosseous ligament favors dorsal angulation of the lunate. Dorsiflexion instability also occurred when there was dorsal angulation of the radial articular surface and other angulatory displacements of the wrist and carpus as the result of malunion of a fracture. In our experiments on freshly amputated wrists, division of both the scapholunate ligament and the palmar radiocarpal ligament anterior to its distal scaphoid attachment appeared to be necessary before the scaphoid would displace into the vertical position.

Palmar flexion instability was observed after only one scaphoid fracture but was seen in varying degrees in three patients who had dorsiflexion injuries of the wrist. While originally we believed that rupture of the palmar radiocarpal ligament was responsible for this condition, re-examination of two of these patients showed a similar deformity in both of their wrists, suggesting that it is a congenital condition or a sequel of ligamentous laxity. Support for this concept was found in two patients who could spontaneously subluxate their wrists into the position of palmar flexion instability. Since this deformity also occurred in another patient who had lost the distal end of the ulna, the triangular fibrocartilage and the triquetrum, we concluded that

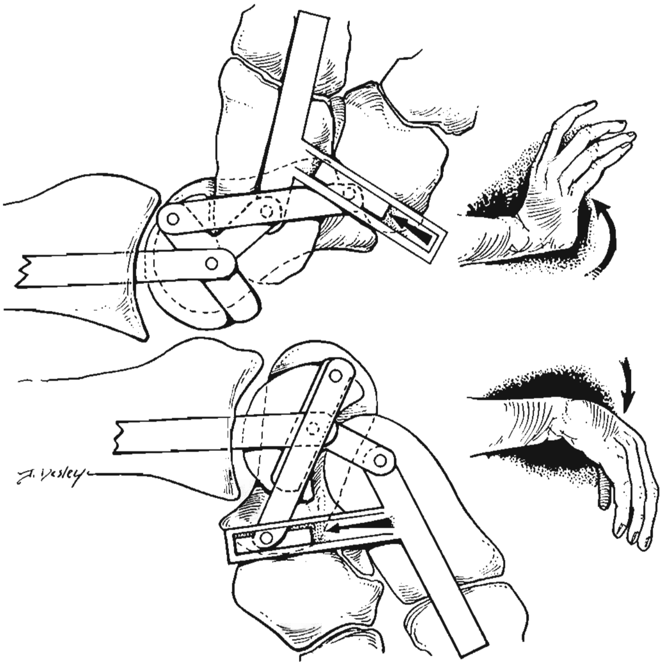

FIG. 15

Slider-crank mechanical model for motion of the intercarpal joint in the sagittal plane. The three-bar linkage shown represents the linkage composed of the radius, lunate, and capitometacarpal links. This linkage is stabilized by the crank (the scaphoid) the straight component that extends between the two t-shaped components which represent the lunate and capitometacarpal links. The linkages of the crank (scaphoid) are a dorsal "revolute" linkage proximally (on the lunate) and a palmar "prismatic" linkage distally (on the capitometacarpal link). The revolute linkage represents the scapholunate ligament; the prismatic linkage, the scaphotrapezoidal-trapezial joint. In dorsiflexion the scaphoid crank induces dorsal rotation of the lunate link by a compressive force directed proximodorsally along the line of the longitudinal axis of the scaphoid. In palmar flexion an oppositely directed tensile force pulls the lunate into palmar flexion. Note that the crank arm will bisect the line joining the centers of rotation of the capitate and the lunate when the wrist is in neutral position.

ulnar displacement of the proximal row may be responsible for palmar flexion instability. The same deformity is often seen in rheumatoid arthritis. The rheumatoid deformity, therefore, may be analogous to the apparent palmar flexion instability that accompanies radial deviation of the normal hand where the distal carpal row slides ulnarly on the lunate. Ligamentous laxity without disruption of the scapholunate attachment seems to favor palmar flexion instability.

Summary

The scaphoid is a mechanical link that stabilizes the intercarpal joint during motions of the wrist. Without this stability the proximal carpal row acts as an unsupported intercalated link in a three-link system and zigzag collapse occurs with axial loading. A deformity with dorsiflexion of the lunate within the linkage (dorsiflexion instability) occurs commonly after scaphoid fracture and scapholunate dissociation. When dissociation occurs the scaphoid assumes a vertical position, that is, the angle formed by the longitudinal axes of the scaphoid and the lunate approaches a right angle. Rupture of the distal attachments of the palmar radiocarpal ligament and of the scapholunate ligament appears to induce dissociation. It is therefore concluded that ligamentous injury along with scaphoid fracture is probably necessary if dorsiflexion instability is to develop.

Palmar flexion instability characterized by palmar flexion of the lunate within the wrist linkage appears to be associated with ulnar displacement of the carpus as is seen in rheumatoid arthritis or after loss of the distal end of the ulna. This position may be normal in a small percentage of patients. The direction of the intercarpal collapse is related to the location of the pressure of the head of the capitate against the concave surface of the lunate, that is, whether this pressure is dorsal or palmar to the plane of the radiolunate fulcrum on the proximal convex surface of the lunate. The direction of the collapse is also related to the normal oblique path of motion (rotation and sliding) of the capitate during ulnar and radial deviation and is intimately controlled by the geometric configuration of the bones and the resultant of forces on the carpus. These forces are determined by the strength, direction, and leverage of the musculotendinous units, which cross the joints of the wrist complex.

References

1. ANDREWS, F. T.: A Dislocation of the Carpal Bones—The Scaphoid and the Semilunar: Report of a Case. Michigan Med., **31:** 269-271, 1932.
2. ARMSTRONG, G. W. D.: Rotational Subluxation of the Scaphoid. Canadian J. Surg., **11:** 306-314, 1968.
3. BASMAJIAN, J. V.: Recent Advances in the Functional Anatomy of the Upper Limb. Am. J. Phys. Med., **48:** 165-177, 1969.
4. BOYES, J. H.: Bunnell's Surgery of the Hand, Ed. 4, pp. 638-639. Philadelphia, J. B. Lippincott Company, 1964.
5. BUZBY, B. F.: Isolated Radial Dislocation of Carpal Scaphoid. Ann. Surg., **100:** 553-555, 1934.
6. CAMPBELL, R. D., JR.; LANCE, E. M.; and YEOH, C. B.: Lunate and Perilunar Dislocations. J. Bone and Joint Surg., **46-B:** 55-72, Feb. 1964.
7. CAMPBELL, R. D., JR.; THOMPSON, T. C.; LANCE, E. M.; and ADLER, J. B.: Indications for Open Reduction of Lunate and Perilunate Dislocations of the Carpal Bones. J. Bone and Joint Surg., **47-A:** 915-937, July 1965.
8. CONNELL, M. C., and DYSON, R. P.: Dislocation of Carpal Scaphoid: Report of a Case. J. Bone and Joint Surg., **37-B:** 252-253, May 1955.
9. CRITTENDEN, J. J.; JONES, D. M.; and SANTARELLI, A. G.: Bilateral Rotational Dislocation of the Carpal Navicular: Case Report. Radiology, **94:** 629-630, 1970.
10. DOBYNS, J. H., and PERKINS, J. C.: Instability of the Carpal Navicular. *In* Proceedings of The American Academy of Orthopaedic Surgeons. J. Bone and Joint Surg., **49-A:** 1014, July 1967.
11. ENGLAND, J. P. S.: Subluxation of the Carpal Scaphoid. Proc. Roy. Soc. Med., **63:** 581-582, 1970.
12. FISK, G. F.: Carpal Instability and the Fractured Scaphoid. Ann. Roy. Coll. Surg. England, **46:** 63-76, 1970.
13. GILFORD, W. W.; BOLTON, R. H.; and LAMBRINUDI, C.: The Mechanism of the Wrist Joint with Special Reference to Fractures of the Scaphoid. Guy Hosp. Rep., **92:** 52-59, 1943.
14. HARTENBERG, R. S., and DENAVIT, JACQUES: Kinematic Synthesis of Linkages. New York, McGraw-Hill Inc., 1964.
15. KAUER, J. M. G.: En Analyse ven de Carpale Flexir Gebone fe Tilburg, Drukkerij, Lucton et Emergo Leiden, 1957.
16. KUTH, J. R.: Isolated Dislocation of Carpal Navicular: A Case Report. J. Bone and Joint Surg., **21-A:** 479-483, Apr. 1939.
17. LANDSMEER, J. M. F.: Studies in the Anatomy of Articulation. Acta Morph. Neerl. Scandinavica, **3:** 287-321, 1961.
18. LINSCHEID, R. L.: The Mechanical Factors Affecting Deformity at the Wrist in Rheumatoid Arthritis. *In* Proceedings of The American Society for Surgery of the Hand. J. Bone and Joint Surg., **51-A:** 790, June 1969.
19. MACCONAILL, M. A.: The Mechanical Anatomy of the Carpus and its Bearing on Some Surgical Problems. J. Anat., **75:** 166-175, 1941.
20. MCFARLAND, B. G., JR.; KRUSEN, U. L.; and WEATHERSBY, H. T.: Kinesiology of Selected Muscles Acting on the Wrist: Electromyographic Study. Arch. Phys. Med., **43:** 165-171, 1962.
21. RUSSEL, T. B.: Inter-carpal Dislocations and Fracture Dislocations: A Review of Fifty-nine Cases. J. Bone and Joint Surg., **31-B:** 524-531, Nov. 1949.
22. STARK, W. A.: Recurrent Perilunar Subluxation. Clin. Orthop., **73:** 152, 1970.
23. TANZ, S. S.: Rotation Effect in Lunar and Perilunar Dislocations. Clin. Orthop. **57:** 147-152, 1968.
24. THOMPSON, T. C.; CAMPBELL, R. D., JR.; and ARNOLD, W. D.: Primary and Secondary Dislocation of the Scaphoid Bone. J. Bone and Joint Surg., **46-B:** 73-82, Feb. 1964.
25. VAUGHAN-JACKSON, O. J.: A Case of Recurrent Subluxation of the Carpal Scaphoid. J. Bone and Joint Surg., **31-B:** 532-533, Nov. 1949.
26. VERDAN, CLAUDE, and NARAKAS, ALGIMANTAS: Fractures and Pseudarthrosis of the Scaphoid. Surg. Clin. North America, **48:** 1083-1095, 1968.
27. WALKER, G. B. W.: Dislocation of the Carpal Scaphoid Reduced by Open Operation. British J. Surg., **30:** 380-381, 1943.
28. WATSON-JONES, REGINALD: Fractures and Joint Injuries. Ed. 4, Vol. 2, p. 620. Baltimore, The Williams and Wilkins Co., 1952.
29. WHITEFIELD, G. A.: Recurrent Dislocation of the Carpal Scaphoid Bone. *In* Proceedings of The Scottish Orthopaedic Club. J. Bone and Joint Surg., **44-B:** 963, Nov. 1962.