

# A Study of Carpal Tunnel Injury Following Electrical Trauma

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**Abstract -- Carpal Tunnel Syndrome (CTS) is sometimes diagnosed post electrical injury. Unfortunately, there is no clear causal connection between electric shock and the electro-diagnostic indications of CTS. One might thus infer that the electro-diagnostic appearance of signal slowing through the carpal tunnel is indicative of electrical injury to the median nerve as opposed to the mechanical compression as expected in CTS. This hypothesis is evaluated based on an analysis using parametric data for human tissues for ten hand-to-hand electrical contacts.**

## INTRODUCTION

Symptoms following a low ampere electric shock are diverse and often unpredictable [2,4,7,8,10,11,12,14,15,16]. Tissue injury (separate from ventricular fibrillation) is rare and tends to be limited to minor burns at the electrical entry and exit points (where current density is usually highest.) A minority of cases however, exhibit possible low level internal tissue damage along the presumed current path. It is suggested here that this low level damage may be masked by symptomatology that can misdirect the diagnostician in his work.

The traditional theory is that post-shock damage to the body depends mainly on three factors: 1) the pathway and resistance of the tissues traversed by the current, 2) the heat generated by the current and, 3) the duration of the electrical contact [8]. An additional theory suggests that the electric field associated with the current may act on the cell membranes causing cellular atrophy. The greatest injury from an electric field would be anticipated to occur in nerve and muscle cells. [9]

Carpal tunnel syndrome post-electric injury has been reported in case studies done on

individuals receiving electric shocks even when minimal observable tissue damage was noted directly following the electrical incident. [10, 12] In evaluating 10 hand-to-hand electric shock cases with minimal gross tissue damage, three cases showed diagnostic indications of Carpal Tunnel Syndrome. In those three cases, the results of the release surgery proved less than adequate.[10]

The hypothesis is that the current density or charge exposure to the median nerve in the region of the carpal tunnel can exceed the threshold required to cause neural damage even when the source current is not high enough to cause more obvious tissue damage. The damage is presumed to be localized to the carpal tunnel due to the reduction in conductive tissue in the region of the wrist. Localized nerve damage could result from the increased current density.

## CALCULATIONS

The amount of current to which each of the tissues in the wrist is exposed during an electric shock can be reasonably estimated by a piecewise application of the very simple *Current Divider Rule* to individual sections perpendicular to the pathway of electric current. (NOTE: This simple approach ignores capacitive effects in the tissues.)

The cross-sectional area of each tissue type, and the parametric resistivity of each tissue type is first determined. The current delivered by the electrical source must be known. It is then assumed that all electrical pathways in the section are of approximately the same length, and are parallel. (This is a reasonable assumption for a limb but would break down with a larger section such as the torso.)

The *Divider Rule*, and is stated as follows:

$$R_{eq} = 1/(1/R_1 + 1/R_2 + 1/R_3 + \dots + 1/R_n)$$

$$I_i = I_{total} (R_{eq} / R_i)$$

WHERE:  $R_{eq}$  = The equivalent resistance of all pathways taken in parallel

$I_{total}$  = The current introduced from the electrical source

$I_i$  = The current flowing in the  $i^{th}$  pathway (The sum of the currents flowing in all pathways would equal  $I_{total}$ )

$R_i$  = The resistance in the  $i^{th}$  pathway

$n$  = The total number of pathways.

When considering the characteristics of the tissue in any homogenous pathway  $i$ , the resistance ( $R_i$ ) is defined as:

$$R_i = \rho_i l_i / A_i$$

$\rho_i$  = The resistivity for the tissue in pathway  $i$

$l_i$  = The length of pathway  $i$

$A_i$  = The cross-sectional area of pathway  $i$

Table 1 contains values of resistivity ( $\rho$ ) for tissues of the human body. Other than liquids such as blood and urine, nerves have the lowest electrical resistivity [1,5,6].

<b>MATERIAL</b>	<b>RESISTIVITY</b>
Blood	1.6
Nerve	2.5
Skeletal Muscle	7.0
Bone	160
Fat	27

**Table 1. Resistivity of Biological Materials.**

For this analysis,  $n$  paths are developed with each path describing one type of homogenous tissue. The resistance for any path ( $i$ ) at any cross-section is normalized by unit length and is described by  $(R/l)_i$ . Finally, the percent of current distributed to each pathway  $i$  is calculated by an application of the *Current Divider Rule*.

## RESULTS

The calculations as described above were applied to a mid-carpal cross-section. The estimated cross-sectional areas for each tissue type and the associated calculation of resistances per unit length are summarized below. **I%** was calculated for each different tissue type and is then broken out separately for the Median Nerve.

<b>Tissue Type</b>	<b>--- Area ---</b>		<b>--Resistance--</b>	
	<b>%</b>	<b>mm</b>	<b>(R/L)<sub>i</sub></b>	<b>I%</b>
Blood	1.2%	34.2	46,749	14.2
Bone	32.1	899.9	177,797	3.7
Fatty	42.8	1197.0	22,557	29.5
Ligaments	3.6	100.7	198,574	3.3
Muscles	14.8	415.0	16,866	39.4
Nerve	0.7	20.8	120,438	5.5
(Median N.	.47	13.2	189,393	3.3)
Tendon	4.8	132.4	151,045	4.4
<b>R<sub>eq</sub></b>	<b>100%</b>	<b>2800</b>	<b>6640</b>	<b>100</b>

(5)

**Table 2. Cross Sectional Areas and Resistance per unit Length of the Mid-Carpus.**

This analysis yielded the result that 3.3% of the current in the electrical injury modeled passes through the median nerve at the point of the mid-carpal tunnel. The exposure received by the median nerve for each of the ten cases studied was calculated and is presented in Table 3.

<b>Subject</b>	<b>I<sub>total</sub> (A)</b>	<b>Duration (seconds)</b>	<b>I<sub>median n.</sub> (mA)</b>	<b>Expo. (mA-s)</b>
<b>A *</b>	<b>1.1</b>	<b>0.4</b>	<b>36.4</b>	<b>14.6</b>
B	0.02	0.3	0.7	0.2
<b>C *</b>	<b>1.5</b>	<b>0.02</b>	<b>49.6</b>	<b>1.0</b>
<b>D *</b>	<b>2.4</b>	<b>0.3</b>	<b>79.4</b>	<b>23.8</b>
E	0.6	30.0	19.9	595.5
F	2.2	0.5	72.8	36.4
G	0.6	0.3	19.9	6.0
H	0.6	60.0	19.9	1,191.0
I	2.0	0.1	66.2	6.6
J	0.6	1.0	19.9	19.9

**Table 3. Source Current, Current through Median Nerve, Shock Duration, Charge Exposure (\* Denotes those subjects who were diagnosed with Carpal Tunnel Syndrome.)**

## DISCUSSION AND CONCLUSIONS

In the ten hand-to-hand electrical injuries reviewed, the current flow calculation for the Median nerve, based on source current estimation, ranged from a low of 24 ma to a high of 100 ma. The three individuals who were diagnosed with Carpal Tunnel Syndrome were subjected to median nerve currents estimated at 44 ma, 60 ma. and 100 ma. However, two individuals not affected by Carpal Tunnel

Syndrome were also subjected to similarly high median nerve currents (82 ma. and 90 ma.)

It has been reported that a current of 40 ma for 3 mm of nerve diameter applied for a duration of 5 seconds is sufficient to cause lasting disorders in function and structure in peripheral nerves of cats[15]. For the three individuals diagnosed with Carpal Tunnel Syndrome, none had a total charge exposure exceeding the level observed in that study. However, all three individuals were exposed to currents in excess of those specified to be dangerous. Shock duration was brief in each injured individual thus limiting overall charge exposure. In the converse, two other individuals who were subjected to lower current density, longer duration shocks causing charge exposure far in excess of that suggested to cause injury showed no diagnostic evidence indicating CTS.

Worth noting is that of five individuals exposed to median nerve currents of 35 ma or higher, three were diagnosed with CTS. These numbers clearly raise some flags when considered from a practical perspective but do not firmly indicate that the diagnostically observed Carpal Tunnel Syndrome is the result of electrical injury.

The variability and diversity of the human machine make it difficult to develop decisive heuristics regarding the correlation between electric shock and post-shock CTS. Still, the numbers suggest a real possibility of low level median nerve damage in the Carpal tunnel following an electric shock injury when the source current is estimated to exceed 1 ampere even if shock duration is known to be brief.

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