Carpal tunnel area was investigated as a risk factor for carpal tunnel syndrome (CTS). It was hypothesized that if canal area is a risk factor for the syndrome, individuals who develop the syndrome should have smaller carpal canal areas than those who remain free of the syndrome. Sixty-one subjects, approximately equally divided by sex, age group, and diagnosis, were examined. A measurement of cross-sectional areas of the carpal canal by computerized axial tomography indicated that individuals diagnosed as carpal tunnel patients had significantly larger carpal canal areas than controls. The results indicate that a small carpal canal area does not appear to be a risk factor for carpal tunnel syndrome.
Key words: carpal tunnel syndrome • median nerve • computerized axial tomography • nerve conduction studies • ergonomic stress

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CARPAL TUNNEL AREA AS A RISK FACTOR FOR CARPAL TUNNEL SYNDROME

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Numerous studies have been conducted to delineate the causes of, and the risk factors for, carpal tunnel syndrome (CTS). Several investigators contend that certain work-related activities are largely responsible for the development of CTS.[1,2] Other investigators believe that individuals may possess personal factors (e.g., area of the carpal canal, ganglia, deposits of calcium) that put them at risk for developing the syndrome.[4,16] If a reliable and predictive indicator of CTS could be identified, individuals at risk may have an activity altered or environment redesigned to reduce biomechanical stress to the wrist.

Phalen, as well as Hybbinette and Mannerfelt, have reported that females (who have been found to have smaller canal sizes than males[5,6]) have a higher incidence of CTS.[11,16] While sex differences in the incidence of CTS are reliable, they are not predictive (i.e., not all women will develop CTS).

Three separate studies, using computerized axial tomography (CT), have found smaller carpal tunnel areas for individuals with CTS than for controls.[4–6] Dekel[5,6] and his colleagues completed two of these studies comparing female CTS patients with both male and female controls. In the first study, Dekel reported that the proximal, but not the distal, measure of canal area was significantly smaller for the female CTS group than for the female controls.[5] In the second study, Dekel reported that both proximal and distal measures of canal area were significantly smaller for the female CTS group than for the female controls.[6] A similar study of carpal tunnel area was reported by Bleecker and her colleagues in which all the CTS cases and controls were males.[3,4] The results of the study indicates that carpal tunnel cases had smaller carpal canal areas than the controls on both of the measures reported.[4]

Since carpal canal area, like other physical attributes, is on the average larger in males than in females,[5,6] there is a need to examine the canal areas of both male and female CTS cases and controls to determine if the size of the canal is related to the diagnosis of CTS for both sexes. That is, do people who develop CTS have smaller carpal canal areas than people who are free of the syndrome? The purpose of the present study was to reexamine, using approximately equal numbers of

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male and female CTS and control subjects, previous findings that individuals with a smaller carpal canal area are more likely to develop CTS than individuals with larger canal areas.

MATERIALS AND METHODS

Subjects. Thirty male and 31 female subjects were identified for this study. Twenty-seven subjects were diagnosed as suffering from CTS and 34 were asymptomatic controls. CTS cases were workers employed in the Baltimore Metropolitan Area who were being seen in the Neurology Clinic at the Francis Scott Key Medical Center, Baltimore, MD. A worker was included in this study and considered a possible CTS "case" if he/she reported one or more of the median nerve sensory symptoms or two or more of the median nerve motor symptoms listed in Table 1. After the subject was classified as a possible CTS case, he/she was examined by a neurologist. The neurological exam was conducted to exclude those individuals with hand/wrist disorders other than CTS or those with dermatologic abnormalities which might have interfered with testing.

Controls were selected from individuals who responded to advertisements on public bulletin boards and were screened by telephone for the absence of symptoms noted in Table 1. Each possible control subject was examined by the same neurologist who screened the CTS group. The results of the neurological exams were used to exclude those individuals selected for the control group who had any type of hand/wrist disorder other than CTS or those who exhibited dermatologic abnormalities which might have interfered with testing.

The first analysis contains data from 58 subjects. This was necessitated by data collection problems associated with the computerized axial tomography. Subsequent data analyses were based on the full sample of 61 subjects.

Table 1. Criteria for assignment as a carpal tunnel case.

A positive response to one or more of the following median nerve sensory symptoms:

1. Numbness in hands or fingers.
2. Pain in shoulder, arm, hand, or finger.
3. Wake in morning with symptoms listed in #1 or #2 above.

OR

A positive response to two or more of the following motor symptoms:

1. Decrease in grip strength.
2. Difficulty in opening jars or lifting.
3. Tendency to drop small objects.

For the first analysis, 12 of the 27 male subjects and 13 of the 31 female subjects were diagnosed with CTS. The remaining 15 males and 18 females were designated as controls.

All subjects had volunteered for participation and were selected so that the CTS and non-CTS groups were matched for sex and by age group (e.g., 20–30, 30–40). The average ages of the male CTS and controls were 37.3 (SD = 12.73 years) and 40.6 years (SD = 13.49 years), respectively, whereas the average ages of the female CTS and controls groups were 44.4 (SD = 8.45 years) and 34.9 years (SD = 9.17 years), respectively. Age differences between the CTS subjects and controls ($t = 1.095$) and between males and females ($t = 0.25$) were not significant ($p > 0.05$).

PROCEDURE

Subjects were required to complete the following: (1) a medical questionnaire, (2) evaluation of both wrists by computerized axial tomography (CT), (3) assessment of median nerve function by nerve conduction velocity (NCV) studies,[10] and (4) an examination by a neurologist. The procedure used for obtaining the CT (GE8800 CT/T scanner), as well as the methods for ensuring proper wrist alignment, have been described by Bleecker.[4]

Five consecutive CT slices at 5 mm intervals were made through the carpal canal. The first CT slice was made just distal to the hook of the hamate. The computer then calculated the cross-sectional area enclosed by the carpal bones and the projected flexor retinaculum. Three of the five CT slices were used in the analyses. The measurements used were those from the wrist crease and approximately 12 mm and 25 mm distal to the wrist crease.

NCV studies provided measures of amplitude, latency, and velocity for sensory and motor fibers of the median and ulnar nerves for both the right and left hands. Median and ulnar conduction velocities at the wrist were measured following a procedure described by Bleecker.[4]

RESULTS

First-Order Analysis: Diagnosis Based on Symptoms and Neurological Exam. Subjects were included in this analysis if they met the requirements listed above and had three interpretable CT measurements from each wrist. As noted above, three of the 61 subjects did not meet this criteria. Table 2 presents the mean values of the proximal, middle, and distal CT measurements for the remaining 58 subjects comprising the CTS and control group. The 25 CTS subjects had consistently larger carpal canal areas than the 33 control subjects. This size differential was observed for both the right and left wrists.

An analysis of variance (ANOVA), with diagnosis (CTS versus control) and sex (male versus female) as "between factors" and hand (right versus left) and slice (proximal, median, or distal CT measurement) as "within factors" indicated significant ($P < 0.01$) differences between the CTS and control groups. Differences between CT measurements for the right and left hands were not significant for the carpal tunnel subjects and/or controls. Differences between the various slice measures across both hands and groups combined were also significant ($P = 0.017$). A multiple comparison procedure (Tukey HSD) indicated that the distal CT measurement was significantly smaller than either the proximal ($P < 0.05$) or the median ($P < 0.05$) CT measurements for the combined CTS and non-CTS groups. The carpal canal areas measured by the proximal and medial CT slices were not significantly different, suggesting that the carpal canals examined in this study were somewhat cone shaped. This finding may eventually prove important because of its relationship to findings reported by Kimura.[14] Kimura, using electrodiagnostic studies, reported evidence that median nerve neuropathy occurs in what we found to be the smallest part of the cone. The differences between the proximal, medial, and distal CT slices hold for both the left as well as the right hands, and for females as well as males. This conclusion is based on the absence of significant two-, three-, or four-way interactions.

Table 2. Mean values for computerized axial tomography measures for the right and left wrist—by sex (all measurements in cm^2).

	Carpal tunnel (N = 25)		Controls (N = 33)	
Measurement:	Male (N = 12)	Female (N = 13)	Male (N = 15)	Female (N = 18)
Right wrist				
Proximal	2.179	1.796	2.053	1.579
	(0.261)	(0.287)	(0.356)	(0.246)
Middle	2.210	1.797	1.977	1.627
	(0.289)	(0.286)	(0.277)	(0.301)
Distal	2.162	1.732	1.929	1.459
	(0.360)	(0.283)	(0.321)	(0.291)
Left wrist				
Proximal	2.115	1.865	2.071	1.667
	(0.304)	(0.348)	(0.388)	(0.242)
Middle	2.148	1.745	2.065	1.574
	(0.305)	(0.297)	(0.359)	(0.221)
Distal	2.168	1.668	1.915	1.472
	(0.750)	(0.351)	(0.434)	(0.190)

The results, that CTS subjects have larger carpal canal areas than asymptomatic controls, are the opposite of what Dekel[5,6] and Bleecker[4] have reported. These findings could cause some concern about the accuracy of the CT measurements. An indirect verification that the CT system was operating correctly is provided by Table 2. Table 2 presents the mean values of the various measurements for the CTS and control groups separated by sex. The findings indicate that the carpal canal area for females was significantly smaller than that for males ($P < 0.001$). The finding applies to both hands and replicates reported sex differences in carpal canal area.[11,16]

Second-Order Analyses: Diagnosis Based on NCV Studies. The results of the first-order analysis may be considered suspect for two reasons. First, the diagnostic criteria used for classifying subjects as CTS or controls may be considered less rigorous than other available criteria. Dorwart,[7] for example, contends that a diagnosis of CTS should be considered suspect if the results of NCV studies are not considered. The second reason for considering the results suspect is provided by Bleecker and her colleagues. They argue that the measure of choice in determining differences between CTS and asymptomatic controls is the smallest measure of canal size.[4] Their argument is based on the assumption that the smallest of the CT cross-sectional measurements is the most likely site for compression of the median nerve to occur. Therefore, this analysis only used the smallest CT measurement from each wrist.

The neurologist who provided the original examination was not involved in the reclassification of the remaining subjects for this analysis. Therefore, a set of uniform decision rules, based on NCV, were sought to assign cases. A literature review yielded five decision rules (Table 3) for classifying cases as CTS or controls. Based on these criteria, subjects previously diagnosed as CTS were assigned to the CTS group in this analysis if they met the minimum requirements for any one of the five rules described in Table 3. If an individual previously diagnosed with CTS did not show

Table 3. Decision rules used for classification as carpal tunnel syndrome using nerve conduction velocities.

Carpal Tunnel Cases: A carpal tunnel case in the first-order analysis remained a carpal tunnel case in the second-order analysis if it met any one of the following decision rules:

1. Difference of 1.0 msec in median distal motor latency between symptomatic and nonsymptomatic hand.[9,20]
2. A median distal sensory latency 3.5 msec or greater.[14,15]
3. Difference between the two hands of 0.5 msec or more for the distal sensory latencies of median nerve.[9,20]
4. Difference of 1.5 msec in the distal motor latency between the median and ulnar nerve.[8,9]
5. Difference of 1.0 msec between median and ulnar sensory latencies in the same hand.[13,17]

Controls: A control in the first-order analysis was classified as a carpal tunnel case in the second-order analysis if it met any one of the following decision rules:

1. Difference of 1.25 msec in median distal motor latency between symptomatic and nonsymptomatic hand.[9,20]
2. A median distal sensory latency greater than 3.75 msec.[14,15]
3. Difference between the two hands of 0.7 msec or more for the distal sensory latencies of the median nerve.[9,20]
4. Felsenthal[9] reported that the mean plus two standard deviation difference for normals was less than 1.0 msec. A 1.5 msec difference was felt to be a conservative measure.[8,9]

any NCV decrement, that case was discarded from further analysis. The results of the analysis indicated that carpal canal area of CTS subjects was larger than the controls ($P < 0.01$). The remainder of this section, including two data tables, was included for the review process. The interested reader can obtain tables and the remainder of the text by request from the senior author.

Third-Order Analysis: Diagnosis Based on Symptoms, Neurological Exam, and NCV Studies. Seven control subjects, who were asymptomatic for CTS in the first-order analysis, were reassigned to the CTS group in the second-order analysis. These 7 subjects, all of whom were examined by a neurologist for the first-order analysis, exhibited decrements in NCV despite the absence of symptoms. Bleecker[4] has referred to these subjects as "subclinical cases." Since it could not be determined if the NCV decrements, indicating median nerve neuropathy, were due to CTS, it was decided that the data set should be reanalyzed without these suspect cases. Such an analysis would control for the possibility that these cases had larger canal areas, thereby biasing the data. The CTS group included for this analysis consisted of the 13 CTS subjects from the first-order analysis who also had NCV findings in the second-order analysis consistent with a diagnosis of CTS. This CTS sample consisted of 8 male and 5 female subjects. To match for sample size and sex, 13 controls, consisting of 8 males and 5 females, were randomly selected from the control group used in the second-order analysis. Table 4 indicates that carpal tunnel area was again significantly larger for the CTS group than for controls ($P < 0.01$). Sex and diagnosis did not interact, with males having a significantly larger carpal canal area in both diagnostic categories ($P < 0.01$).

DISCUSSION

The results of these three analyses were consistent: CTS cases had larger carpal canal areas than controls, a finding that applies to both the right and left canals and does not interact with sex (male versus female), hand (right versus left), or slice (proximal, median, or distal CT measurement).

This is not the first study that has failed to report smaller canal areas in CTS patients. It is, however, the first study to report larger areas for CTS patients. Dekel and Coates[5] reported two measures of canal area, but found that CTS patients differed significantly on only one of those measures. This discrepancy could be a function of sampling procedures. In the current study, an equal number of male and female CTS patients were initially used. Controls were matched for sex

Table 4. Mean and standard deviation for the smallest measure of carpal canal size from the right and left wrist by diagnosis and sex (all measurements in cm^2).

	Cases (N = 13)		Controls (N = 13)	
Measurement	Male (N = 8)	Female (N = 5)	Male (N = 8)	Female (N = 5)
Smallest Measure	2.031	1.694	1.736	1.394
Carpal Canal Right	(0.295)	(0.224)	(0.237)	(0.134)
Smallest Measure	2.014	1.760	1.728	1.418
Carpal Canal Left	(0.342)	(0.285)	(0.230)	(0.157)

and were selected so that they were approximately the same age as the CTS group. This selection procedure minimized the possibility of confounding the effects because of differences in age and sex. In both studies reported by Dekel,[5,6] the samples were not matched for sex, and the average age of the CTS groups was not reported. Bleecker,[3,4] reporting on 14 male electricians, found smaller canal areas in the 11 "symptomatic" and "subclinical" CTS patients than for controls. The use of only three controls, however, makes the reported comparisons unreliable since a single deviant score could bias the results.

The contradictory effects for canal size found between this study and earlier studies may indicate that another anatomical risk factor, independent of carpal canal size, may underlie CTS. This risk factor may be the residual volume of the carpal canal area after accounting for the various nerves, tissues, and vessels passing through it. An inflammation of any of these structures could result in reduced volume and compression of the median nerve. This explanation is consistent with the data of John[12] who, using CT, has reported a reduction in volume in the carpal tunnels of patients with CTS.

The discrepancy between these and previous findings also should underscore the possible significance and interactive role of work-related factors in the etiology of the syndrome. Factors such as repetition rate, force level, and awkward hand/wrist postures are most commonly cited as contributing factors for CTS.[18,19] In addition, Bleecker has suggested that the issue of canal size as a risk factor must be considered within the context of hand exposure to the "appropriate ergonomic stresses."[3] What the appropriate ergonomic stresses are, however, remains to be determined. For this study, information on the work and ergonomic exposure histories of the subjects was unavailable. Determining the relative contribution of canal size and ergonomic factors to CTS will require longitudinal studies where information on work history and ergonomic stresses can be monitored, along with periodic neurological examinations, to document the onset of preclinical symptoms. Such studies would provide needed dose-response data and an index of ergonomic exposure for each subject. Given equivalent ergonomic exposures, the incidence of CTS for individuals with small canals could then be compared with the CTS incidence for individuals having larger canals.

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