Introduction

Man engages in various actions with use of his hands. For the effective and smooth execution of these actions, wrist joints have a unique bearing mechanism not seen in other joints. However, as the bearing mechanism of the wrist joints is complicated, repair of this mechanism once damaged is difficult. Thus, establishment of diagnosis and therapy of diseases of the wrist joints has been delayed for a long period. For the elucidation of the pathology of carpal instability and the etiology of dorsal intercalated segmental instability pattern of scaphoid fracture, which have attracted much attention in recent years, it is extremely important to ascertain the kinematics of normal wrist joints.

The wrist joint is a mixed joint composed of radiocarpal joint, midcarpal joint, and pisotriquetral joint for the radius and eight carpal bones. Furthermore, the carpal bones are divided into proximal carpal row and distal carpal row with scaphoid, lunate, triquetrum, and pisiform included in the former and trapezium, trapezoid, capitate, and hamate included in the latter. Active movement of the two rests with the distal carpal row that is connected by joints with metacarpal bones to which are inserted wrist extensors and wrist flexors forming the power source of wrist joint movement, and the carpal bones of the proximal carpal row excluding pisiform have only passive movement. Thus, the proximal carpal row serves as a bearing for wrist joints and only when this bearing mechanism is normal to various movements of the wrist joints become possible.

A large number of studies have been made on the kinematics of the wrist joints. [1,2,3,4,5,6,7] Based on radiograms obtained by changing body position the authors have reported on the involvement rate on wrist joint movement of radiocarpal joints and midcarpal joints. Arkless and Youm [8,9] with the use of cineradiography have studied the mutual kinematics of various carpal bones. In these previous analytical methods employing radiography and cineradiography, the angle among the various carpal bones on antero-posterior view and lateral view was measured and studied. According to these reports, the changes in the angles formed by radius and lunate were used as indices of movement of radiocarpal joint and the changes in the angles formed by capitate and lunate were used as indices of movement of midcarpal joints. The report was made on the involvement rate in wrist joint movement of radiocarpal joints and midcarpal joints. In all these reports, actual measurement was made on lateral views with measurement being feasible between radius and lunate, between radius and scaphoid, between capitate and lunate, between capitate and scaphoid, and between scaphoid and lunate. Measurement of kinematics around the triquetrum is extremely difficult. It was possible by previous methods of analysis to ascertain the maximum range of movement of the scaphoid at dorsal–volar flexion and at radial–ulnar flexion. On the basis of these findings, most of the reports have supported the columnar theory of Taleisnik [10]. However, by the heretofore employed method of analysis, movement on the ulnar side, particularly the movement around the triquetrum, had been extremely difficult and even by two-directional radiography only the outline of the movement of the carpal bones could be obtained by antero-posterior view and in most cases angle measurement could only be
done based on the lateral view, thus limiting analysis of movement from one direction. Furthermore, carpal bones are small with complicated morphology and as their movement is primarily rotational, by angle measurement using radiograms characteristic findings are scanty and measurement has been limited to carpal bones. As carpal bones have multiaxial rotational movement without a fixed axis, the measured values do not necessarily accurately reflect the movement of carpal bones. Furthermore, a weakness has been pointed out that even by a slight twist during radiography the measured values show a great variation. In order to make a more detailed study of the kinematics of the wrist joints, the need has been emphasized that a measurement method to accommodate the three-dimensional movement of the carpal bones showing a multiaxial rotational movement should be employed. We therefore directed our attention to a strain gauge which is used in measuring the strength of machines and structures, and decided to employ strain gauges in analysis of wrist joint movement. A measurement apparatus was fabricated with the central part 5 mm in diameter made arch shaped so that even during multiaxial rotational movement of the carpal bone, strains corresponding to movement could be measured. Therefore, with the use of this measurement apparatus, we analyzed the kinematics of various carpal bones, particularly scaphoid, lunate, capitate, and triquetrum in volar-dorsal flexion of wrist joints, especially the movement of the triquetrum whose analysis had been extremely difficult.

Materials Methods

Cadaver Specimens

As materials, 20 cadavers preserved by arterial embalming without any trauma to the wrist joints, and 31 wrist joints were employed. The cadavers were composed of 10 males and 10 females and the 31 wrist joints were composed of 15 right wrist joints and 16 left wrist joints. Age at time of death ranged from 36 to 76 years with a mean of 65.7 years.

In arterial embalming, coagulated blood within the blood vessels of the cadaver was removed by a special infusion pump, followed by infusion of fixative in the blood vessels. Following embalming, the cadaver was preserved in a cold room at 5°C. In comparison with cadavers embalmed only by formalin, in cadaver specimens treated by this embalming procedure the elasticity of soft tissue is satisfactorily maintained and the range of motion of the joint is almost equivalent to that of the wrist joint of a living human.

Measuring Apparatus

The measuring apparatus consisted of a board made of 20 × 6 × 1 mm-sized polyethylene that was shaped into an arch with a diameter of 5 mm at the center. The top and sides were 4 mm in diameter, and a double axial strain gauge (Kyowa Dengyo) was attached. The objective of attaching a strain gauge at two sites was to investigate the possibility that measured strains would differ depending on where the gauge was attached.

By fixing both ends of this measuring apparatus with screws and adhesive, the measuring apparatus moved intimately with the carpal bones. In order to measure the strain corresponding to movement even when the carpal bones rotated multiaxially, the center part was processed into an arch shape with a diameter of 5 mm. This allowed a measurement that reflected three-dimensional movement of the carpal bones, and also enabled the analysis of movement on the ulnar side of the wrist, especially the triquetrum periphery, which had conventionally been very difficult to analyze.

Measuring Sites and Procedure

In order to elucidate the kinematics among the carpal bones during wrist movement, we selected the four carpal bones; i.e., the capitate, scaphoid, lunate, and triquetrum.

To avoid the breakdown of the physiological condition, we exposed the dorsal side of the wrist joint of the cadaver specimens. We preserved the ligaments and capsule on the dorsal side. Then we took bidirectional X-ray