Ulnar-sided perilunate instability: An anatomic and biomechanic study

A staging system for ulnar-sided perilunate instability is presented based on a series of cadaver dissections and load studies. Stage I: partial or complete disruption of the lunotriquetral interosseous ligament, without clinical and/or radiographic evidence of dynamic or static volar intercalated segment instability deformity; stage II: complete disruption of the lunotriquetral interosseous ligament and disruption of the palmar lunotriquetral ligament, with clinical and/or radiographic evidence of dynamic volar intercalated segment instability deformity; and stage III: complete disruption of the lunotriquetral interosseous and the palmar lunotriquetral ligaments, attenuation or disruption of the dorsal radiocarpal ligament, with clinical and/or radiographic evidence of static volar intercalated segment instability deformity. (J HAND SURG 1990;15A:268-78.)

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Carpal instability includes a spectrum of bone and ligamentous injuries. There is an ever-increasing volume of information on instabilities involving the radial or lateral column of the wrist, i.e., scapholunate dissociation, rotatory scaphoid instability, and perilunate instability.1-14 There is considerably less information available on the ulnar or medial column instabilities, and the information that does exist includes inconsistent, speculative and confusing reports.15-23 The ulnar column instabilities are believed to be less than one sixth as common as their radial counterparts.24 Over the past several years, instabilities involving the ulnar aspect of the wrist have become better recognized. However, a considerable amount of uncertainty still appears to exist with regard to the cause, clinical impact, and treatment of these injuries.1,5,15-28 Volar intercalated segment instability (VISI) has been attributed to triquetrolhamate ligament disruption, which Lichtman has called midcarpal instability26 and would be classified as a carpal instability nondissociative (CIND) type by Dobyns and Linscheid.29 Disruption of the scaphotrapezial ligament has also been cited as a cause for a CIND type of VISI.18 This study however will deal...
only with a progressive carpal instability dissociative (CID) type of problem, which has a lunotriquetral interosseous ligament tear as part of the pathology.

The purpose of this study is to demonstrate anatomically, progressive ligament disruptions that result in increasingly severe ulnar-sided perilunate instability that give rise to dynamic and subsequently static VISI instabilities. This study also assesses the effect of these instabilities on the load distribution within the wrist joint.

Materials and methods

Anatomic study. Seven unembalmed upper extremities were used for a series of dissections done by one of the authors (S. V.). Specimens ranged from 21 to 67 years of age. Five were male and two were female. The specimens were dissected free of soft tissue down to the level of the dorsal wrist capsule. Specific ligaments were sectioned in the following sequence: Stage I, the lunotriquetral interosseous ligament was sectioned (Fig. 1); stage II, the palmar lunotriquetral ligament was sectioned (Fig. 2); stage III, the dorsal radiocarpal ligament was sectioned at its insertion into the scaphoid and lunate (Fig. 3). After each phase of ligament sectioning, the wrist was brought through its range of motion both in the loaded and unloaded mode, as well as with externally applied dorsal, palmar, radial, and ulnar forces.

Two carpal fusions (lunate-triquetrum and lunate-triquetrum-capitate-hamate) were simulated by placing threaded half pins into the carpal bones and connecting them with a mini external fixation system. The effect of these fusions on each of the stages of instability was assessed.

Load study. Six unembalmed cadaver upper extremities, ranging from 21 to 63 years of age and free from any visible or radiographically identifiable deformities and/or degenerative changes, were studied. Each specimen was stripped of all its soft tissues except the joint capsule, the palmar and dorsal radiocarpal, ulnocarpal, and interosseous ligaments, the triangular fibrocartilage complex, and the radioulnar interosseous membrane. Radiographs showed that the radioulnar length ranged from 1.5 mm ulnar positive to 0.5 mm ulnar negative variance, and that the inclination of the distal radial articular surface ranged from a palmar angle of 6 to 13
Fig. 3. A diagram depicting the additional disruption of the dorsal radioscapulotriquetral ligament (RSLT), also called the dorsal radiocarpal ligament, in a stage III ulnar-sided perilunate instability.

Fig. 4. Lateral radiograph of one of the specimens with a stage III instability demonstrating a VISI.

degrees. The radial inclination of the distal radial articular surface ranged from 20 to 25 degrees.

Each specimen was mounted on a loading jig, which permitted positioning of the wrist anywhere in its range of motion. Twelve positions were studied. The forearm was maintained in neutral pronation and supination and the wrist was positioned in combinations of 20 degrees of radial deviation, neutral or 10 degrees of ulnar deviation, and in 20 degrees of flexion, neutral, 20 or 40 degrees of extension.

An axial load of 32 pounds (143 Newtons) was applied by weights to a ball joint fixed to 4 mm diameter pins that were drilled into the medullary canals of the second and third metacarpals. The elbow was postured in 90 degrees of flexion, and the humerus was fixed with two transverse threaded pins to the base plate of the loading jig. The 32 pound load was selected based on previous work, as being optimal for the Fuji film measurements.

Contact areas and pressures within the radioulnar carpal joint were measured in each position by Fuji prescale super low pressure-sensitive paper (C. Itoh, New York, N.Y.). The film was cut to match the surface of the distal radius and triangular fibrocartilage. The joint was distracted and the film inserted through a dorsal capsular incision. Spatial orientation of each area was determined by a “U” marker located externally to the distal radius and included on each print. The print image was then videodigitized and analyzed by a Better Basic program. The analysis calculated values based on pressure calibrations defining the intensity of color on the print. Contact areas, area centroids, and pressures were measured on each print for every position.

Tests were initially done on all 6 wrists in all 12 positions. The lunotriquetral interosseous ligament was sectioned in two wrists and they were then tested again (stage I instability). The lunotriquetral interosseous and the palmar lunotriquetral ligaments were then sectioned in all six wrists and the wrists then tested again (stage II instability). The positions of neutral and of 20 degrees flexion were tested again with a dorsal force exerted against the capitate during loading, which was shown to result in a VISI alignment in the anatomy study.
Tests were also done after sectioning of the dorsal radiocarpal ligament (stage III instability) at which point the carpus assumed a volar intercalated segment instability alignment in the positions of neutral and of 20 degrees flexion, without a dorsal force applied (Fig. 4). This had also been demonstrated in the anatomy portion of this study.

Results

Anatomic study. Six of the seven specimens had no identifiable radiographic or anatomic abnormalities. One of the seven specimens had a complete tear of the lunotriquetral interosseous ligament. All six of the specimens that had no identifiable abnormalities were found to have increased motion between the lunate and triquetrum after transection of the lunotriquetral interosseous ligament (stage I ulnar-sided perilunate instability). In the wrists with this stage of disruption, even with a translational force applied to the dorsal aspect of the capitate and/or hamate, a VISI pattern of carpal alignment could not be obtained. Transection of the palmar lunotriquetral ligament (stage II ulnar-sided perilunate instability) resulted in an increased laxity between the lunate and the triquetrum. In this stage, a VISI deformity could be obtained, although only while a translational force was applied to the dorsal aspect of the capitate and/or hamate and only with the wrist in a neutral or flexed position and/or radial or limited ulnar deviation. In positions of extension and/or ulnar deviation of more than 20 degrees, a VISI alignment could not be induced even with the application of a dorsal force. The transection of the dorsal radiocarpal ligament at its insertion into the scaphoid and lunate (stage III ulnar-sided perilunate instability) resulted in a VISI deformity. Once this posture was attained it remained in this VISI deformity until a translational force was applied to the palmar aspect of the capitate or the wrist was brought into more than approximately 25 degrees of ulnar deviation or into extension, at which point the carpus would reduce into a normal alignment for that particular wrist posture.

The seventh specimen, which had a disruption of the lunotriquetral interosseous ligament, was found to have the same findings as in the other six specimens with surgically-induced stage I instability. The sequential transection of the other ligaments followed the same sequence and resulted in the same findings as in the other six specimens.

Load study. Statistical analyses were done on the data using PC-SAS (SAS Institute, Cary, N.C.). Initially univariant statistics were done on each condition and position to determine the frequency distributions and the suitability of using analysis of variance (ANOVA). A two-way ANOVA using the Proc GLM (General Linear Model) in PC-SAS was used to test for differences in areas, pressures, and high-pressure centroid x,y coordinates. To provide guidance in comparing specific positions and conditions, Scheffe’ Multiple Comparison tests were performed based on the findings of the analysis of variance. Based on these results, specific contrast analyses were done to test specific hypotheses about conditions and positions. Unless explicitly stated otherwise, in this report, a p-value of less than 0.05 was considered to be statistically significant.

Contact areas. Variability of size between joints was accommodated by dividing the contact areas within each joint by the total area of that joint. Individual scaphoid and lunate contact areas are therefore reported as a ratio of the available joint surface.

There were no significant differences in the overall total scaphoid contact area between any of the conditions studied except in the condition of stage II ulnar-sided perilunate instability [without a dorsal translational force] in which there was a small but significant difference: [normal (0.127), i.e., the contact area was 12.7% of the available joint area], stage II ulnar-sided perilunate instability [without a dorsal translational force] (0.149), VISI alignment [as in a stage II, with a dorsal translational force or a stage III ulnar-sided perilunate instability] (0.117).

There was no significant difference in the overall total lunate contact area between any of the conditions studied: [normal (0.101), stage II ulnar-sided perilunate instability [without a dorsal translational force] (0.087), VISI alignment [as in a stage II, with a dorsal translational force or a stage III ulnar-sided perilunate instability] (0.099)].

There were no significant differences in the overall high pressure scaphoid or lunate contact areas between any of the conditions studied: [scaphoid: normal (0.085), stage I (0.079), stage II, without a dorsal translational force (0.073), stage II, with a dorsal translational force (0.068), stage III (0.057)], [lunate: normal (0.041), stage I (0.037), stage II, without a dorsal translational force (0.051), stage II, with a dorsal translational force (0.045), stage III (0.044)].

Scaphoid/lunate area ratios. There was no significant differences in the overall scaphoid/lunate contact area ratio between any of the conditions studied. [Normal (1.15), stage I (0.91), stage II, without a dorsal translational force (0.86), stage II, with a dorsal translational force (1.08), stage III (0.79)].

Average high pressures. There was no significant
Fig. 5. A series of prints of one of the wrists, in one position, at different points in the study. (a) A print of that wrist in the "normal" state, showing capitate contact on the right (double arrows), the lunate contact on the left (single arrow), and the "U" mark on the lower portion of the print from the metal reference marker located outside the joint at the dorsal aspect of the distal radius. (b) A print after sectioning of the ligaments to result in stage II ulnar-sided perilunate instability. (c) A print once the carpus has assumed a VISI alignment, as it does in stage II ulnar-sided perilunate instability with an applied dorsal translational force and/or in the stage III ulnar-sided perilunate instability, demonstrating the concentration of the scaphoid and lunate high pressure areas in the palmar aspect of the joint. Diagramatic representations of (d) the superimposed outlines of the high pressure zones for the normal (---), stage II ulnar-sided perilunate instability (----), and VISI deformity (-----), as well as (e) the plotted high pressure area normalized centroids for the scaphoid, on the right, and the lunate, on the left, of the wrists in the conditions of normal (n), stage II ulnar-sided perilunate instability (II), and VISI deformity (v).

differences in the average high pressures in the high pressure zones between any of the conditions studied.

High pressure area centroid locations. The centroid is a point representing the mathematical center of the contact area of the high pressure zone but does not define or reflect the shape of the contact area. The centroids of the scaphoid and lunate high pressure areas shift as a function of the posture of the normal wrist. The centroids were noted to shift more palmar when the carpus assumed a VISI alignment. The actual contact areas demonstrate, even more dramatically, this palmar shift with VISI alignment when the wrist is in positions of flexion and neutral (Fig. 5).

Discussion
There is a great deal of confusion over carpal instabilities, particularly in the ulnar aspect of the wrist. This, in part, may arise from the duplicity and lack of uniformity in the use of terms such as dynamic and static, and the various classifications such as CID and CIND, and VISI, DISI, and midcarpal instability, which are not always quoted or used within the defined parameters the original authors had intended.

This article uses the term dynamic as follows: there is or would be no evidence of abnormal carpal alignment in the standard anteroposterior (AP) and lateral radiographs; there is evidence of abnormal carpal alignment
in standard AP and lateral radiographs with stress exerted by the patients themselves or someone else; and/or there is evidence of abnormal carpal alignment in positions other than that assumed by the wrist in standard AP and lateral radiographs. The term static is used to address what would be an abnormal carpal alignment in the position assumed by the wrist in standard AP and lateral radiographs. The term VISI is used to describe the following carpal alignment on a standard lateral radiograph: the lunate in a subluxated palmar and flexed posture and the capitate in a position in which the proximal pole is subluxated palmar to the radio-lateral plane. A carpal instability dissociative (CID) lesion is one in which the lunotriquetral and/or the scapholunate interosseous ligaments are disrupted. A carpal instability nondissociative (CIND) lesion would be one in which neither of these ligaments is disrupted.

The first reference to carpal instability is attributed to Gilford and colleagues. Linscheid, Dobyns and associates have described common posttraumatic intercarpal instability collapse deformities. Their classification is based primarily on the capitolunate angle. Two of the basic patterns that they describe are the dorsal intercalated segment instability (DISI) and the volar intercalated segment instability (VISI).

A number of different lesions have been reported to result in a VISI deformity. Garth and associates described laxity of the capitotriquetral ligament, that resulted in failure of the triquetral-hamate joint which, in turn, they believe allows a VISI deformity to occur. Trumble et al. also list triquetral-hamate disruption and capitolate-lunate laxity as causes of VISI deformity. These kinds of VISI deformities are what Dobyns, Linscheid et al. would classify as carpal instability nondissociative (CIND) lesions. The cause most commonly attributed to the development of a VISI deformity is linked to lunato-triquetrum lability. This, on the other hand, would be categorized as a dissociative type of carpal instability (CID). Perhaps a more specific and descriptive name for this type of instability is ulnar-sided perilunate instability. This would mirror the work that Mayfield, Johnson, and Kilcoyne delineated on the radial perilunate instability and hopefully add some uniformity in addressing the various types of instabilities.

Different authors have speculated that there is a progressive sequence of ligament disruption that may occur on the ulnar side of the carpus, similar to what Mayfield, Johnson, and Kilcoyne have described on the radial side of the carpus. Reagan, Linscheid, and Dobyns have divided the triquetrolunate instabilities into two groups. Lunotriquetral sprains, which have partial tears in the lunotriquetral interosseous ligament and lunotriquetral dissociations, which have complete tears of the lunotriquetral interosseous ligament. Others divide triquetrotunate instability into two types, those without radiographic or clinical evidence of VISI and those with an evident VISI deformity.

There is a relative paucity of cases in the literature of what could be classified as a volar intercalated segment instability. In 1913, Chaput and Vaillant reported on a radiographic study of patients with carpal injuries, one of which had a typical case of what would now be classified as VISI. In 1913, Mayersbach also reported a case of what would now be recognized as a VISI deformity in a 72-year-old man. In 1921, Navarro described a carpal deformity, which again today would be categorized as a VISI. Sutro, in 1946, reported two cases, which also had VISI deformities. Two cases of VISI are also included in the series presented by Linscheid et al. Taleisnik presented one case of VISI in 1982, which was preceded by a palmar scapholunate dislocation. In 1984, Lichtman et al. reported one case of a dynamic VISI deformity. Reagan and colleagues presented a series of patients in 1984 that they grouped into 24 lunotriquetral tears and 11 lunotriquetral dissociations. Trumble and associates documented seven cases of dynamic and static VISI deformities in 1988.

Despite these scattered reports in the literature, there has not been a consensus of opinion in regard to what pathology is required to result in dynamic and static VISI deformities arising from the area of the lunotriquetral joint. However, clinical cases that involve documented disruptions of the lunotriquetral interosseous ligament without any VISI pattern of deformity are not uncommon.

Previous experiments with cadavers have demonstrated increased divergent motion between the lunate and triquetrum after sectioning of the lunotriquetral interosseous and the palmar and dorsal radiotriquetral ligaments. Some studies have also been able to reproduce dynamic VISI patterns with the application of a dorsal force on the capitate and/or hamate. Other cadaver studies that have attempted to reproduce this instability pattern have been unsuccessful. A static VISI deformity in the cadaver model has not been previously simulated.

In the series of dissections reported in this study, increased motion developed between the lunate and the triquetrum with a tear of the lunotriquetral interosseous
ligament. However, with a disruption of this ligament alone, an appreciable dynamic or static VISI deformity was not evident and could not be induced. This is compatible with the findings of the load studies, which overall, did not demonstrate significant differences in load distribution between the scaphoid and lunate fossa in the normal and a stage I instability. This would imply that the load distribution is not appreciably altered in cases where the lunotriquetral joint alone was disrupted. This is consistent with clinical findings that patients with incongruity between the lunate and the triquetrum generally had satisfactory clinical results.

In a stage II ulnar-sided perilunate instability, a definite VISI deformity was evident during the application of a translational force on the dorsal aspect of the capitate and/or hamate when the wrist was in neutral or some degree of flexion and radial, neutral or limited ulnar deviation. Sectioning the dorsal radiocarpal ligament and capsule at their attachment to the scaphoid and lunate, which resulted in a stage III ulnar-sided perilunate instability, allowed a static VISI deformity to arise in the wrist. This static VISI deformity could only be demonstrated, however, in those same positions in which the dynamic VISI deformity could be attained. Whenever the wrist was brought into greater than 25 degrees of ulnar deviation or into extension, this would result in changing the VISI position to a position of normal carpal alignment. Reduction of the VISI deformity by ulnar deviation of the wrist has been described clinically. The symptomatic “clunk” that patients often describe can often be reproduced by this maneuver.

This is still consistent with the classic definition of a VISI deformity since it applies to the capitulunate angle in the lateral radiograph with the wrist in neutral flexion and neutral radioulnar deviation.

Previous work has shown that in positions of flexion, the normal wrist contact areas and high pressure centroids are located in the palmar aspect of the joint. However, in the positions of neutral and flexion tested with a stage II instability (with a dorsal translational force applied inducing a VISI alignment of the carpus) and in the stage III instability (with a VISI alignment of the carpus) the contact areas and high pressure centroids, of both the lunate and scaphoid, shifted more palmar than normal. These were the same conditions in which the carpus was seen to assume a VISI pattern of collapse in the anatomy dissection portion of this study.

In the positions of ulnar deviation and extension, the scaphoid and lunate assume relatively normal postures even in wrists with a VISI deformity, perhaps because of the extension force exerted on the scaphoid by the palmar radioscaphocapitate ligament and by the capitate. Differences in the load distribution, would not be expected in these positions between the normal wrist and a wrist with a stage III ulnar-sided perilunate instability. When all positions were analyzed together, there was no significant overall change in the scaphoid/lunate area ratios, scaphoid and lunate contact areas, and average high pressure areas compared with the normal wrist.

The information from these load studies would suggest the following: with the overall distribution between the scaphoid and the lunate remaining essentially the same throughout the progressive stages of ulnar-sided perilunate instability, as defined in this article, and the fact that even the high pressure centroids shifted to normal locations within portions of the functional range of motion of the wrist, one would not expect significant changes in the wear pattern in the radiocarpal joint. This expectation, coincides with the clinical observation of sparing of the radiocarpal joint in patients with VISI deformities.

There is clinical support for this concept of a sequential, progressive ligament disruption leading eventually to a static VISI deformity. Previous clinical studies of transscaphoid fracture dislocations have made an argument for the existence of a spectrum of lesions in these kinds of injuries. Specifically, the palmar transscaphoid fracture dislocation is a more severe injury than the dorsal transscaphoid perilunate fracture dislocation. Anatomically, the difference between these two injuries is the disruption of the scaphoid and lunate attachment of the dorsal radiocarpal ligament and dorsal capsule. After fixation of the scaphoid fracture component of these injuries, the remaining pathology includes all the components of a stage III ulnar-sided perilunate instability, as defined in the anatomic model described in this article. It is not surprising therefore, that in these cases, a static VISI can develop. Taleisnik reported a case of palmar dislocation of the scaphoid and lunate as a unit, in which the interossesous ligament between the scaphoid and the lunate remained intact. In this case a VISI deformity also developed and here again the scaphoid and lunate portions of the dorsal radiocarpal ligament were disrupted. Taleisnik explained the VISI deformity as a continuation of lunotriquetral dissociation. However, he emphasized the importance of the flexion force of the scaphoid on the lunate without any counterforce from the dissociated triquetrum. He did not comment on the role, if any, of the dorsal capsule and radiocarpal ligament. The anatomic dissections in this study appear to support the concept that it is not only the flexion force exerted by
Fig. 6. A, A posteroanterior (PA) radiograph demonstrating the lytic lesions in the scaphoid, lunate, and triquetrum, without any disruption of the normal carpal arcs in the left wrist of a patient with rheumatoid arthritis. B, A lateral radiograph of the same wrist demonstrating a mild degree of VISI deformity. Radiographs of the same patient, obtained 3 1/2 years after those in A and B, demonstrating C, on the PA view the disruption of the carpal arcs I and II, and D, the lateral projection, which demonstrates a much greater degree of VISI deformity, with osteophyte formation at the point of impingement between the lunate and the capitate (arrow).
the scaphoid on the lunate, which is unopposed by the triquetrum but also the fact that the lunate and scaphoid are unrestrained by the disrupted dorsal radiocarpal ligament, that allows the carpus to posture in a static VISI alignment.

Several authors have commented on the frequency of a VISI deformity in severe rheumatoid arthritis of the wrist.\textsuperscript{23, 25, 28} It is easy to explain the attenuation of the dorsal ligaments by the chronic recurrent inflammation and swelling that often occurs within the radiocarpal joint in these patients. The resulting imbalance that occurs in the carpus with mild VISI deformity could explain further attenuation of the dorsal capsule and radiocarpal ligament (Fig. 6). The osteophytic and erosive changes that can occur at the site of capitolumate impaction must occur after the loss of integrity of the dorsal ligament and capsule. The resulting imbalance allows the lunate to flex, which apparently shifts the load more palmar at the radiocarpal joint in certain positions and at the midcarpal joint allows the dorsal lip of the flexed lunate to impact on the dorsal aspect of the capitate (Fig. 7). Trumble et al.\textsuperscript{24} demonstrated in their clinical series that stabilization of the lunotriquetral joint alone did not prevent the VISI deformity or "clunk." It would seem, in fact, that fusion of the lunate and the triquetrum in a case with a static VISI as defined by the stage III instability model of this study, would simply change a CID-VISI into a CIND-VISI.

In the cadavers stabilization of the lunotriquetral joint by means of Steinmann pins or a mini external fixator in the stage I and II instabilities eliminated the motion between the lunate and triquetrum. In the stage II instability, stabilization of the lunotriquetral joint also prevented the ability of the carpus to assume a VISI pattern even with a significant dorsal force applied to the capitate and/or hamate. In the stage III instability, stabilization of the lunotriquetral joint alone did eliminate motion between the lunate and the triquetrum;
however, it did not prevent the VISI alignment of the capitate and lunate. Similarly, transection of the dorsal capsule and the radiocarpal ligament alone in a cadaver wrist will also allow a VISI alignment of the capitate and lunate which would seem to fit the CIND-VISI category. Thus if a static VISI deformity does include the compromise of the dorsal ligament and capsule, unless they are reconstructed or the midcarpal joint is stabilized such as in a LTCH fusion, a LT fusion is merely changing a VISI deformity of the dissociative type into a VISI deformity of the nondissociative type. Even in cases of trauma, once a dynamic or stage II ulnar-sided perilunate instability develops there may be a sufficient tension on the dorsal radiocarpal ligament and capsule, that over time those structures will attenuate leading to the development of a stage III ulnar-sided perilunate instability with a static VISI deformity.

Summary

A staging system for ulnar-sided perilunate instability is presented based on a series of cadaver dissections and load studies. The staging system includes the following:

Stage I: Partial or complete disruption of the lunotriquetral interosseous ligament; no clinical and/or radiographic evidence of dynamic or static VISI deformity.

Stage II: Complete disruption of the lunotriquetral interosseous ligament and disruption of the palmar lunotriquetral ligaments; clinical and/or radiographic evidence of dynamic VISI deformity.

Stage III: Complete disruption of the lunotriquetral interosseous and the palmar lunotriquetral ligaments; attenuation or disruption of the scaphoid and lunate portion of the dorsal radiocarpal ligament; clinical and/or radiographic evidence of static VISI deformity.

REFERENCES