Position of the Wrist Associated with the Lowest Carpal-Tunnel Pressure: Implications for Splint Design*

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ABSTRACT: **Increased carpal-tunnel pressure has been implicated in the pathophysiology of carpal tunnel syndrome, but it is not known whether splints that immobilize the wrist in a functional position of extension minimize carpal tunnel pressure. To determine the position of the wrist that results in the lowest carpal-tunnel pressure, twenty control subjects and four patients who had carpal tunnel syndrome were evaluated with use of a new, dynamic method that continuously measures carpal tunnel pressure throughout the range of motion of the wrist. The pressure was measured by means of a pressure transducer connected to a flexible catheter that had been inserted into the carpal canal. The position of the wrist was measured simultaneously with use of a two-axis electrogoniometer. Aided by a computer monitor that displayed a moving line of real-time carpal-tunnel pressure, each subject was instructed to move the wrist throughout the range of motion and to adjust it to the position that corresponded to the lowest carpal-tunnel pressure. For the control subjects, the lowest carpal-tunnel pressure averaged 8 ± 4 millimeters of mercury (1.07 ± 0.53 kilopascals), and the average position of the wrist associated with the lowest pressure was 2 ± 9 degrees of extension and 2 ± 6 degrees of ulnar deviation. For the patients who had carpal tunnel syndrome, the average position of the wrist (2 ± 9 degrees of flexion and 1 ± 9 degrees of ulnar deviation) associated with the lowest pressure was similar to that in the control group, but the average lowest carpal-tunnel pressure (19 ± 2 millimeters of mercury [2.53 ± 0.27 kilopascals]) was more than twice as high ($p < 0.003$). For all of the subjects, the carpal tunnel pressure had a parabolic relationship with the position of the wrist: it increased with greater deviation from neutral. These data indicate that splints that immobilize the wrist in a functional position of extension do not minimize carpal tunnel pressure.**

Immobilization of the wrist has long been used as conservative treatment of carpal tunnel syndrome. Originally, this practice was inspired by the observation that symptoms often become manifest or more severe after a period of overuse and can be relieved by prolonged inactivity[16,27]. The finding that flexion or extension of the wrist increases carpal tunnel pressure[3,9,11,28,34-36] and the implication of increased carpal-tunnel pressure in the pathophysiology of carpal tunnel syndrome[1,3,9,11,20-23,28,29,33-36] suggest that immobilization in a splint benefits the patient by preventing the elevation of carpal tunnel pressure.

Some authors have recommended immobilization of the wrist in extension[2,5,6,24,31] or in neutral[7,10,12,14-17,19,25,26], and many commercially available splints place the wrist in a functional posture of 20 to 30 degrees of extension. However, the validity of these recommendations is uncertain because the position of the wrist associated with the lowest carpal-tunnel pressure is not actually known. To determine this position, we conducted a study in which patients who had carpal tunnel syndrome and control subjects were evaluated with use of a new, dynamic method that continuously measures carpal tunnel pressure throughout the range of motion of the wrist.

Materials and Methods

Twenty control subjects who ranged in age from twenty-three to fifty years old and four patients with carpal tunnel syndrome who ranged in age from twenty-nine to forty-nine years old participated in the study. Ten of the control subjects and all of the patients who had carpal tunnel syndrome were women.

Each participant was interviewed and examined by a hand surgeon for the signs and symptoms of carpal tunnel syndrome. Muscle strength (thumb opposition,

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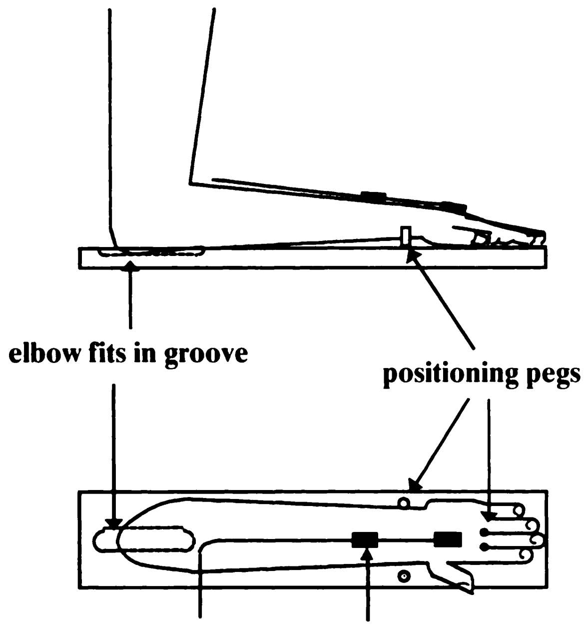

FIG. 1

Drawing showing the calibration of the two-channel electrogoniometer, which was performed with the arm positioned in a jig and the wrist in 0 degrees of flexion and 0 degrees of ulnar (radial) deviation.

interossei, and grip), evidence of thenar atrophy, and sensation to touch in the hand and fingers were evaluated, and testing for the Phalen and Tinel signs was performed. A neurologist carried out electrodiagnostic studies of the median nerve by recording from the thenar muscle, measuring antidromic sensory conduction between the wrist and index finger, and recording the orthodromic short-segment between the palm and wrist; the temperature of the palmar skin was maintained at 31 degrees Celsius, or more, when testing was performed. Data were compared with the results for the ulnar nerve as well as with normative values. Latency, conduction velocity, and amplitude of the responses were considered abnormal at 2.5 standard deviations, or more, above the normal average[32]. The findings of the physical examinations and nerve-conduction studies were normal for all of the control subjects. All of the patients who had carpal tunnel syndrome had tingling, pain, or decreased sensation in the median-nerve distribution; positive results on the Phalen and Tinel tests; and abnormal findings on studies of median-nerve conduction.

The experiment was performed in the non-dominant hand for the control subjects. An 18-gauge epidural needle (Tuohy-Schliff; Burron Medical, Bethlehem, Pennsylvania) was inserted at a 45-degree angle about five millimeters proximal to the distal volar wrist crease, immediately radial to the palmaris longus, as previously described[9]. Before insertion of the needle, the area was anesthetized with a subcutaneous injection of Xylocaine (lidocaine). A saline-solution-filled 20-gauge epidural catheter (Burron Medical) with three side-ports near the distal tip was threaded through the hub of the needle and into the carpal tunnel. The needle was withdrawn, and the catheter was secured with a suture. The proximal end of the catheter was connected to an in-line pressure transducer (model 041-576-504; Cobe, Lakewood, Colorado). All connections were secured in a way that allowed maximum freedom of motion. To prevent occlusion, a continuous flow of saline solution (approximately one milliliter per hour) was maintained by means of a low-flow continuous-flush device (Soren-

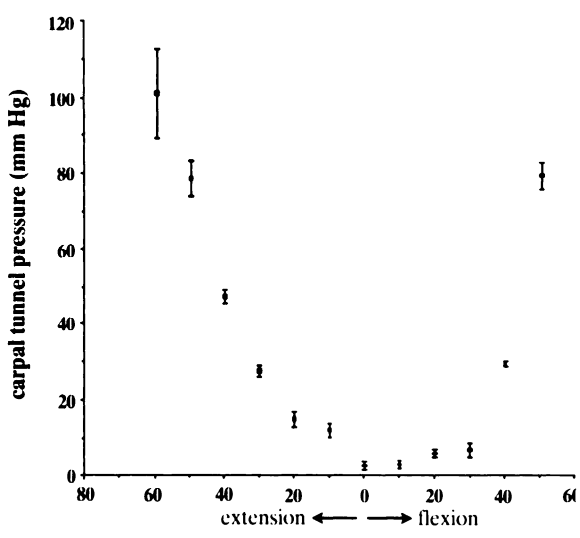

FIG. 2-A

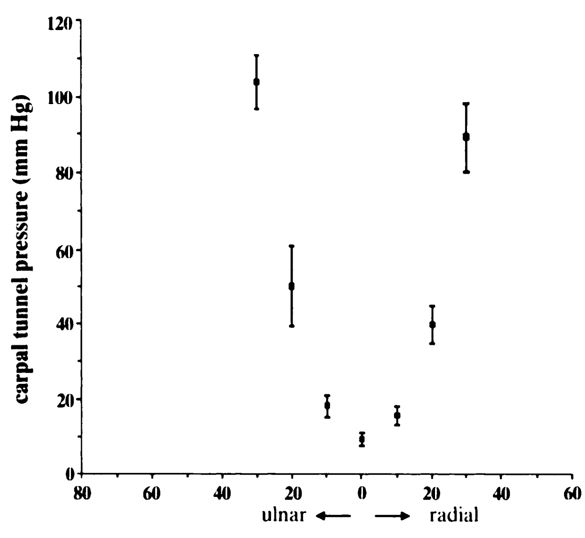

FIG. 2-B

Figs. 2-A and 2-B: Graphs of the results from one subject, showing the carpal tunnel pressure as a function of the position of the wrist. The data-plots for each subject produced similar parabolic curves. The error bars represent the standard error.

Fig. 2-A: The pressure as a function of extension and flexion of the wrist.

Fig. 2-B: The pressure as a function of ulnar and radial deviation of the wrist.

TABLE I

POSITION OF WRIST ASSOCIATED WITH LOWEST CARPAL-TUNNEL PRESSURE

	Lowest Carpal-Tunnel Pressure (*mm Hg [kPa]*)		Position of Wrist Asssociated with Lowest Carpal-Tunnel Pressure (*Degrees*)	
	Average	Standard Deviation*	Average	Standard Deviation*
Control subjects (n = 20)	8 (1.07)	3/4 (0.40/0.53)	2 extension, 2 ulnar deviation	7/9 extension, 6/6 ulnar deviation
Patients who had carpal tunnel syndrome (n = 4)	19† (2.53)	3/2 (0.40/0.27)	2 flexion, 1 ulnar deviation	7/9 flexion, 4/9 ulnar deviation

*Values are given as the sample pooled within subject/sample observed between subject.
†$P < 0.003$.

son Intraflow II, model 42002-02; Abbot, Mountain View, California).

A two-axis electrogoniometer (model M110; Penny and Giles, Santa Monica, California) was secured to the dorsal surface of the hand and forearm. It was used to measure continuously the flexion or extension angle as well as the radial or ulnar deviation of the wrist. The device, which has an accuracy of ±3 degrees, was calibrated with the hand held in neutral[30] (0 degrees of flexion, 0 degrees of ulnar [radial] deviation, and full pronation) before and after each experiment (Fig. 1). Carpal tunnel pressure and the angle of the wrist were sampled at forty hertz, and the readings were stored in a computer that was connected directly to the pressure transducer and electrogoniometer.

The subject was seated with the arm at the side and the elbow flexed to 90 degrees so that the pressure transducer and carpal tunnel were at the same level during the experiment. A moving line of real-time carpal-tunnel pressure was displayed on a computer monitor. Aided by this visual feedback, the subject slowly moved the wrist through the range of motion in all directions, repeating motions and positions until the position resulting in the lowest carpal-tunnel pressure was identified. This task took approximately five to ten minutes and was repeated seven times during a four-hour period.

Average values for the pressure and for the position of the wrist were determined for all tasks and all subjects. Sample pooled within-subject and observed between-subject standard deviations were calculated with use of SAS software (SAS Institute, Cary, North Carolina).

Results

For all of the control subjects, the carpal tunnel pressure had a parabolic relationship with the position of the wrist, increasing with greater deviation from neutral (Figs. 2-A and 2-B). The average lowest carpal-tunnel pressure (and standard deviation) for the control subjects was 8 ± 4 millimeters of mercury (1.07 ± 0.53 kilopascals), and the average position of the wrist associated with the lowest pressure was 2 ± 9 degrees of extension and 2 ± 6 degrees of ulnar deviation (Table I).

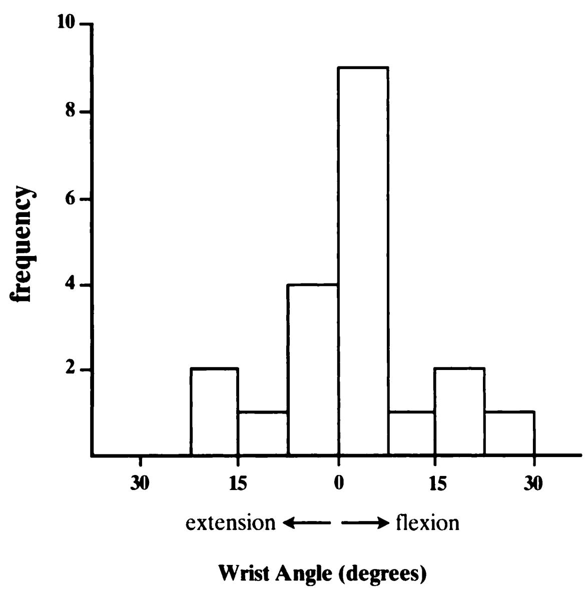

FIG. 3-A

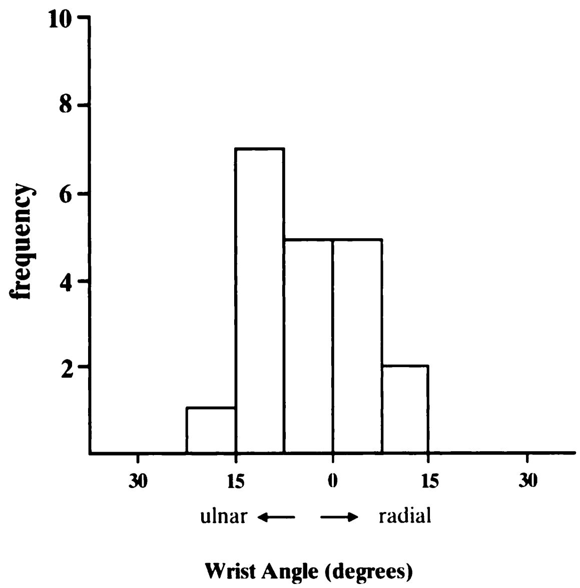

FIG. 3-B

Figs. 3-A and 3-B: Graphs showing the distribution, among the twenty control subjects, of the positions of the wrist that were associated with the lowest carpal-tunnel pressure.

Fig. 3-A: The distribution of the wrists in extension and flexion.

Fig. 3-B: The distribution of the wrists in ulnar and radial deviation.

TABLE II

AVERAGE CARPAL-TUNNEL PRESSURE WITH THE WRIST IN DIFFERENT POSITIONS

Study	Patients Who Had Carpal Tunnel Syndrome				Control Subjects			
	No. of Wrists	Neutral*	Flexion*	Extension*	No. of Wrists	Neutral*	Flexion*	Extension*
Gelberman et al.[9] (1981)	15	32 (4.27)	94 (12.53)	110 (14.66)	—	—	—	—
Werner et al.[36] (1983)	16	31 (4.13)	75 (10.00)	105 (14.00)	—	—	—	—
Szabo and Chidgey[34] (1989)	22	10 (1.33)	32 (4.27)	51 (6.80)	6	5 (0.67)	16 (2.13)	27 (3.60)
Okutsu et al.[23] (1989)	62	43 (5.73)	192 (25.60)	222 (29.60)	32	14 (1.87)	144 (19.20)	158 (21.06)
Luchetti et al.[20] (1989)	30	26 (3.47)	—	—	4	13 (1.73)	—	—
Rojviroj et al.[28] (1990)	61	12 (1.60)	27 (3.60)	33 (4.40)	32	4 (0.53)	9 (1.20)	13 (1.73)
Graham et al.[14] (1991)	22	20 (2.67)	—	—	13	12 (1.60)	—	—
Average	—	26 (3.47)	—	—	—	9 (1.20)	—	—

*Values are given as millimeters of mercury with kilopascals in parentheses.

The individual angles of the wrist associated with the lowest pressure in the control group followed a normal distribution (Figs. 3-A and 3-B).

For the patients who had carpal tunnel syndrome, the average position of the wrist (2 ± 9 degrees of flexion and 1 ± 9 degrees of ulnar deviation) associated with the lowest pressure was similar to that for the control subjects, but the average lowest carpal-tunnel pressure (19 ± 2 millimeters of mercury [2.53 ± 0.27 kilopascals]) was more than twice as high ($p < 0.003$). In neither group did the lowest carpal-tunnel pressure or the position of the wrist associated with this pressure change significantly during the four-hour testing period. Intrasubject and intersubject variations in the two groups were comparable (Table I).

Discussion

Previously, carpal tunnel pressure in living subjects has been measured with use of a Foley catheter connected to a mercury-filled bag[35] or with the wick-catheter[9] or slit-catheter[28] technique. The device in the current study — a small, flexible, saline-solution-filled indwelling catheter connected to a pressure transducer and a low-flow flush device — allows complete freedom of hand movement. The technique is unique in that carpal tunnel pressure is measured continuously as a function of the angle of the wrist. The method can be performed with the subject awake and with only slight discomfort. Subcutaneous skin anesthesia is used, which does not modify the effects of muscle and tendon tone on carpal tunnel pressure, as may have occurred in studies in which general[34,36], axillary[9], or Bier block[1] anesthesia was employed.

As others have reported[1,8,9,11,14,20,22,23,28,34-36], carpal tunnel pressure was lower in the control subjects than in the patients who had carpal tunnel syndrome, and it was elevated at the extremes of motion. Carpal tunnel pressure was elevated most at the extremes of flexion and extension, but it was also elevated at smaller angles. The magnitude of the carpal tunnel pressure at its lowest point (eight millimeters of mercury [1.07 kilopascals] for the control subjects and nineteen millimeters of mercury [2.53 kilopascals] for the patients who had carpal tunnel syndrome), which was near the neutral position of the wrist, was also consistent with previous research (Table II).

The available data on immobilization of the wrist in a splint for the treatment of carpal tunnel syndrome are difficult to interpret because the trials on which they are based vary greatly with respect to the criteria for selection of subjects, the duration of and schedule for the immobilization in the splint, the duration of follow-up, the design of the splint, the use of controls, and other aspects of the design of the study[4,7,12,13,16-19,25,26]. What is evident, however, is that many patients need an operation for the permanent relief of the symptoms, while some can be managed sufficiently with this conservative measure. A number of studies[7,13,19] have suggested that the latter individuals are those who have early disease.

The prevention of carpal tunnel syndrome would probably involve the identification of activities that critically elevate carpal tunnel pressure. The dynamic method for measuring carpal tunnel pressure described in the current study could be used to identify such activities. It might also be applied in the development of more ergonomic designs for tools and in the evaluation of treatment for carpal tunnel syndrome. Use of this method has already shown that splints of a traditional design that place the wrist in 20 to 30 degrees of extension may not be of maximum benefit for the treatment of carpal tunnel syndrome because they do not minimize carpal tunnel pressure; instead, the ideal position for immobilization is closer to neutral.

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