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ORIGINAL ARTICLE

Increased Carrying Angle is a Risk Factor for Nontraumatic Ulnar Neuropathy at the Elbow

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Abstract The literature suggests a possible relationship between carrying angle and nontrauma-related ulnar neuropathy. To confirm that relationship, we asked whether carrying angle is a risk factor in patients with nontrauma-related ulnar neuropathy. We measured the carrying angles of the elbow in 36 patients with a clinically and electrophysiologically confirmed diagnosis of nontraumatic ulnar neuropathy at the elbow and in 50 healthy control subjects. Correlation analysis was performed between carrying angles and parameters of nerve conduction studies, including nerve conduction velocities and amplitudes of muscle and nerve action potentials. The mean carrying angle was greater in the patients than in the control subjects. Females had a greater carrying angle than males. We observed an inverse relationship between carrying angles and motor nerve conduction velocities at cross-elbow segments of the ulnar nerves and with sensory nerve conduction velocities of the distal ulnar nerves. An increased carrying angle of the elbow appears to be an independent risk factor of nontrauma-related ulnar neuropathy.
Level of Evidence: Level III, diagnostic study. See the Guidelines for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

The carrying angle of the elbow is defined as the angle between the long axis of the extended forearm as it lies lateral to the long axis of the arm [21]. It may change with skeletal growth [4, 9]. A recent study of healthy children (600 elbows) showed range of motion of the elbow and carrying angle increase with age to skeletal maturity [9]. Another study also showed clinical carrying angle increases with age up to 15 years, after which there was a slight decrease in the angles [4]. The rate of carrying angle increment for boys and girls is 0.42 and 0.60 per year, respectively [4]. The carrying angle apparently develops in response to pronation of the forearm and keeps the swinging upper extremity away from the side of the pelvis during walking [14]. Anatomically, the carrying angle in human adults is approximately 10° in men and 13° in women [21]. Increasing the carrying angle may lead to elbow instability and pain during exercise or in throwing activities of sports [7, 12], may reduce function of elbow flexion [22], predispose to risk of elbow dislocation [10], and increase evidence of elbow fracture when falling on the outstretched hand and fracture of the distal humeral epiphysis [14].

Entrapment neuropathy of the ulnar nerve at the elbow has been reported in patients with elbow deformities, including cubitus varus after supracondylar humeral fracture [1, 13, 18]. One report described 15 patients with ulnar

neuropathy caused by antecedent trauma with cubitus varus deformity [1] and suggested cubitus varus deformity might increase angulation of the ulnar nerve pathway at the elbow and the risk of ulnar neuropathy.

To confirm that suggestion we asked whether an increased carrying angle also increased the occurrence of ulnar neuropathy at the elbow and explored the hypothesis that increased carrying angle is an independent risk factor for nontrauma-related ulnar neuropathy.

Materials and Methods

We retrospectively identified 36 patients who had a clinical diagnosis of ulnar neuropathy at the elbow and a diagnosis confirmed electrophysiologically between January 2003 and October 2005. The clinical diagnosis of ulnar neuropathy was based on a history of intermittent paresthesia, numbness, or hypoesthesia occurring spontaneously in the medial aspect of the forearm or in the ulnar nerve distribution frequently involving the little and ring fingers. The position at full range of elbow flexion or compressing the elbow to the table could exacerbate the sensory symptoms. All patients had two or more of the following tests positive on physical examination: (1) Tinel's sign; (2) sensory impairment of the distal ulnar nerve; and (3) hypothenar or interosseous muscle weakness or atrophy. None of the 36 patients had an underlying disease such as diabetes, uremia, hypothyroidism, or blood dyscrasia. Patients with arthropathy of the elbow, previous injuries of the shoulder, elbow, or forearm, history of trauma to the ulnar nerve, or cervical radiculopathy were excluded. Two patients had nonspecific elbow pain. For control subjects, 50 age-matched healthy subjects were enrolled and underwent electrophysiologic studies. Among the control group, 32 subjects were patients' spouses and 18 subjects were medical personnel. None of the control subjects had cubitus varus, rotational deformity, or hyperextension of the elbow.

Before conducting the study, a sample size calculation was made. Using a two-tailed independent sample t test, if $\alpha = 0.05$ and the standard deviation of the carrying angle is estimated as 3°, for an effect of 4°, a sample size of 30 subjects would be needed to have an 80% power ($\beta = 0.20$) to detect a mean difference in carrying angles between a control standard and patient group. Based on a previous study of tardy ulnar nerve palsy caused by cubitus varus deformity [18], 34 patients were sufficient to confirm the occurrence of ulnar nerve palsy caused by cubitus varus deformity, therefore, a minimum of 30 patients would be needed. The sample ($n = 36$) consisted of 23 women and 13 men between 28 and 64 years of age (mean, 42.6 years). Body mass indices measured in 31 patients were between 18 and 24 kg/m^2. Five patients had body mass indices greater than 25 kg/m^2. No patients had cubitus varus, rotational deformity, or hyperextension of the elbow. All patients provided informed consent before the study. The study was approved by the ethics committee of the university in accordance with the international ethical standards of the 1964 Declaration of Helsinki.

With the patient in the supine position, we measured the carrying angle at the shoulder in 0° flexion and 0° extension, full extension of the elbow, and the supinated position of the forearm at the lesion side with ulnar neuropathy. The carrying angle also was measured on the patients' unaffected side. The axis of the arm was defined distally at the midpoint between the medial and lateral epicondyles of the humerus and proximally at the lateral border of the cranial surface of the acromion. The axis of the forearm was defined distally at the midpoint between the distal radial and ulnar styloid processes and proximally at the midpoint between the medial and lateral epicondyles of the humerus (Fig. 1). The carrying angle was measured with a manual goniometer with two drawing axes of the arm and the forearm by three independent observers (CWC, YCW, CHC). Kappa coefficients were used to determine interobserver and intraobserver reliabilities. The kappa values varied from 0.70 to 0.86 with the highest related to using bony landmarks (Table 1).

To verify the carrying angles measured with the goniometer, radiographic examinations of the acromion-elbow-wrist axis were performed with the patients' elbows supinated and with the patients in a supine position. Two conventional methods also were determined to measure carrying angles of the elbow by using the arm and forearm axes from the medial outlines of the arm and forearm [3] and from the midline shafts of the arm and forearm [17]. These three methods of clinical assessment correlated with the radiographic measurements (Table 1).

A Synergy System (Medelec, Surrey, UK) was used for electromyography (EMG) and nerve conduction velocity (NCV). The Neuroline 710 electrode (Ambu Medicotest, Olsykke, Denmark) with a self-adhesive ring and Ag/AgCl content was used for recording. Motor nerve conduction studies were performed on each patient with ulnar neuropathy using a standard belly-tendon method to record the abductor digiti minimi muscle with supramaximal stimulation of the ulnar nerve distally at the wrist and proximally at the lower and upper elbow. We performed sensory nerve conduction studies of the ulnar nerve using an orthodromic method by placing the recording electrodes on the wrist and the stimulating electrodes on the fifth digit. A mixed nerve conduction study was performed over the forearm segment of the ulnar nerve using a stimulation electrode at the wrist and recording electrodes over the ulnar nerve at the elbow. Nerve conduction studies were performed with the elbow flexed 90°. The length of the cross-elbow segment for a

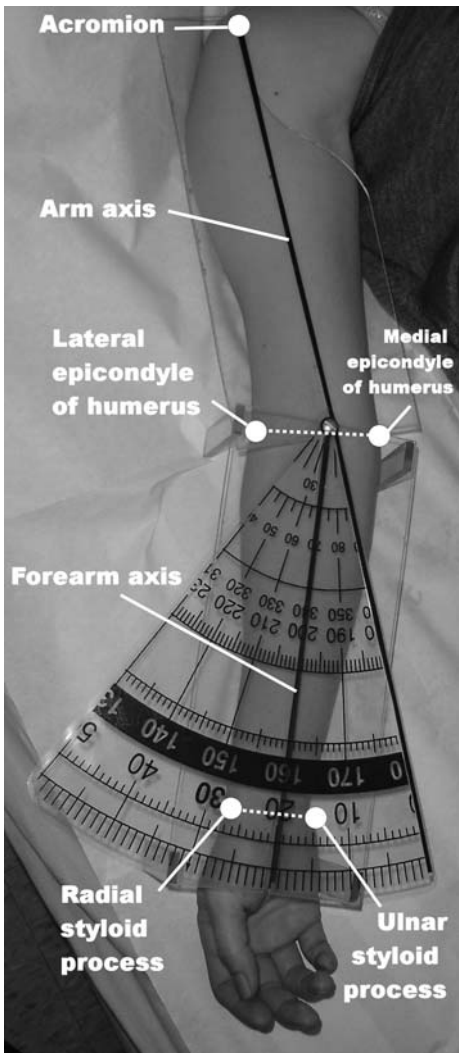

Fig. 1 Carrying angle is measured by a manual goniometer with two drawing axes of the arm and forearm. The axis of the arm is defined by the lateral border of the cranial surface of the acromion to the midpoint of the lateral and medial epicondyles of the humerus. The axis of the forearm is defined by the midpoint of the lateral and medial epicondyles of the humerus to the midpoint of the distal radial and ulnar styloid processes.

nerve conduction study should not be less than 10 cm. The skin temperature of the forearm was kept constantly greater than 31°C with an infrared lamp, if necessary.

Because ulnar neuropathy may cause impairment of the motor and sensory nerve function, electrophysiologic diagnosis of the ulnar neuropathy was based on two or more of the following five criteria [2]: (1) slowed motor nerve conduction velocity (MNCV) at the cross-elbow segment of the ulnar nerve: an MNCV less than 42.9 m/second measured at the cross-elbow segment of the ulnar nerve was categorized as abnormal; (2) slowed sensory nerve conduction velocity (SNCV) from the digit to the wrist: a SNCV measured over the neural segment of the ulnar nerve from the fifth digit to the wrist less than 38.1 m/second was categorized as abnormal; (3) mixed NCV from the wrist to the elbow segment of the ulnar nerve: a mixed NCV less than 48 m/second at the neural segment from the wrist to the elbow was categorized as abnormal; (4) reduced amplitude of compound muscle action potential (CMAP) or sensory nerve action potential (SNAP) in the nerve conduction study: a CMAP amplitude smaller than 4.5 mV or SNAP amplitude smaller than 8.1 μV was categorized as abnormal; and (5) abnormal EMG findings: fibrillations and positive sharp waves were counted together and considered abnormal when found at more than one site of the abductor digiti minimi, first dorsal interosseous, and flexor carpi ulnaris muscles on the needle EMG test. A mean duration of motor unit action potentials greater than 20 ms or fractional polyphasic waves greater than 30% in the tested muscle also were categorized as abnormal.

The highest and lowest normal values in the electrophysiologic studies were obtained from the control subjects. Using the values of mean conduction latency and wave amplitude with ± 2 standard deviations, the corresponding results show 95% confidence.

The data are presented as mean ± standard deviation. We compared ages, carrying angles, motor and sensory NCVs, and amplitudes of CMAPs and SNAPs between the

Table 1. Results of reliability and correlation coefficients

Characteristics	Measured by bony landmarks (n = 36)	Measured by axes of medial margins of arms and forearms (n = 36)	Measured by axes of midshafts of arms and forearms (n = 36)
Carrying angles (degrees)	15.2 ± 4.1	14.4 ± 5.8	14.1 ± 6.3
Ranges (degrees)	11.7–24.3	10.5–22.8	11.3–23.3
Correlation coefficient* (versus radiographic examination)	0.864	0.708	0.732
Intraobserver reliability (kappa values)	0.88 ± 0.7	0.73 ± 1.1	0.69 ± 0.9
Interobserver reliability (kappa values)	0.82 ± 0.6	0.67 ± 1.3	0.71 ± 1.1

Values are mean ± standard deviation; *by Pearson correlation tests.

patient group and control subjects with a Mann-Whitney U test. A Spearman's correlation coefficient was computed between the manual goniometer measurements and those from the radiographic examination. A logistic regression test was used to compare the odds ratios with 95% confidence intervals for potential risk factors in patients with ulnar neuropathy at the elbow, and we studied the relationship between carrying angles and parameters of nerve conduction studies. All analyses were performed with SPSS for Windows (Version 11; SPSS Inc, Chicago, IL).

Results

We found a greater ($p = 0.021$) mean value of carrying angle in patients with ulnar neuropathy than in the control subjects (Table 2). The mean value of the MNCV at cross-elbow segments, the SNCV at finger to wrist segments, and the mixed NCV at forearm segments were slower ($p = 0.023$, $p = 0.011$, and $p = 0.033$, respectively) in the patients with ulnar neuropathy than in the control subjects. The mean value of the SNAP amplitude in the patients with ulnar neuropathy was smaller ($p = 0.002$) than that of the control subjects. We identified the following factors for ulnar neuropathy: gender ($p = 0.034$), slowed MNCV or SNCV ($p = 0.001$), reduced CMAP or SNAP amplitude ($p = 0.016$), and carrying angles of 16° to 25° ($p = 0.022$) Table 3).

The mean carrying angle in females was greater ($p = 0.026$) than the angle in males (16.2° ± 3.2° versus 13.6° ± 3.0°). When we compared carrying angles between patients' elbows with ulnar neuropathy and their unaffected elbows, there was a lesser ($p = 0.034$) mean value of the carrying angle on the unaffected side than on the side with neuropathy (13.2° ± 2.8° versus 15.2° ± 4.1°).

We found an inverse linear relationship ($r = -0.488$, $p = 0.02$) between the carrying angles and MNCVs at the cross-elbow segments of ulnar nerves. An inverse regression relationship ($r = -0.532$, $p = 0.01$) also was found between the carrying angles and the SNCVs measured at finger-to-wrist segments of ulnar nerves. However, CMAP and SNAP amplitude did not correlate ($p > 0.1$ and $p > 0.1$, respectively) with the carrying angles of the elbow.

Table 2. Results of carrying angles and parameters of nerve conduction studies

Characteristics	Patients with ulnar neuropathy (n = 36)	Control subjects (n = 50)	p Values
Age (years)	42.6 ± 8.3	40.5 ± 6.2	0.343
Carrying angles (degrees)	15.2 ± 4.1	12.0 ± 3.8	0.021
NCS of ulnar nerves			
MNCV, cross-elbow (m/s)	44.8 ± 6.6	53.7 ± 5.4	0.023
SNCV, finger to wrist (m/s)	36.9 ± 5.8	44.5 ± 3.2	0.011
Mixed NCV, forearm (m/s)	48.9 ± 5.1	55.4 ± 3.7	0.033
CMAP amplitude (mV)	6.7 ± 3.1	8.5 ± 2.0	0.072
SNAP amplitude (μV)	5.5 ± 3.8	12.5 ± 2.2	0.002

Values are mean ± standard deviation; p values from Mann-Whitney U tests; NCS = nerve conduction study; MNCV = motor nerve conduction velocity; SNCV = sensory nerve conduction velocity; CMAP = compound muscle action potential; SNAP = sensory nerve action potential.

Table 3. Potential risk factors by logistic regression analysis

Risk factors	Adjusted odds ratios*	95% Confidence intervals	p Values
Gender	1.75	0.68–2.21	0.034
BMI	0.16	0.26–0.63	0.534
Elbow pain	0.06	0.15–0.45	0.862
Slowed MNCV or SNCV	4.68	1.10–5.81	0.001
Reduced CMAP or SNAP amplitude	2.10	0.84–12.33	0.016
Carrying angles 10° to 15°	0.57	0.49–1.40	0.117
Carrying angles 16° to 25°	2.39	1.31–3.35	0.022

*Controlled for age; BMI = body mass index; MNCV = motor nerve conduction velocity; SNCV = sensory nerve conduction velocity; CMAP = compound muscle action potential; SNAP = sensory nerve action potential.

Discussion

The literature suggests a possible relationship between carrying angle and nontrauma-related ulnar neuropathy. To confirm that suggestion we asked whether an increased carrying angle also increased the occurrence of ulnar neuropathy at the elbow and explored the hypothesis that increased carrying angle is an independent risk factor for nontrauma-related ulnar neuropathy.

Neither clinical evaluation nor electrophysiologic assessments for ulnar neuropathy allow diagnosis of ulnar neuropathy in all patients. Patients with clinically diagnosed ulnar neuropathy may have inconsistent physical signs and sensory symptoms. In one study, only 63% of patients with ulnar neuropathy at the elbow associated with cumulative stress had sensory symptoms [8]. Clinically, mild sensory impairment or mild muscular weakness could be missed by the physical examinations, thus the patients would not be referred for electrophysiologic studies. Nerve conduction studies and EMG assessments provide objective and quantitative evaluations of nerve function for ulnar neuropathy. However, modern methods of nerve conduction studies and EMG testing likely show sensitivity in approximately 78% to 93% of clinical populations [6, 15]. Thus, it is possible our patient population is biased by the way the patients were selected. Patients not being studied might have different ranges of carrying angles. However, we believe the population reflects those diagnosed clinically and then referred for electrophysiologic studies. The study has other limitations, such as minor variations in manual goniometer measurements of carrying angles. Also, one radiograph is vulnerable to error caused by rotation and degree of elbow flexion. Errors caused by projections or artifacts also may interfere with the bony contour and bias measurement of carrying angles.

The carrying angle at the elbow is assessed conventionally with the elbow in full extension using a protractor goniometer to measure the axes from the surface margin of the arm and forearm. However, variations in the development of the soft tissues in the arm and forearm generally lead to inconsistencies in the measured results. So far, there is no uniform method to measure the carrying angle of the elbow. We measured the carrying angle of the elbow through identification of bony landmarks on the acromion, medial and lateral epicondyles of the humerus, and the distal radial and ulnar styloid processes. This method can be performed easily and the reproducible measurement is constant. It reduces differences resulting from variations in the development of the soft tissues in the arm and forearm and can be used with a thin or an overweight person. We found a higher correlation coefficient with this method, and the radiographic examination and higher kappa values confirm the method is reliable.

Our data show an inverse relationship between carrying angles of the elbow and MNCVs or SNCVs of ulnar nerves suggesting an increase in the carrying angle leads to a tendency for ulnar nerve dysfunction. There are two possible explanations for the pathomechanism of ulnar neuropathy. First, a greater carrying angle may increase angulation of the ulnar nerve pathway and increase the tension or cause a chronic stretching injury of the ulnar nerve at the elbow. Second, the ulnar nerve is angulated at the entrance of the two heads of the flexor carpi ulnaris muscle by forward movement of the ulnar nerve resulting from forward movement of the medial head of the triceps brachii muscle in patients with cubitus valgus or cubitus varus deformity [11]. The ulnar nerve can be stretched easily by the forward lateral movement of the medial head of the triceps brachii muscle by the increase in carrying angle at the elbow. Because the carrying angle of the elbow is not always reversed, the ulnar neuropathy will progress during its later course. In chronic entrapment neuropathy such as carpal tunnel syndrome or ulnar neuropathy at the elbow, damage to the myelinating fibers may begin in the large fibers and extend to the smaller fibers followed by axonal degeneration in the affected nerve [16]. Thus, a slowing MNCV or SNCV may occur during early progression of ulnar neuropathy. This may explain why an increase in the carrying angle of the elbow is considerably correlated with a slowing MNCV or SNCV in the ulnar nerve.

We used an orthodromic method to study sensory nerve conduction of the distal ulnar nerve. This method has the benefits of keeping the stimulating electrodes close to the superficial digital nerves without interference from the muscle response at the finger. Mixed nerve conduction study was used to examine function of the ulnar sensory nerve at the forearm segment. In addition, we measured nerve conduction latency from the onset of stimulation to the peak of the major negative deflection of the SNAP. Although this peak latency measurement does not measure the NCV of the fastest conduction fibers, we prefer this method because the SNAP was easy to identify and was more constant than the onset latency of the SNAP. Peak latency measurement is more reliable in studying a diseased nerve when the SNAP amplitude is small [19].

Our data confirm a greater carrying angle in females than in males [20, 22, 23]. This finding is consistent with those of a normative study of carrying angles in children [4], which showed gender differences in carrying angles seemed to increase gradually with a maximum being around puberty and the carrying angle is greater in girls than in boys by a mean of 1.31°. However, the relationship between the carrying angle and gender remains controversial. A contrasting finding showing no differences in carrying angles between men and women was obtained in a

radiographic study of a large series of 422 patients evaluated for trauma [5]. Discrepancies between the clinical and radiographic findings are most likely the result of the increased joint laxity in women, which allows for a greater degree of elbow extension [20].

Patients with ulnar neuropathy at the elbow have a greater carrying angle of the elbow. We suggest an increased carrying angle may be a risk factor for nontrauma-related ulnar neuropathy.

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