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In Vivo Kinematics Study of Wrist Flexion Extension Motion: An Ultrafast Computed Tomographic Study of the Wrist with Distal Radius Fracture.

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ABSTRACT

OBJECTIVE: To quantify in vivo carpal kinematics of a normal wrist in a dynamic continuous model. DESIGN: The instantaneous changes in the radiocarpal and midcarpal joints during normal wrist motion were analyzed using ultrafast computed tomography (CT). BACKGROUND: Wrist injuries account for a considerable and growing proportion of work-related disorders and disability. However, little is known about normal wrist kinematics. METHODS: Ten uninjured subjects were studied using ultrafast CT to measure the continuous motion of the wrist from full flexion to full extension. Sagittal plane scanning was performed mediolaterally at six different locations as the wrists were moved slowly and repeatedly from full flexion to full extension. The data were printed to X-ray film and transferred to an independent work station with a video camera. The motion of the radiocarpal, midcarpal and wrist joints was determined by an image analyzing system. RESULTS: Wrist motion was expressed as a ratio of capitate-lunate (C-L) (midcarpal) motion and radio-lunate (R-L) (radiocarpal) motion. In the volar flexion of the wrists, the contribution of the midcarpal joint is much higher than the radiocarpal joint ($P<0.01$). While dorsal flexion of the wrist occurred mainly at the midcarpal joint. CONCLUSIONS: In the wrists with distal radius fracture, the midcarpal joint contribute more than the radiocarpal joint in the volar flexion, while the motion of midcarpal joint is also more important in dorsal flexion. RELEVANCE: In this study, we demonstrated the suitability of using two-dimensional computed tomographic images in a quantitative study of flexion/extension kinematics of the wrist with distal radial fracture.

INTRODUCTION

Wrist injuries account for a considerable and growing percentage of disability and dysfunction in the *workplace;* Although treatment of ligamentous carpal instability may be difficult, early radiologic diagnosis is imperative for a good result. Untreated, these conditions may progress and leave the patient severely disabled. Radiologic demonstration of carpal instability may be quite difficult, especially when there is no associated fracture and the injury is exclusively ligamentous (White et al. 1984). Diagnostic modalities, including arthrography and magnetic resonance imaging, may help to define injuries to intercarpal ligaments, but are not capable of determining the magnitude of the ligament injury or the function of the remaining ligaments during motion. Stress radiographs are notoriously difficult to compare between subjects because of inconsistencies in carpel positioning (Garcia-Elias et al. 1989). "Dyanmic carpal instability", while a well recognized clinical condition, is diagnosed currently by history and clinical signs of abnormal carpal motion (Watson et al. 1993, Wintman et al. 1905). There are no acceptable X-ray criteria to help in establishing this diagnosis.

Appreciation of the integrated function of the wrist and hand has close correlation of pathological processes involving the hand and those affecting the wrist (Arkless 1966). Initially, the investingation of normal wrist kinematics used plain radiographs to study both cadaver specimens and living subjects were highly qualitative in nature (Bryce 1896, Johnston 1907, Cyriax 1926, Von Bonin 1929, Kauor 1985). Review of the literature shows that the initial studies covered many significant aspects of normal wrist movement. Recognizing the limitation of plain radiographs, investigators have used cineradiography (Arkiess 1956, 1967), simple anatomical dissection (Lewis et al. 1970), and stereoscopic radiographs to attempt to analyze the three-dimensional (3D) properties of wrist kinematic (Savelberg et al. 1993, Von-Bonin 1929). Other investigators have used three-dimensional techniques such as sonic digitizrs (Andrews and Youm 1979, Berger et al. 1982, Brumfield et al. 1982, Youm and Flatt 1980, Youm et al. 1978, Gilula and Weeks 1976), instrumented electromechanical linkage (Sommer et al. 1980, Jackson et al. 1994), radiosterophotogrammetric techniques (Andrews and Youm 1979, Berger et al. 1982, Brumbaugh et al. 1982, deLange et al. 1985, Jackson et al. 1994, Ruby et al. 1988, Sarrafian et al. 1993, Savelberg et al. 1993, Seradge et al. 1995, Smith et al. 1989, Sommer et al. 1980, Von-Bonin 1929, Youm and Flatt 1980, Youm et al. 1978), or 3D computer imaging (Belsole et al. 1986). These studies gave the first insight into carpal bone kinematics, but their methods were based on static analyses of wrist motion constrained to move in orthogonal planes.

Thus, a firm foundation of qualitative observations of the anatomy of the normal wrist and its kinematics was established early in this century, and later more efforts were toward making quantitative measurement of the pathological changes (Youm et al. 1978, Gilula and Weeks 1978, Rosenthal et al. 1982). Investigators have studied the effect of selective ligament injury on kinematics, using implanted metal markers or pins, but the invasiveness of these methods has precluded their application in vivo. Unfortunately, there has been no unanimity among the authors who described the normal kinematics of the wrist. The relative contribution of the proximal and distal carpal rows to wrist motion is still controversy, and the subject of many investigations using cadaveric wrist (Berger et al. 1982, Gellman et al. 1988, ruby et al. 1988, Savelberg et al, 1991). In our previous report (Sun JS, Shih TTF, Ko CM, Chang CH, Hang YS, Hou SM. In vivo kinematic study of normal wrist motion: an ultrafast computed tomographic study. Clinical Biomechanics 2000;15:212-216), the contribution of the radiocarpal joint and midcarpal joint were equal in the volar flexion of normal wrists, while dorsal flexion of the normal wrist occurred mainly at the midcarpal joint. Consequently, little is known about in vivo injured wrist kinematics, or the effects of muscle forces, neural inhibition, or rehabilitation. The purpose of this study was to quantify in vivo carpal kinematics of the injuried wrist with healed distal radius fracture in a dynamic continuous model.

MATERIALS AND METHODS

The goal of this experiment was to continually monitor the relative contribution of the radiocarpal and midcarpal joint motion at various global wrist position. In this kinematic investigation of the wrist joint we used live volunteers. Thirteen healthy subjects were selected for kinematic analysis. Informed consent was obtained from each subject participating in the protocol, which was approved by the Medical College's Human Investigation Committee. Inclusion criteria were subject without previous major wrist injury, normal radiograph; and no wrist pain at]east in recent 6 months. Average age of the study group was 43.3 ± 10.0 years old (range 29-59 years old).

Anteroposterior and lateral plain radiography of the both wrist were taken. A lateral radiograph was defined as one in which the axis of the third metacarpal and long axis of the radius are colinear. Radiogarph were analyzed by measuring the radiolunate angle and lunocapitate angle using accepted tangential techniques (Larsen et al. 1991).

Each subject underwent kinematic computed tomography (CT) of the wrist using a Ultrafast CT scanner (lmatron, Model C-150L, South SF, CA, USA). The subject was positioned as standing beside the gantry, with the elbow flexed, such that a sagittal computed tomographic image could be obtained through the distal radius, lunate, capitate, and the third metacarpal. The hand and distal forearm was positioned and pre-scan performed to adjust the subsequent scanning profile (Fig. 1). Six different locations were scanned in sagittal plane through the wrist mediolaterally. The scan thickness was 1.5mm. with equal interspace 10mm covering the middle two third of the wrist

The field of view was 16 cm. The wrist were moving cyclically from flexion to extension at about 10° increments per seconds. The scan time for each image was 0.05 second. The first six images (image 1 to 6) were scanned for the wrist in six different location. Another twelve images were taken subsequently for the wrist in the same location but different flexion-extension axis. Totally seventy-two image were taken for each wrist covering the wrist motion from full flexion. The data was printed to image film and transferred to an independent work station by CCD video camera. Motion of the radiocarpal, midcarpal and wrist joints were determined by MICD image analyzing system (MICD Software Series, Image Research Inc. Ontario, Canada).

Analysis of the data was based on the assumption that there is minimal motion between the capitate and third metacarpal during wrist flexion and extension. We assumed that that capitate-radius (or 3rd - metacarpal-radius) motion is equivalent to total wrist motion. Capitate-lunate (LC) and lunate-radius (LR) motion was plotted for the entire group against total wrist motion (capitate-radius: CR). The "LC/CR or LR/CR ratio" were plotted against wrist motion, and is equal to the number of degrees of midcarpal motion (capitate-lunate) or radiocarpal motion (lunate-radius) which occurs for each degrees of wrist motion (capitate-radius) during wrist motion.

In the third year's study. We aimed to focus on the carpal motion of the patients with distal radius fracture. Totally 16 cases were included and their age ranged from 41 to 74 years (59.1 ± 14.7). These patients had history of distal radius fracture and received complete cast immobilization. Plain radiography showed complete union of the fractured bone and adequate callus formation. They were confirmed by at least 6-months follow-up. Each patient underment kinematic computed tomography (CT) of the wrist as above mentioned.

RESULTS

Clinical information for the sixteen subjects are presented in Table 1. According to established criteria, the increased lunate tilting in the lateral radiographs were not diagnostic for abnormal carpal ligament (Linscheid and Dobyns 1992; Linscheid et al. 1972). In this population the "LC/CR or LR/CR ratio" were plotted against wrist motion, and is equal to the number of degrees of midcarpal motion (capitate-lunate) or radiocarpal motion (lunate-radius) which occurs for each degrees of wrist motion (capiatae-radius).

When the wrist motion was analyzed in flexion and extension at different position, the contribution of the midcarpal and radiocarpal joints to the flexion/extension motion of the wrist varied significantly (Table 1). Between 30 to 70 degrees of wrist volar flexion, the LC/CR gave an average of 42.1 to 49.2% (SD 11.1 to 24.0%). This indicates that 50-55% of wrist flexion occurred at the midcarpal joint. It seemed that midcarpal join contribute more than the radiocarpal joint in this range of wrist flexion. Between 30 to 80 degrees of wrist extension, the LC/CR gave an average of 41.9 to 47.4% (SD 7.4 to 18.7%). This indicates that 50% ~ 55% of wrist extenesion occurred at the midcarpal joint. The midcarpal rotation contributed slightly more than the radiocarpal joint. The large scale standard deviation of both midcarpal and radiocarpal rotation near the neutral position (i.e. from 30° of flexion / extension) nullified the significant change in midcarpal / radiocarpal ratio outside this range (Fig. 1).

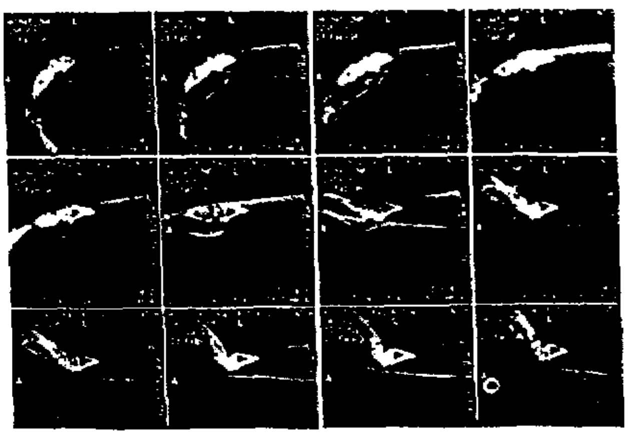

Fig. 1. Midsagittal computed tomographic image through metacarpal, capitate, lunate, radius. The wrists were moved slowly and from full flexion to full extension. Twelve images were obtained for each location from flexion to extension.

DISCUSSION

The wrist is a complex association of eight carpal bones that produce a full and stable range of motion. Much work has been done related to the qualitative osseous anatomy of the wrist, yet there are still few references for its biomechanical or kinematic characteristics (Patterson et al. 1997). A variety of methods have been used to measure individual carpal motion. There is considerable controversy concerning the relative contributions of the radiocarpal and midcarpal joints to total wrist motion in previous studies (Andrews and Youm 1979, Youm et al. 1978, Ruby et al 1988). Ruby et al, reported that flexion and extension was nearly equally divided between the motion at the midcarpal and radiocarpal joints, with a slightly greater contribution of the midcarpal joint to wrist flexion. Berger et al. (1982) stated that the radiocarpal joint contributes more to flexion and extension than the midcarpal joint. By indirectly calculation the radiocarpal and midcarpal motion in a series of intercarpal and radiocarpal fusion, Gellman and coworkers (1988) concluded that 63% of flexion and 53% of extension occurs at the midcarpal joint. DeLange et al (1985) found that the capitolunate joint contributed more to wrist flexion / extension than the midcarpal joint.

There are few in vivo studies on the wrist motion. Studied with plain radiography, Sarrafian et al. (1977) concluded that 67% of extension occurred at the midcarpal joint, and 60% of flexion occurred at the radiocarpal joint, while Brumfield and coworker concluded that the midcarpal joint contributed 57% of total wrist flexion / extension (Brumfield and Champooux 1984). Recently, an in vivo passive wrist kinematics was performed by Wolfe et al. (1997). The range of motion of normal wrist occured equally at the midcarpal and radiocarpal joints (Wolfe et al. 1997). A limitation of method used by Wolfe et al is to measure carpal motion is that wrist must be held at a selected static position while data are collected. In our study, collection of carpal kinematic data while the wrist is moving continuously and the data is quite reproducible to get repeatable motion to permit comparison among subjects. Our results previous for normal wrist motion showed that in the volar flexion of normal wrists was in agreement with Wolfe et al. (1997), the contribution of radiocarpal joint is equal to that of midcarpal joint, while dorsi-flexion of the normal wrist was in agreement with DeLange et al. (1985), showing an increased contribution of the midcarpal joint to wrist flexion / extension. In the diseased wrist, the radiolunate motion is limited due to fractured, deformed distal radius. The wrist motion occured mainly at the midcarpal joint during the flexion and extension.

Flexion/extension is the principal motion of the wrist. Wrist motion is nearly uniplanar (Savelberg et al. 1991), intercarpal motion about the other two axis is minimal in this plane (Kobayashi et al. 1997). The technique of two-dimensional feature of sequential sagittal CT scans is likely to be valid in the flexion/extension plane. One limitation of our approach is that it is two-dimensional, and this may introduce a source of error. Some scan sessions in the subjects were deleted from the analysis because of errors, i.e. the shapes of the bones varied significantly from the theoretical longitudinal sections. Previous three-dimensional studies in cadaveric models have demonstrated that wrist motion is multiplanar, and that a significant degrees of out-of-plane rotation of bone rows occur during wrist motion (Ruby et al. 1988, Savelberg et al. 1991). The highest degrees of "out of plane" motion occurs during ulnar/radial deviation. The complex three-dimension position of a carpal bone projected upon a two-dimension radiograph may lead to measurement error. Advances in computed tomography have made possible techniques for non-invasive kinematic analysis to wrist motion. The technique of two-dimensional feature of computed tomographic images lends itself well to a quantitative study of three dimensional flexion / extension kinematics of the normal wrist in vivo. Further study with three-dimensional CT reconstruction of carpal bones may further elucidate the relationship of radial / ulnar deviation kinematics of the normal wrist in vivo. In this study, we demonstrated that the two-dimensional media of computed tomographic images could provide a good quantitative study of 3D flexion/extension kinematics of the injuried wrist in vivo. Further study with 3D CT reconstruction of carpal bones may further elucidate the relationship of radial / ulnar deviation kinematics of the normal wrist in vivo. Establishing the kinematics of injuried wrist motion will provide a set of criteria for investigating the diagnosis and treatment of ligamentous carpal instability.

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Table 1.

The contribution of the midcarpal (capitate-lunate: C-L) and radiocarpal (radio-lunate: R-L) joints to flexion / extension motion of the wrist with distal radius fracture at different wrist positions.

Wrist motion	C-L motion		R-L motion		*P*-value
(Degrees)	Degrees	S.D.	Degrees	S.D.	
Volar flexion					
70-60	30.11	6.57	26.41	6.87	0.13
50-60	26.35	12.98	22.31	14.14	0.24
40-50	23.91	11.21	13.46	11.11	0.04
30-40	19.11	11.23	9.87	9.13	0.03
20-30	10.95	11.46	7.11	12.94	NS
10-20	5.46	9.84	3.16	8.96	NS
0-10	0.80	9.41	0.74	9.49	NS
Dorsal flexion					
0-10	-2.12	10.36	-3.92	10.81	NS
10-20	-7.64	10.07	-8.00	10.71	NS
20-30	-7.11	9.41	-11.17	9.75	NS
30-40	-11.65	6.47	-12.41	6.29	0.121
40-50	-18.61	7.11	-11.47	7.09	0.0004
50-60					
60-70					
70-80					

C-L motion: capitate-lunate motion; R-L motion: radio-lunate motion; S.D.: standrad deviation; NS: not stgnificant.