

Externally Applied Forces to the Palm Increase Carpal Tunnel Pressure

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Change in carpal tunnel pressures that result from externally applied forces to the palm of the hand were assessed in five cadaveric specimens. MIKRO-TIP transducers were percutaneously placed into the carpal tunnel at the level of the hook of the hamate. A 1 kg force was applied to the palm of the hand in 16 separate locations. Significant elevations in carpal tunnel pressure were observed for external forces applied over the flexor retinaculum (103 mm Hg) and also for the hypothenar (37 mm Hg) and thenar (75 mm Hg) areas adjacent to the distal aspect of the carpal tunnel. These data demonstrate that the application of external forces on the palm of cadaver hands increases carpal tunnel pressure and the magnitude of the pressure change in the carpal tunnel depends on the location of the applied force. (*J Hand Surg* 1995;20A: 181-185.)

Carpal tunnel syndrome is the most common entrapment syndrome in the upper extremity. Although this disease has been studied extensively, its cause remains unknown. A strong correlation has been shown between carpal tunnel syndrome and work related activities. Work activities involving repetitive motion of the hand and wrist are thought to predispose to the development of carpal tunnel syndrome.¹ Furthermore, the incidence of carpal tunnel syndrome among employees correlates with the duration of employment.²

The authors have observed increased carpal tunnel pressures as a result of externally applied forces to the palm of the hand. Previous studies have documented increased carpal tunnel pressure resulting from externally applied pressure over the flexor retinaculum. Gelberman et al.,³ Lundborg et al.,⁴ and Szabo et al.⁵ have each demonstrated that externally applied pressure over the flexor retinaculum results

in an increase in carpal tunnel pressure. However, the authors are not aware of any investigations on the effect of external forces applied to the palm on carpal tunnel pressure. A better understanding of this phenomenon is required for proper interpretation of carpal tunnel pressure studies that incorporate a component of the external palmar forces, such as a tightly closed fist, and may be of benefit in preventive measures to minimize carpal tunnel pressures in the workplace through ergonomics.

The magnitude of carpal tunnel pressure change relative to the location and amount of an externally applied force on the palm of the hand has not been described and is the basis for this report.

Material and Methods

Five fresh, frozen and thawed cadaveric upper extremities were removed by above elbow amputation. The specimens were kept frozen until they were used. After thawing, the palm of each specimen was marked (Fig. 1). Pressures were measured with the MIKRO-TIP transducer system (SPR-524, Millar Instruments, Houston, TX). This system is a solid-state transducer in the tip of a 2.5F catheter.

The transducer catheter was placed in the palm by insertion of an angiocatheter at the level of the proximal wrist flexion crease and adjacent to the palmaris longus tendon. The catheter was directed

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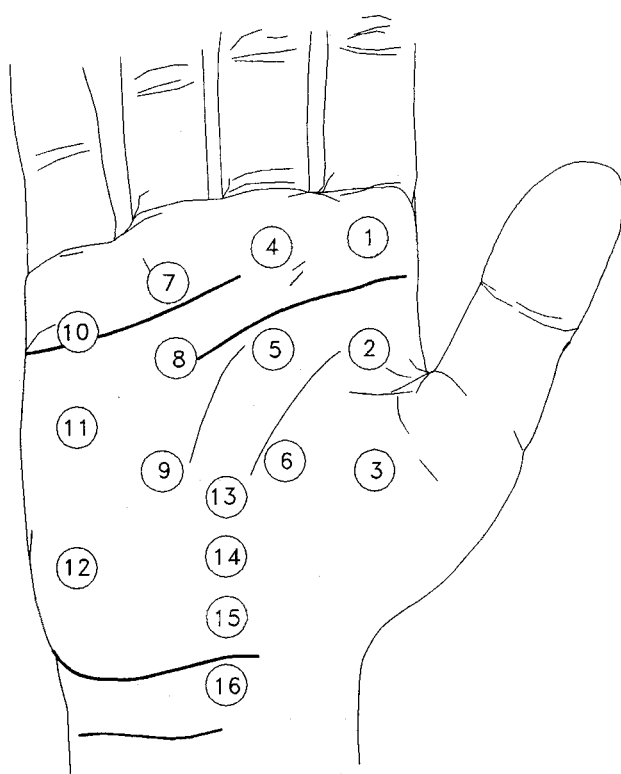


Figure 1. Sixteen locations where an external force (1 kg) was applied to the palm of the hand. Carpal tunnel pressures were recorded at the level of the hook of the hamate (near position 14). (By permission of Mayo Foundation.)

dorsally and distally at an angle of 45° until the proximal portion of the flexor retinaculum was penetrated. Penetration was identified by a marked increase in resistance followed by a pop and subsequent decrease in the resistance of catheter advancement. The catheter was advanced distally in the anterior aspect of the carpal canal next to the median nerve. The position of the hook of the hamate was marked by using topographic lines,⁶ and the length of the transducer catheter needed to reach the hook of the hamate was measured. The needle was removed from the angiocatheter and the transducer catheter was placed within the angiocatheter and advanced the specific length to the hook of the hamate. The angiocatheter was withdrawn, and the transducer catheter was secured in place by suturing it to the skin.

Force was applied to each of the numbered areas on the palm of the hand (Fig. 1) by means of a force dial (Wagner Instruments, Greenwich, CT) which applied 1 kg force to the palm in a palmar to dorsal direction at each of the specified locations.

The MIKRO-TIP transducer and the control unit (model TC-510) were assembled, calibrated, and set

at zero according to the manufacturer's specifications before placement. The system was attached through an analog to digital board to a computerized data-acquisition system. A conventional transducer system generated signals that served as event markers. A saline-filled syringe was attached to the transducer system. The conventional transducer was also hooked up through the analog to digital board of the computerized data-acquisition system. The tests were performed in a sequential manner with the head (5 mm diameter) of the force dial placed on each of the numbered locations of the palm of the hand (Fig. 1). The plunger of the syringe connected to the conventional system was withdrawn so that a negative reading was recorded by the data-acquisition center (event marker) before placement of positive pressure by the force dial. After depressing the syringe of the event marker, the head of the force dial was depressed onto the specific location of the palm in a palmar to dorsal direction until the force dial read 1 kg. This pressure was maintained for approximately 1.5 second and then released. The event marker was depressed and the force dial was applied to the next specified location. The sequence was continued until all specified areas on the palm of the hand had been tested. Repeated measures analysis of variance was used to determine differences in carpal tunnel pressures resulting from forces applied to various regions on the palm. The paired *t*-test tested for differences between the proximal palm and the distal palm.

Results

The average carpal tunnel pressure resulting from pressure on the palm was calculated from the five specimens (Fig. 2). Some degree of increase in carpal tunnel pressure was observed as a result of an externally applied force for all locations tested. After withdrawal of the external force on the palm, the carpal tunnel pressure returned to baseline in each instance. Externally applied pressures applied to the distal aspect of the palm (positions 1, 4, 7, and 10) had little effect on pressures in the carpal tunnel. A 1 kg force applied to the palm of the hand in the region of the metacarpal heads resulted in a total mean pressure of 6 mm Hg in the carpal tunnel. Higher levels were noted in specimen 3. This specimen had a total mean pressure of 18 mm Hg carpal tunnel pressure for the metacarpal region. Table 1 contains the mean, median, standard deviation, and standard error of the mean for the carpal tunnel pressures resulting from a force applied to each of the 16 positions.

Similar pressures were noted for the next more

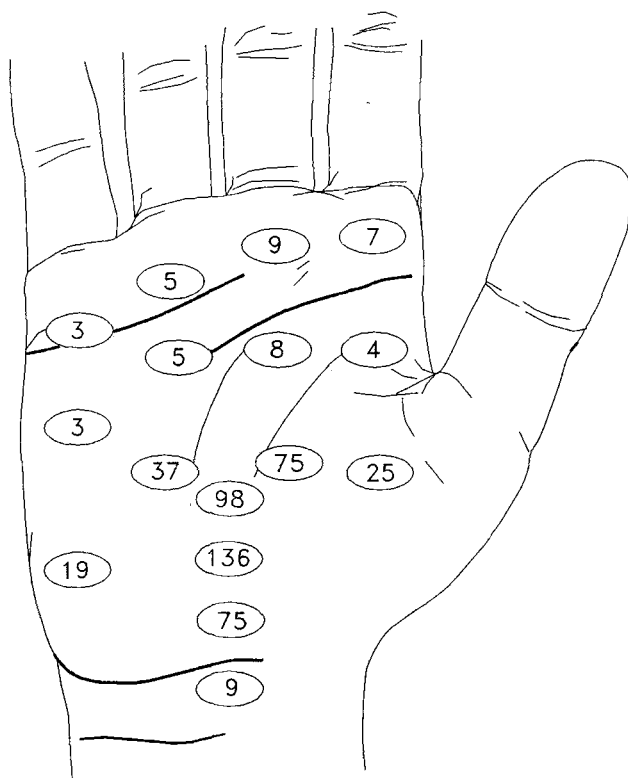


Figure 2. The mean carpal tunnel pressure in mm Hg at each location from an externally applied force to the palm for the five specimens. (By permission of Mayo Foundation.)

Table 1. Mean, Median, Standard Deviation, and Standard Error of the Mean for the Carpal Tunnel Pressures Resulting From a Force Applied to Each of the 16 Positions*

Position	Mean	Median	SD	SE
1	7.00	5	5.24	2.35
2	4.20	3	3.03	1.36
3	25.40	15	20.50	9.17
4	8.60	5	8.73	3.91
5	8.00	9	4.85	2.17
6	74.60	66	25.60	11.50
7	4.80	3	5.40	2.42
8	4.60	4	3.58	1.60
9	37.00	39	18.29	8.18
10	2.80	2	2.78	1.24
11	3.20	3	2.05	0.92
12	18.60	18	16.59	7.42
13	98.00	105	63.10	28.20
14	136.40	160	70.20	31.40
15	77.00	29	86.70	38.80
16	9.40	1	18.26	8.16

* N = 5 for all positions.
SD, standard deviation; SE, standard error of the mean.

proximal row (positions 2, 5, 8, and 11), that included the region of the palm over the metacarpal necks and distal to the thumb web space. The total mean carpal tunnel pressure for a 1 kg force applied to this region was 5 mm Hg. The range for this region was 0 to 14 mm Hg in the five specimens.

Intermediate pressures were noted for the proximal hypothenar area (positions 9 and 12). The total mean carpal tunnel pressure for a 1 kg force applied to this region was 28 mm Hg (range, 4 to 54 mm Hg). Pressure applied at position 9, just distal to the hook of the hamate, resulted in the highest mean carpal tunnel pressure for this region (mean, 37 mm Hg; range, 7 to 54 mm Hg).

The region of the thenar eminence (positions 3 and 6) resulted in higher carpal tunnel pressures than those of the hypothenar eminence, with a total mean carpal tunnel pressure of 50 mm Hg. The medial aspect of the base of the thenar eminence (position 6) yielded the highest pressure in the region, with a mean of 75 mm Hg (47 to 113 mm Hg).

The region over the flexor retinaculum in the central aspect of the proximal region of the hand had the greatest effect on the carpal tunnel pressures (positions 13, 14, and 15). The resulting total mean carpal tunnel pressure for a 1 kg force applied to this region was 103 mm Hg (mean, 1 to 226 mm Hg). The highest pressures were generated by pressure applied in the midline of the palm adjacent to the hook of the hamate at position 14 (mean, 136 mm Hg; range, 60 to 226 mm Hg).

Repeated pressure analysis of variance demonstrated that the carpal tunnel pressures were higher for forces applied to positions 13 and 14 than for other regions ($p < .05$). Position 13 had higher carpal tunnel pressures compared to other positions, except for positions 15 and 16, which were not significantly different from position 13 ($p < .05$). The

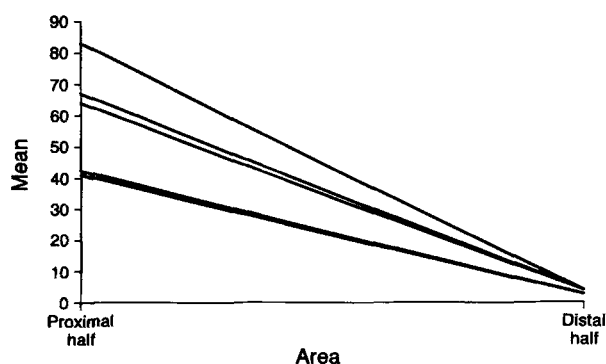


Figure 3. Distribution of the mean differences in carpal tunnel pressure resulting from a palmar force for each of the five specimens. Note that the proximal half of the palm has consistently higher differences in pressure.

paired *t*-test demonstrated significantly higher carpal tunnel pressures for the proximal aspect of the palm (including positions 3, 6, 9, 12, 13, 14, 15, and 16) compared to the distal aspect of the palm (including positions 1, 2, 4, 5, 7, 8, and 10) ($p = .002$). Since position 11 is on the border of the proximal and distal aspect of the palm, the test was performed with position 11 on both sides without a change in significance (Fig. 3).

Discussion

This study showed that an externally applied force to the proximal aspect of the hand results in significantly increased carpal tunnel pressures. Gelberman et al.⁷ found the average intracarpal canal tissue pressure for patients with carpal tunnel syndrome was 32 mm Hg. With this value as a reference, significant mean pressures were observed at position 9 (mean, 28 mm Hg), just distal to the hook of the hamate; position 6 (mean, 50 mm Hg), the medial aspect of the base of the thenar eminence; position 13 (mean, 98 mm Hg), distal aspect of the aponeurotic portion⁸ of the flexor retinaculum; position 14 (mean, 136 mm Hg), adjacent to the hook of the hamate; and position 15 (mean, 75 mm Hg), roughly at the junction of the proximal and central portions of the flexor retinaculum. The findings are consistent with those of earlier studies^{4,5} that examined carpal tunnel pressures. These authors found that increased pressures (ranging from 30 to 90 mm Hg) caused dysfunction of the median nerve, including numbness and tingling within 15 minutes and complete sensory block⁷ after 30 minutes of sustained pressure. The response of the median nerve to sustained pressure is a function of both time and pressure. Sensory response decreased rapidly and disappeared totally at 60 mm Hg, whereas nerves exposed to 30 mm Hg responded more slowly and with a less complete response.⁷ The exact position of pressure measurement relative to the hamate hook was not described in these studies. The authors are not aware of any studies that have evaluated the effect of intermittent pressure on the median nerve. Although pressures measured in the carpal tunnel in our study are within the range of those found to induce symptoms of carpal tunnel syndrome, such a mechanism of pressure induction would be of short duration and the clinical significance has not been established. The additive effect of numerous short-lived elevations in carpal tunnel pressure, as expected in many work environments, may contribute to the development of carpal tunnel syndrome and should be evaluated *in vivo*.

Significant increases in pressure at positions 6 and 9 are not explained by direct effects on the carpal

tunnel because these positions are located radial and ulnar to the carpal tunnel, respectively. It is likely that pressure on the thenar and hypothenar muscles, that contribute to the distal portion of the flexor retinaculum,⁸ results in stretch on this structure and increases in pressure within the canal. A second likely cause for increased pressures in the carpal tunnel as a result of externally applied pressure over positions 6 and 9 is the distribution of pressure through compartmental anatomy, including the flexor tendon sheaths. Forces applied at these positions may exert their effect through the bursal connections, as described by Parona.⁹ A third likely cause is simple soft tissue compression effects, which are transmitted to adjacent tissues. This phenomenon was described by Guyton¹⁰ and Guyton et al.¹¹ in their early studies of tissue pressure. They used a blood pressure cuff to exert a mechanical force, resulting in increases in both solid and fluid pressures. This phenomenon has also been observed by the present authors in the laboratory. Externally applied pressure over a catheter in a muscular compartment results in pressure increase. The amount of pressure increase recorded by the catheter is a function of the distance of the catheter from the externally applied pressure and the tissue through which the pressure is transmitted. The concentric distribution of pressures observed in this study is consistent with this type of phenomenon. The highest pressures recorded were those directly over the catheter tip (position 14 in Fig. 1), and they decreased as a function of the distance away from the catheter.

The findings in this study have helped the present authors explain some of the findings of other pressure studies in which unexplainably high pressures were measured within the canal when a component of external pressure at the base of the hand was included as a portion of the variable assessed. An example of this is pressures measured within the carpal canal as the result of flexion of the fingers. As the fingers are brought into tight flexion, the force of the fingertips on the base of the hand has a profound effect on pressures measured in the canal with active grip.

These findings are also of clinical importance for the purpose of tool design. Alterations in median nerve conduction in humans, which imitate the first stages of carpal tunnel syndrome, have been shown to occur at a pressure of 30 mm Hg.⁴ Nerve dysfunction and decrease of intraneural^{12,13} blood flow as a result of increased pressure have been shown to occur in animal models at 30 mm Hg.¹⁴⁻¹⁶ Therefore, median nerve dysfunction occurs with pressures at or less than those recorded in our study for a 1 kg force applied in positions 6, 9, 13, 14, and 15. Fur-

thermore, the amount of force exerted in the palm of the hand with stressful labor is considerably greater than the 1 kg force used in this study. Therefore, tool grip design should include characteristics that would allow externally applied forces to the palm to be minimized in these regions. Specifically designed gloves may also allow distribution of forces away from these sensitive areas.

The duration of pressure increase has been shown to be an important factor in determining the pathologic effect¹⁵ and the recovery of nerve function.¹⁷ The chronic effects of intermittent pressure increases as might be seen during prolonged repetitive activities have not been investigated but could theoretically contribute to carpal tunnel syndrome. Therefore, preventive measures such as specially designed gloves may prove beneficial in preventing work-related carpal tunnel syndrome.

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