Biomechanical Measurement of Painful Wrist by Flexible Electro-goniometry

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Abstract

Wrist pain is a common complaint in hand clinics. More and more computer programmers, typists and TV game addicts sustained wrist pain because of cumulative trauma disorders. The general wrist examinations only record statically the terminal wrist range in flexion/extension and ulna/radial deviation. To evaluate the functional range of motion of an injured joint during motion is very significant for clinical application in pain prevention and treatment determination. Flexible electro-goniometry offers a convenient method to investigate joint kinematics in clinical environment. The flexible electro-goniometer consists of a central strain gauged flexible shim with two end sensors attached to the shim for detecting relative motion between these two ends. The patient can comfortably wear the flexible electro-goniometer while performing their daily activities without any hindrance. This study attempted to measure the functional range of wrist motion by flexible electro-goniometer and provide a biomechanical model for clinical application.

This study recruited thirteen subjects with wrist pain of different causes. The flexible electro-goniometer was worn on the dorsal aspect of the wrist and forearm to detect the angle changes in wrist motion. The subject was asked to perform wrist flexion-extension, radial-ulnar deviation as well as clockwise/anti-clockwise circumduction movements under three forearm positions (pronation, neutral position, and supination). The painful points and ranges during movement were also marked simultaneously. After completing the regular treatment, one subject was assessed for improvement in ranges of motions. The angular data were plotted to show the range and loci of the wrist motion for biomechanical analysis. The circumduction index (CI) was introduced to represent the size of the wrist circumduction. The results showed the various characteristics of the pain points during wrist motion of the different diagnosis groups. The CI value of the subject improved very much in the follow-up measurement. This study demonstrates the current method is useful in clinical application and may lead to an efficient investigation protocol for wrist evaluation, treatment and biomechanical interpretation.

Keywords: Electro-goniometry, Wrist motion, Circumduction

Introduction

Wrist pain is a common complaint in hand clinics [1]. Athletes and the elderly usually suffer wrist pain due to fractures or ligament and cartilage tears. Labors and housekeepers, even art performers tend to complain wrist pain caused by tendon problems or nerve involvement. Nowadays, there are more and more computer typists and TV game addicts undergo wrist pain because of repetitive strain injury. However, evaluation of wrist pain can be a challenging task because of the complicated anatomy and biomechanics of the wrist. The general wrist evaluation in clinics includes visual inspection, range of motion (ROM) measurement, and topographic examination as well as radiographic procedures. Most of these examinations can only record the static ranges and pictures of the painful wrist in flexion-extension and radial-ulnar deviation. The dynamic changes in ROM and circumduction range of the wrist are not possible with these evaluations. To evaluate the functional range of motion of an injured joint dynamically is very important in the clinics for pain prevention and treatment determination. Especially, the dynamic assessment is more accurate in the actual wrist performance from static- observation neglect. Sophisticated motion analysis systems consisting of force plates, cameras, EMG, and computerized recording equipment are now available to record the patient's motion in laboratory [2]. The study results by these systems of motion analysis can help to build up a full biomechanical model of wrist motion and

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Table 1. The background information of the subjects

	Sex	Age	Diagnosis	Impaired History	Occupation	Pain provoking tasks
1	F	27	Right deQuervain's tenosynovitis	1.5 yrs.	teacher	writing, typing
2	M	30	Left wrist sprain	3 ms.	therapist	heavy carrying
3	M	23	Left Colles' fracture	2 ms.	student	heavy carrying
4	M	42	Left radial comminuted fracture	2.5 ms.	professor	eating; writing
5	F	55	Rheumatoid arthritis	3 yrs.	housekeeper	heavy carrying
6	M	24	Left distal radial fracture and arthritis	6 yrs.	student	heavy carrying
7	F	31	Left wrist sprain	1 ms.	nurse	holding stuff
8	F	75	Left distal radial fracture	11 ms.	farmer	heavy carrying
9	F	22	Right radial fracture with dislocation	2 yrs.	clerk	most daily tasks
10	F	50	Bilateral CTS	10 yrs.	housekeeper	most daily tasks
11	F	38	Right deQuervain's tenosynovitis, Left FCU/ECU tendonitis	9 yrs, 6 yrs	clerk	most daily tasks
12	F	45	Left CTS, Right deQuervain's tenosynovitis	2 yrs.	cashier	most daily tasks

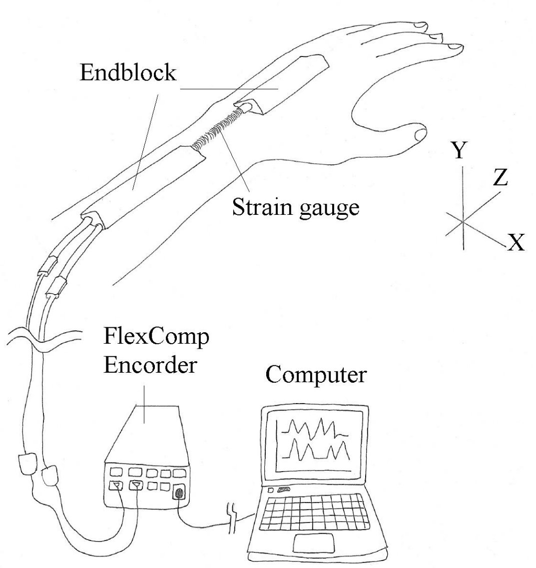

Figure 1. The experimental system and the coordinate system

provide valuable information for treatment consideration. However, such motion analysis systems are very expensive and their operations are very time consuming so not to be generally used in clinical examination [3].

Flexible electro-goniometry offers the convenience to investigate joint kinematics in clinical environment. The flexible electro-goniometer consists of a central strain gauged flexible shim with two sensor endblocks attached to the shim for collecting the data of the relative motion of the two endblocks. The system is inexpensive, portable, light and comfortable to wear [4]. The patients can easily wear the flexible electro-goniometer to do their daily activities without any hindrance [3]. The reliability and validity of this method have been reported in several articles [2, 4, 5]. This study attempts to use this new technique to investigate the performance of the painful wrist and to establish a practical assessment protocol by this method for future clinic application.

Methods

Experimental Apparatus

The system of flexible electro-goniometry included a flexible electro-goniometer (Biometrics®: XM-65, Biometrics Ltd, Gwent, UK, Figure 1) with twin axis sensor for measuring the relative angles between two endblocks. The strain gauge was located between two endblocks and protected by a spring. This electro-goniometer had two separate output channels and thus permitted the simultaneous measurement of motion angles in two planes: wrist flexion-extension and radial-ulnar deviation. The outputs of the two channels were the angular changes relative to X-axis and Y-axis respectively and were independent of linear displacement along Z-axis. The system contained other main elements including sensor adapters, FlexComp® encoder, fiber optical cable, and a notebook computer (Figure 1). The strain gauge measured the relative angular movement of the wrist joint and generated signals to FlexComp® encoder through adapters. The angular signal input range was from –180 degree to +180 degree with 5 degree of variation. The sampling rate was set as 16 Hz. The signals then were translated via the fiber optical cable and recorded as ASCII codes for later processing. The real-time data can be displayed on the monitor for error checking.

Subjects and Procedures

This study included two parts: one was to evaluate the painful wrists caused by different impairments; the other was to follow a case with Colles' fracture. For the first part, patients with wrist pain and no other problems of central nervous system were recruited as subjects. There are twelve subjects (eight female and four male) with painful wrist. The average age was 38.5 years old with range from 22 to 75 years old. All of them are all right handed. Seven wrists were diagnosed as soft tissue impairments (such as muscle sprain, tenosynovitis, and tendonitis). Five wrists had osteo-chondrous disorders (such as arthritis, fracture, and dislocation). Three wrists had carpal tunnel syndrome. They all suffered wrist pain with durations varied from one month to ten years, and were receiving clinical intervention at the time of the experiment. Their occupations and pain provoking tasks involving the wrist are listed in Table 1. The participants followed the routine clinical examination and treatment in the hand clinic and rehabilitation department. All subjects signed inform consent before joining the study.

The subjects were asked to sit on a seat with height-adjustable armrests. The shoulders were kept in a neutrally adducted position, upper arm close to the trunk, and the elbow in a 90° flexion on armrest while the wrist over-hanged freely. Two sensor endblocks of the flexible electro-goniometer were attached firmly to the dorsal surface of the measured wrist by double-sided tape over the third metacarpal and the midline of the forearm. The sensor spring were placed appropriately across the wrist joint and allowed maximal range of wrist motion with minimal skin stretch. Each subject was asked to actively perform the following wrist motion: flexion-extension, radial-ulnar deviation, and anticlockwise-clockwise circumduction at a comfortable speed under three fixed positions of the forearm (90° pronation, neutral position, and 90° supination). Following three active trials of each of the above movements, the passive trials were done three times by an occupational therapist. Both wrists of each subject were measured. The pain points and ranges were marked simultaneously according to the subject's indication. The angular data were processed and plotted to show the dynamic change of the degrees of wrist motion in the transverse plane (the radial-ulnar deviation about the X-axis and the flexion-extension about the Y-axis).

For the second part of the study, a female patient suffered from left Colles' fracture and had received open reduction with internal fixation. After removing the fixation pins, she was prescribed to wear a cock-up splint for immobilization and doing functional activities. At that time, the initial measurements of her wrists by flexible electro-goniometer were done according to the above procedures. Her right intact wrist was measured for contrast. After two-month rehabilitation program, the injured wrist was measured again to assess the recovery of the range of wrist motion.

Data analysis

The maximal range of the wrist in flexion-extension and radial-ulnar deviation could be read directly from the data. The angular data of the wrist motion projecting on the transverse plane were clearly plotted to show the angular change in wrist movement as a locus. The locus of the wrist circumduction thus could be plotted as an envelope. The characteristics of the circumduction envelopes such as shape, size, and skewed axis were analyzed both qualitatively and quantitatively. The normalized radius of the circumduction envelope was defined as circumduction index (CI), which could demonstrate the size of the envelope generated by wrist circumduction. The algorithms are as followings.

$$\text{Circumduction Index : CI} = \frac{\sum_{i=1}^{n} \sqrt{x_i^2 + y_i^2}}{n} \qquad (1)$$

x_i : the degree on X axis at time i

y_i : the degree on Y axis at time i ;

The range difference as well as the CI difference between active and passive wrist motion of the various impaired groups were analyzed by paired-t test statistically. The wrist ROMs and CI values of the case in follow-up study were described to compare the difference in recovery.

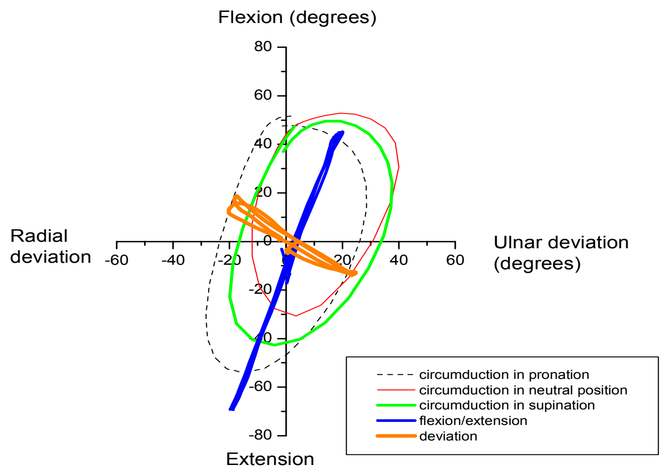

Figure 2. An example of the motion loci of a sound right wrist.

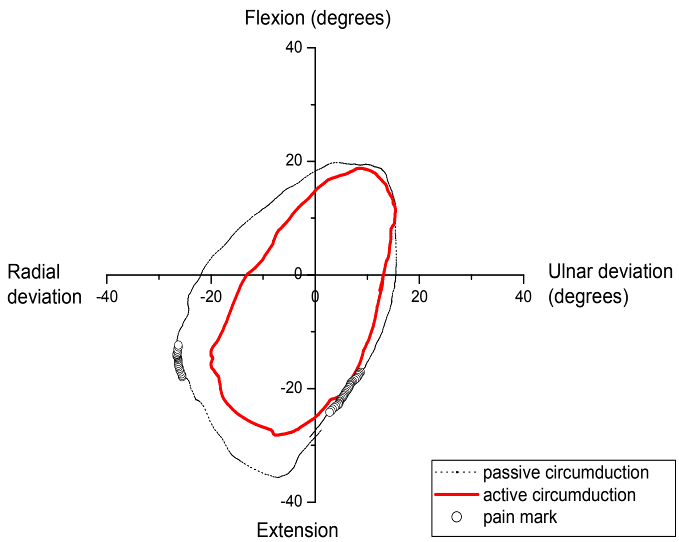

Figure 3. An example of the circumduction envelope of a right wrist with radial fracture.

Results

The two-dimensional figures can clearly demonstrate the loci and ranges of each wrist motion on the transverse plane (Figure 2, 3). The painful points and regions are also clearly localized.

First, the flexion-extension and radial-ulnar deviation of the wrists movements are not purely on the sagittal plane and coronary plane but coupled. Figure 2 demonstrates an example of a sound right wrist. We noted that wrist ROMs measured by electro-goniometer were larger than those of the traditional goniometry. All the circumduction envelopes of the sound wrists were found to be oval shaped and much similar in size in three forearm positions. The ends of the long axes of the oval shapes match the loci of flexion-extension in ulna-volar

Table 2. Range and CI difference between active and passive wrist motion in different group

	Flexion/Extension Range	Radial/Ulnar Deviation Range	Circumduction Index
OCD	20.41 ± 12.22**	11.69 ± 6.02**	0.86 ± 5.99
STI	13.48 ± 9.75**	7.55 ± 8.41**	2.67 ± 9.81
CTS	31.56 ± 14.06**	8.39 ± 4.88**	6.25 ± 4.19**

**: $p < 0.01$

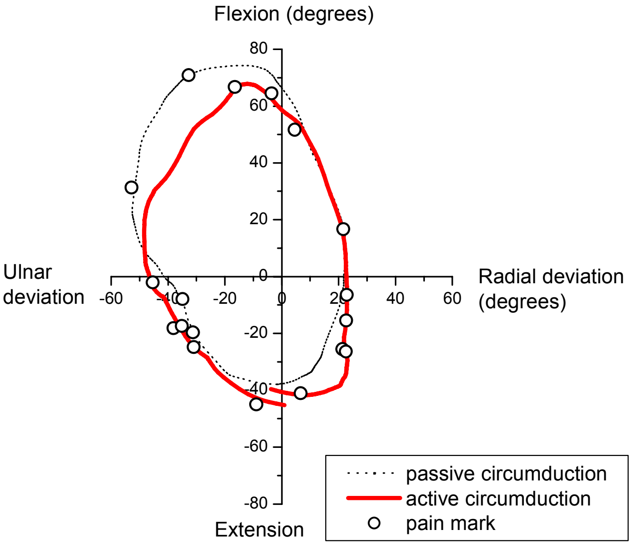

Figure 4. An example of the circumduction envelope of a left wrist with muscle sprain.

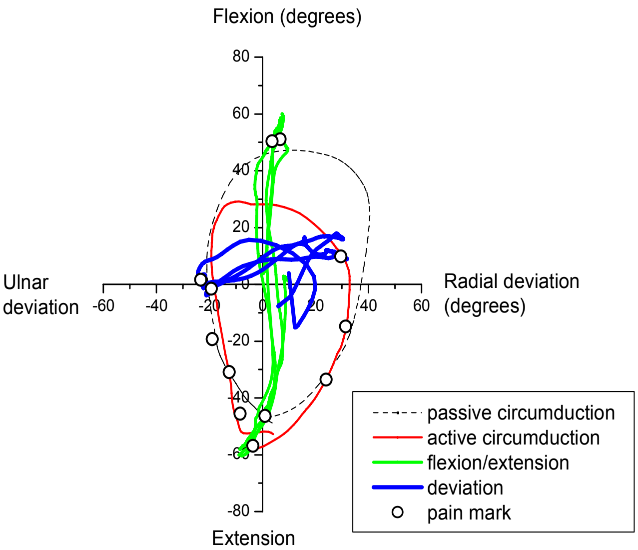

Figure 5. An example of the motion loci of a left wrist with carpal tunnel syndrome.

and radio-dorsal directions. The wrists with osteo-chondrous disorders (OCD) had smaller ranges in active circumduction than those of passive movement (Figure 3). Pain points occurred only in passive motion which might have indicated that the subject intended to avoid painful range when he/she circumducted actively. For the wrists with soft tissue impairment (STI), the pain points mostly located during active movements and some during passive movements (Figure 4). The figure demonstrates the pain points located mainly during active movement towards the injured site. The pain points in wrists with carpal tunnel syndrome (CTS) were at the terminal range of each movement, especially in wrist extension during both active and passive movement (Figure 5).

The range difference as well as the CI difference between active and passive wrist motion of the wrist in various impaired groups are shown on Table 2. There are statistically significant differences between active and passive ROMs of flexion-extension and radial-ulnar deviation among all three subjects groups. The CI values differed only in the subjects with carpal tunnel syndrome.

At the time of the follow-up, the subject participated in the second part of the study showed great improvement in the ROMs of flexion-extension (degrees) and radio-ulnar deviations (degrees) and in CI (values). The data of this subject's wrist motion are listed on Table 3 to demonstrate the recovery progress after rehabilitation program. In the first measurement, the subject could not assume her left wrist into supination so that the values are not available. To compare with the intact right wrist, we calculated the recovery ratio by dividing the data of the left wrist by those of the right one and indicated the obvious improvement.

Discussion

The result shows the loci of wrist flexion-extension in an ulna-volar to radio-dorsal direction, which support the finding of Ojima and his colleague's [2, 5]. This can be attributed to the anatomical structure of the wrist, which has irregularly shaped carpal bones and complicated ligament network [6, 7, 8]. Ojima and colleague's also reported that the normal wrist have oval loci of circumduction. The circumduction envelopes of the sound wrists in this study are found to be more consistent in shapes and size in the three forearm positions tested than that of the painful wrists. The pain points of the wrist motion in different diagnosis groups demonstrate various characteristics. Subjects with osteo-chondrous disorders experienced pain mostly during passive motion in specific ranges. The group with soft tissue impairment indicated that pain points occurred mostly during active motion and some during passive stretch. The paint points of the group with carpal tunnel syndrome are scattered at the terminal range of wrist motion and during extension movement in circumduction. This result is consistent with the report that wrist extension increases pressure in the carpal tunnel and tends to induce pain.

The circumduction index (CI) is defined as the normalized mean radius of the wrist envelope and represents a generalized value of the wrist circumduction. The CI difference between active and passive motion was significant in the carpal tunnel syndrome group, but not in the other two groups.

In the follow-up study, the graphic loci of the wrist motion can clearly demonstrate the discrepancy among the intact right wrist, the injured left wrist before and after

Table 3. Recovery ratio of the range and CI in the follow-up subject

	Flexion-extension		Radial-Ulnar Deviation		Circumduction	
	Range	Recovery (%)	Range	Recovery (%)	CI (SD)	Recovery (%)
R pronation	107.01°	100	44.78°	100	43.42 (16.44)	100
R neutral	110.42°	100	41.46°	100	32.97 (10.32)	100
R supination	96.77°	100	47.62°	100	38.28 (15.31)	100
R average	**104.73°**	**100**	**44.62°**	**100**	**38.22 (14.02)**	**100**
L I pronation	13.19°	12.32	5.43°	12.12	5.74 (2.59)	13.21
L I neutral	15.65°	14.17	5.74°	13.84	10.49 (2.85)	31.81
L I supination	-	-	-	-	-	-
L I average	**14.42°**	**13.76**	**5.59°**	**12.52**	**8.11 (2.72)**	**18.67**
L II pronation	93.1°	87.00	34.6°	77.26	46.75 (26.39)	107.66
L II neutral	88.11°	79.79	35.69°	86.08	35.24 (19.7)	106.88
L II supination	69.55°	71.87	25.73°	54.03	30.33 (14.22)	79.23
L II average	**83.59°**	**79.81**	**32.0°**	**71.71**	**37.44 (20.1)**	**97.96**

Left I: the first measurement before rehabilitation program; Left II: the second measurement after rehabilitation program

intervention. The CI value appears to be a better indicator of recovery than the ranges of motion in flexion-extension and radial-ulnar deviation. The patient also indicated that she had no trouble in doing most activities of daily living except for exertion at the extreme ranges of flexion-extension and radial-ulnar deviation. Several scholars [9, 10] have reported that the functional ROM of the wrist utilized in most daily tasks was smaller than the actual ROM available for the wrist. This study suggests that CI can objectively describe the dynamic wrist motion and thus worth respecting. The CI recovery ratio (value of the impaired wrist to that of the intact one) could be more effective in demonstrating the actual wrist functions than the conventional methods of measuring ROM of flexion-extension and radial-ulnar deviation only.

Conclusion

This study adopted the flexible elctro-goniometry to evaluate the painful wrist with different diagnosis categories to investigate their pain points and to demonstrate its convenience as well as accuracy. The 2-D graphs clearly show its usefulness in detecting the pain location and the shape of the loci during the wrist motion for qualitative analysis. The CI of the wrist envelope appears to be a good indicator of the dynamic wrist function and its recovery. However, this study did not provide a definite conclusion on the issue of the influence of forearm posture on wrist circumduction, possibly due to limited sample size. Further researches are needed in the future.

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