Normal and radiculopathic cutaneous pain tolerance levels evaluated by heat-beam dolorimetry

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✔ The heat-beam dolorimeter has previously been used to obtain cutaneous pain tolerance measures in normal volunteers and patients with chronic pain. In the present study, normal reference data were collected at two stimulus intensities for 24 volunteers, and the stimulus-effect relationship (decreasing tolerance latency with increasing stimulus intensity) was found significant (p < 0.001) for all body sites tested. No overall sex differences were found; males behaved slightly more stoically than females, with differences significant only at the T_3 site over the breasts. At the second evaluation at the higher stimulus intensity, females exhibited lower pain tolerance (greater pain sensitivity) at the right breast than males (p < 0.05). No significant lateral asymmetry was found in cutaneous pain tolerance except at the dorsum of the hand: the right hand evinced elevated pain tolerance compared with the left hand in both right- and left-handed subjects. Eight radiculopathic pain patients with clinically involved left L_5 nerve roots were evaluated and their responses were compared with the volunteer normal reference data. The radiculopathic group evinced elevated tolerance levels in both the radiculopathic dermatome and noninvolved sites compared with normal individuals (p < 0.05).

KEY WORDS • dolorimetry • pain tolerance • radiculopathy • intervertebral disc

I T has previously been shown that patients with chronic pain exhibit higher cutaneous thermal pain tolerance latencies than normal volunteers, and that this elevation of tolerance is lost when the patients are relieved of their pain.[8] This earlier study utilized a heterogeneous group of patients whose pain arose from diverse etiologies, including radiculopathy, trigeminal neuralgia, reflex sympathetic dystrophy, brachial plexus avulsion, and metastatic cancer. Pain amenable to neurosurgical resolution was the only common factor among these patients who otherwise suffered conditions presenting with varied sensory involvement. In previous work on radiculopathy patients, we had anecdotally observed that the clinically involved dermatome, presenting with dysesthesia and paresthesia, gave measurably longer tolerance latencies than other sites, and we did not therefore include data from clinically involved dermatomes in that analysis. Our conclusions were therefore generalized to the response of the individual rather than the site of nerve entrapment or root compression.

The present study sought to compare responses from normal volunteers and radiculopathic patients on a site-by-site basis and, as a corollary, to establish the normal reference parameters (including prior experience, site sensitivity, sex, handedness, and stimulus intensity) which are responsible for the control response of healthy volunteers in this test. We hypothesized that the tolerance latency of the sensorially impaired clinically involved dermatome of radiculopathy patients would differ from that of the sensorially intact dermatomes of both these pain patients and normal volunteers. We further hypothesized that these data might have diagnostic utility in the clinical examination of patients with this disease.

Clinical Material and Methods

Subjects

Twenty-four normal pain-free volunteers and eight patients with acute radiculopathy, suffering "significant" pain by self-report category scales, were examined in these studies. Volunteers were recruited from among the investigators, their colleagues, and students. Eight were male, 16 were female; the mean age (± standard deviation) of the group was 31 ± 9 years (range 19 to 55 years). Three were left-handed. Eight acute radiculopathy patients with involvement of the left L_5 der-

matomes were selected; five of these patients were male and three were female. The group had a mean age of 51 ± 15 years (range 30 to 65 years). None had taken pain medication for 24 hours prior to the test after admission to the Clinical Research Center.

Heat-Beam Dolorimetry

The heat-beam dolorimeter has been described previously,[8] together with its present application for measurement of cutaneous pain tolerance levels rather than pain threshold. The device directs a beam of white light and heat at a 1-sq cm cutaneous target positioned 5 cm from the heat source. Prior to its use in the present study, the dolorimeter was calibrated by positioning the lamp 5 cm above a 1-sq cm opening in an air-filled calorimeter formed of a totally internal reflective Dewar flask with a sensitive thermocouple embedded in a "black body" at its base. The black body was coated with the same matte-black paint used to coat the skin of test subjects (see below). At various power settings, the device was then calibrated in terms of heat output per second in the range of 0 to 20 seconds, which is the maximum operating time for a clinical estimation. Heat delivery was found to be uniformly constant within this time and proportional to the power setting of the lamp. On this basis, two power settings were selected for the present studies which corresponded to 15.33 and 75 $mW \times cm^{-2} \times sec^{-1}$ of heat power received by the calorimeter. To additionally describe these intensities in more familiar terms: the lower stimulus intensity raises the temperature of a 0.35-cc mineral oil bath by $0.67°F/sec$; the higher stimulus intensity raises it by $1.06°F/sec$. The measurements and their recording were made in each case by a male (J.J.L.) and a female (P.L.L.) investigator, who were together in the temperature-controlled examining room with the subject at all times during the test.

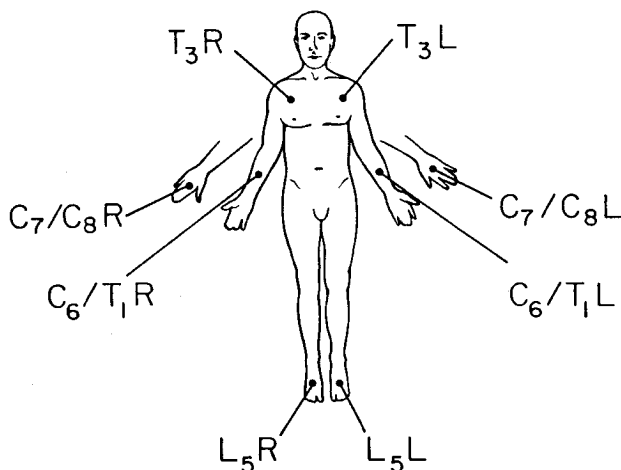In use, the heat-beam dolorimeter was directed at

nonreflective black discs of paint applied to various dermatomal loci on the skin of the subject. The sites evaluated in the present study are illustrated in Fig. 1. The subject was advised that "You will at first feel warmth, then heat, and then you will feel pain. We want to measure the maximum amount of pain that you can stand, and you should not move or respond until you feel that the pain is intolerable." The patient was further advised that "We will test each site that we have painted in turn and we will go around your body several times. We cannot tell you in advance how many times we will need to do this and we ask that you be patient." The purpose of the latter enjoinder was to avoid anticipatory changes in set that might be engendered by the subject believing or knowing that the final test sequence had commenced. When the individual responds, a photocell detects movement of the subject, disengages the beam, and reports the stimulus time (latency) to effect (pain tolerance latency) in hundredths of a second. Each site around the body was evaluated in turn a total of five times during any one session. The first exposure at each site served to sensitize the skin and acted as a training experience for the subsequent four exposures during the same session. The latencies of these subsequent four exposures, obtained from each site at intervals of approximately 2 minutes, were recorded and entered into a dedicated microcomputer-based data management program (written in dBASE III Plus).

The 24 normal volunteers were tested at the two stimulus intensities during studies conducted 1 year apart to minimize learning effects. In the first study, the 24 subjects were evaluated at the higher intensity ($75 \ mW \times cm^{-2} \times sec^{-1}$) on two occasions (first and second evaluations) 14 to 21 days apart. The second study, conducted 12 months later, involved 17 of the same subjects entered into the first study joined by seven additional subjects (24 total). The lower stimulus intensity of $15.33 \ mW \times cm^{-2} \times sec^{-1}$ was then used, also in two evaluations (first and second evaluations) 14 to 21 days apart.

In addition to the above normal volunteers, 14 acute radiculopathy patients suffering lumbar pain and sensory changes in the lower extremities were evaluated by heat-beam dolorimetry. The higher intensity of 75 mW $\times cm^{-2} \times sec^{-1}$ was used in this evaluation during the standard diagnostic workup leading to the diagnosis of prolapsed intervertebral disc, on which diagnostic basis these patients were selected. Following surgical treatment for relief of their pain, the patients were again tested after an interval of 21 to 25 days. Only those eight patients whose left L_5 root was clinically involved are described in this report.

Statistical Analysis

Analysis of variance (ANOVA) was used to detect interactions, and Student's unpaired t-test was used to compare unpaired groups. Correlations were computed by the linear least-squares method.

FIG. 1. Cutaneous dolorimetric test sites evaluated in the present study.

Results

Normal Reference Data

Analysis of variance was conducted on the interaction between site, stimulus intensity, and sex, which revealed a significant difference between the pain tolerance latencies at different sites of the body ($p < 0.01$). Table 1 gives the 95% confidence limits of the normal mean latency responses of volunteers' initial tests at the two stimulus intensities. Overall, tolerance latencies were dependent on stimulus intensity (ANOVA $p = 0.0006$), and there was no overall sex difference (ANOVA $p = 0.8427$). The difference in tolerance latency at the two stimulus intensities was significant for all body sites tested ($p < 0.01$, Student's paired t-test). Assuming a linear function (which may not be the case), the slope relationship differs slightly between the different sites (in mW × cm^{-2}: $C_6/T_1L = 0.027$; $C_6/T_1R = 0.027$; $C_7C_8L = 0.016$; $C_7C_8R = 0.043$; $T_3L = 0.039$; $T_3R = 0.049$; $L_5L = 0.044$; and $L_5R = 0.037$). Normal tolerance latencies were lower in naïve volunteers (first evaluation) than when these individuals were retested 14 to 21 days later (second evaluation), and this phenomenon occurred at both stimulus intensities. This increase in tolerance latency due to retesting alone was significant at all sites except L_5 (Fig. 2). The lateral variation in latencies exhibited by our volunteers were negligible at either stimulus intensity ($p > 0.05$), with the exception of the C_7/C_8 site on the dorsum of the

hand ($p < 0.001$, Fig. 2). The right hand was found to have uniformly greater tolerance than the left. To determine whether such lateral asymmetry was a function of handedness, we examined the cutaneous pain tolerance profile of left- and right-handed individuals separately. It can be seen from Fig. 3 that nominally left-handed individuals (that is, those who were left-handed for handwriting) exhibited the same right-handed elevation of pain tolerance as do nominally right-handed individuals. The difference between left and right hand was, however; appreciable ($p < 0.001$) only at the lower stimulus intensity of 15.33 mW × cm^{-2} × sec^{-1}.

We were surprised that an ANOVA had revealed no overall interaction between sex and site, and therefore sought to examine these data on a site-by-site basis (Fig. 4). Clearly, males appeared uniformly more stoical in their mean tolerance latency than females. This difference was not significant and the only site and test where this was appreciable was at the second evaluation conducted at the higher intensity (75 mW × cm^{-2} × sec^{-1}). Under these conditions, the T_3 sites of females were found to be significantly more sensitive to pain than in males, particularly on the right ($p < 0.05$). No association could be found between the females' pain tolerance level and menstrual cycle phase (ANOVA $p > 0.05$), due perhaps to the small number tested. Of the 16 females tested, equal numbers of the total (24) were in the 1st, 2nd, 3rd, and 4th weeks of their cycle.

Effect of Acute Radiculopathy Syndrome on Tolerance

The tolerance latencies of the eight acute radiculopathy syndrome patients with left L_5 clinical involvement were examined and compared with data from normal volunteers. Figure 5 illustrates these comparisons. Before surgery (while in pain) the tolerance laten-
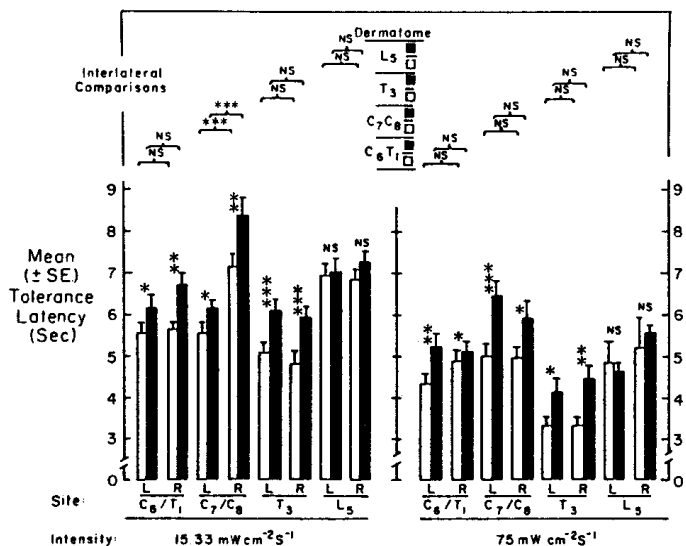

FIG. 2. Tolerance latencies obtained at the first (open columns) and second (black columns) evaluations from 24 normal volunteers at two stimulus intensities: 15.33 (left) and 75 (right) mW × cm^{-2} × sec^{-1}. Statistical comparisons shown in the body of the figure (lower) are between first and second evaluation latencies. These show significant increase in tolerance latency at the second evaluation at all sites except L_5. The interlateral (left-to-right) differences (upper) are not significant at any site at either first or second evaluation except C_7/C_8 measured at the lower stimulus intensity. Significance assessed by Student's unpaired t-test: * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$; NS (not significant) = $p > 0.05$. S.E. = standard error of the mean.

TABLE 1

Mean tolerance latencies and 95% confidence limits of initial tests in normal volunteers at two stimulus intensities

| Intensity	Stimulation Site	Mean Latency (sec)	95% Confidence Limits	
			Lower (sec)	Upper (sec)
15.33 mW · cm^{-2} · sec^{-1}	C_6T_1L	5.96	5.36	6.55
	C_6T_1R	6.09	5.56	6.61
	C_7C_8L	6.00	5.44	6.56
	C_7C_8R	7.48	6.87	8.09
	T_3L	5.57	4.96	6.17
	T_3R	5.30	4.73	5.87
	L_5L	7.35	6.72	7.99
	L_5R	7.25	6.56	7.94
75 mW · cm^{-2} · sec^{-1}	C_6T_1L	4.31	3.85	4.78
	C_6T_1R	4.45	3.89	5.01
	C_7C_8L	4.99	4.33	5.64
	C_7C_8R	4.89	4.32	5.46
	T_3L	3.25	2.78	3.71
	T_3R	3.25	2.84	3.66
	L_5L	4.72	3.54	5.90
	L_5R	5.01	3.35	6.66
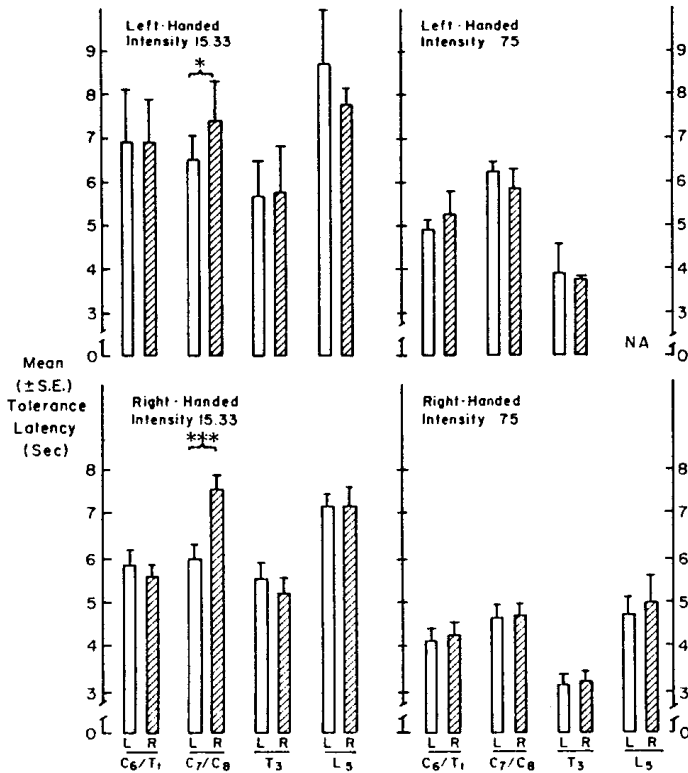
FIG. 3. Heat-beam dolorimetry cutaneous tolerance latencies of left-handed *(upper)* and right-handed *(lower)* normal volunteers at two stimulus intensities: 15.33 *(left)* and 75 *(right)* mW × cm^{-2} × sec^{-1}. Significance assessed by Student's t-test for paired data: * = p < 0.05; *** = p < 0.001; NA = data insufficient; S.E. = standard error of the mean.

FIG. 4. The tolerance latencies obtained at the first *(left)* and second *(right)* evaluations for eight males *(cross-hatched columns)* and 16 females *(open columns)* in the normal volunteer group at two stimulus intensities: 75 *(upper)* and 15.33 *(lower)* mW × cm^{-2} × sec^{-1}. * = p < 0.05 by Student's unpaired t-test. The left and right sides are shown separately for each dermatome. S.E. = standard error of the mean.

cies of patients with acute radiculopathy syndrome were globally greater than those of normal volunteers (p < 0.05). By far the largest tolerance latency measured was found at the clinically involved dermatome, although the interlateral (left-to-right) symmetry observed in normal volunteers at L_5 (see Table 1) was not lost. Thus, both the clinically involved dermatome and the contralateral L_5R site latencies were elevated over normal levels in presurgical acute radiculopathy syndrome patients with an L_5L clinically involved dermatome, and there was no statistically significant difference between responses at these L_5 sites (p > 0.05).

Following surgery and relief of the acute radiculopathy syndrome patients' pain, a marginal decrease was noted in the L_5L clinically involved dermatome tolerance latency (p > 0.05), and this was accompanied by a significant global decrease (p < 0.05) in latencies measured over the remaining body sites. The latencies at these sites, which had previously been significantly elevated over those of normal controls, were indistinguishable from the latter at postsurgical (second evaluation) testing (p > 0.05, unpaired t-test).

Discussion

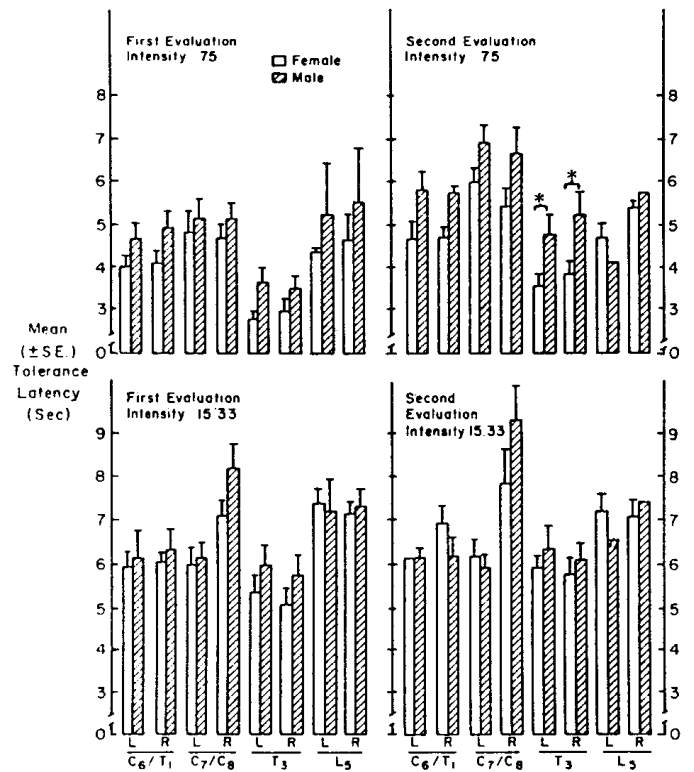To a certain extent, the perception of both pain threshold and pain tolerance is probably a mixed indicator of sensory and psychological factors. The patient's mind set and the setting for the tests are clearly relevant to the interpretation of perception, as (we have suggested) is the presence or absence of an interfering pain. The construct that is "pain perception" is not readily separated into its component elements.[8]

To the extent that our experimental design permits, however, these measurements were made in patients with radiculopathic pain before and after their relief of pain. That is, the presence or absence of pain was the feature identifying the two "mental and physical states" in which measurements were made. Inevitably, such changes in condition incorporate inherent changes in set, in anxiety and anticipation, yet these cannot readily be controlled. We feel, therefore, that by limiting our conclusions to the highest cognitive level of explanation (that of the perception of pain tolerance) we incorporate in our explanation all of the (possibly different) psychological features which attend the two states and characterize them.

Although a type of heat-beam dolorimeter was used in the pioneering work of Hardy, *et al.*,[7] for estimation of regional cutaneous pain threshold, we believe that the present study provides the first survey of normal cutaneous thermal tolerance levels in humans. Hardy, *et al.*, found the pain threshold to be approximately uniform over the cutaneous integument, in contrast to

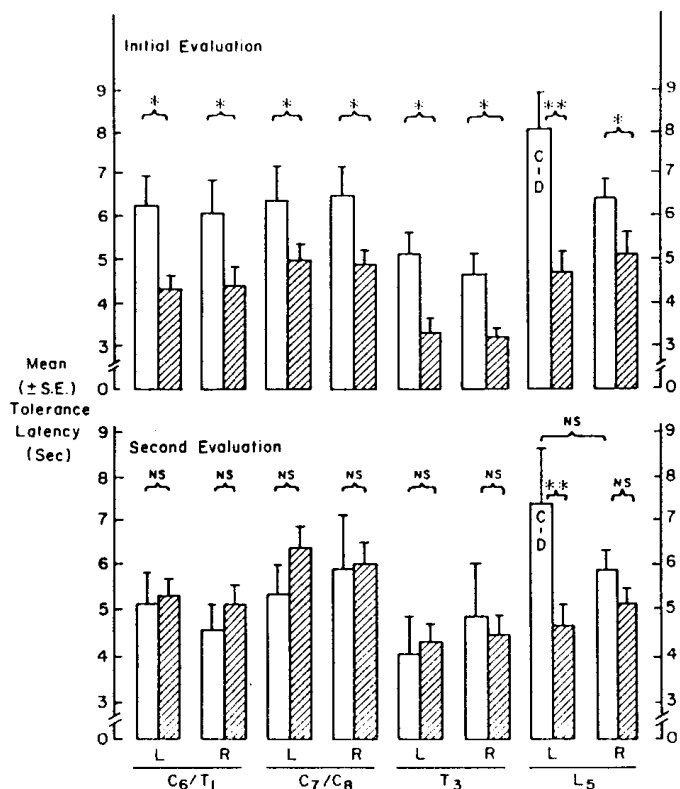# Normal and radiculopathic cutaneous pain tolerance levels

Fig. 5. The tolerance latencies of patients with left L_5 radiculopathy *(open columns)* and of volunteers *(cross-hatched columns)* at the first evaluation (presurgery for patients) *(upper)* and at the second evaluation (postsurgery for patients) *(lower)*. The clinically involved dermatome (CID) is indicated. Stimulus intensity was 75 mW $\times$ cm^{-2} $\times$ sec^{-1}. Significance assessed by Student's t-test for paired data to compare intersite differences and for unpaired data to compare patients with volunteers: NS (not significant) = p > 0.05; * = p < 0.05; ** = p < 0.01; S.E. = standard error of the mean.

the tolerance measurements presented here (Table 1), and found no difference between males and females. Examination of our Fig. 4 reveals that the sex difference in pain tolerance did not manifest in a simple manner; it was present to an appreciable degree only at the higher stimulus intensity when tolerance limits were relatively low and was only significant (p < 0.05) when amplified by the greater stoicism of males evident on retesting (second evaluation) and then only at the T_3 (breast) sites. We cannot escape the conclusion that the difference is due, therefore, to the sexual dimorphism of this one site and its reduced ability in the female to increase in tolerance latency to quite the same extent as in males when retested. Although Fig. 4 reveals a qualitatively similar separation in T_3 response latencies when naïve males and females were tested for the first time, this did not reach statistical significance in our sample.

Table 1 reveals that the T_3 sites (unselected for sex) were generally and significantly more sensitive than other sites at this higher stimulus intensity but not at the lower stimulus intensity. The literature reveals very

little objective evidence regarding gender difference in cutaneous sensory acuity or pain perception. Vibratory sensibility is known to differ between the sexes,[5] and Nathan and Rice[9] have shown that intense heat-beam stimuli (such as the present) are localized with the same acuity as are tactile stimuli. It is possible, therefore, that the gender difference arises in central processing of spinal anterolateral or lemniscal fiber systems. The present study would suggest that a significant adaptation effect contingent on prior stimulation is involved in such central processing. The "relative stoicism" or "relative tolerance" of body sites in relation to other sites would appear to be generally dependent on the stimulus intensity used to elicit the reaction (Table 1 and Fig. 5). This is suggestive of a truncation in the intensity-tolerance relationship at different body sites, which we venture to propose is a reflection of the different pain sensitivity ranges of different body areas: some areas hurt more (have lower tolerance) than others, with little or no change in basal sensory thermal discriminability.[1] The present assay system does not allow us to describe the psychophysics of this differential sensibility in absolute terms. Our use of two known stimulus intensities, however, does enable us to make a relative comparison when these are applied to the same body sites under identical conditions. An exact description of the psychophysical relationship would require that the thermal energy received by the sensory nerve endings of the receptive field be known precisely. As discussed by Hardy and Stolwijk,[6] this is not simply related to skin temperature but is a complex function of the tissue density, thermal conductivity, tissue specific heat, blood flow, "temperature diffusivity," and the three-dimensional geometry of the skin's neuronal investment. Beyond the scope of this present investigation, we have begun these studies in a porcine experimental model and our data will form the basis of a future report.

We have previously reported the finding of increased pain tolerance latency on retesting in a similar group of 27 normal volunteers[8] evaluated at a stimulus intensity of 75 mW $\times$ cm^{-2} $\times$ sec^{-1}. The present study extends these findings to the lower stimulus intensity of 15.33 mW $\times$ cm^{-2} $\times$ sec^{-1} with the expected difference that the extent of change (increase) measured at the second estimation differs for different body sites (Fig. 2). Thus, we find that the small C_7/C_8 asymmetry observed at the higher stimulus intensity is amplified when this test is conducted at the lower stimulus intensity.

We are uncertain how to interpret our findings with regard to this C_7/C_8 asymmetry. Our initial hypothesis, that it arises as a consequence of handedness, was disproved by the finding that right dominance extends to nominally right- and left-handed subjects alike (Fig. 3). We remain, therefore, with the conclusion that right dominance for pain tolerance at the dorsum of the hand represents an absolute not found at other extremities in this population of volunteers. Hardy, *et al.*,[7] did

not investigate interlateral differences of pain threshold, and the vibratory sense (which perceptually may bear some relationship to gender as might our heat-beam tolerance measure) shows no lateral asymmetry at the fingertips.[10]

Our studies in radiculopathic patients provide some intriguing findings and conclusions. We initially hypothesized that the sensorially impaired clinically involved dermatome would exhibit higher than normal tolerance latencies and this was indeed the case. It is quite clear, however, that the tolerance latencies of nonradiculopathic zones in these pain patients (Fig. 5) were also significantly elevated. This finding is consistent with our earlier report[8] that pain tolerance latencies of a heterogeneous group of pain patients were elevated above normal while they were in pain and that these latencies were indistinguishable from second-evaluation latencies of normal volunteers after relief of their pain. In the present study, we had hoped to find that the ratio of the tolerance latency of the clinically involved dermatome to the contralateral site (in this case, L_5 left: L_5 right) would diagnostically reveal the extent of sensory deficit of the clinically involved dermatome (each patient serving as his own control). Clearly, this does not occur in any simple manner, due to the pain tolerance-elevating effect of the coexistent endogenous radiculopathic pain on the nonclinically involved "L_5 right" (and other) sites. Nevertheless, the group increase in clinically involved dermatome tolerance latency is clearly more abnormal than that of noninvolved dermatomes, and it is possible that examination of a larger group of similar patients may reveal that dolorimetric measures of increased latency parallel the severity of the root compression, as has been suggested for other sensory modalities.[2-4]

Interestingly, the tolerance latency of the clinically involved dermatome remained abnormal after surgical treatment and relief of pain, even when the nonclinically involved dermatome site latencies had been normalized by pain relief. The possibility that this represents a persistent sensory impairment in the biological substrate of dermatomal pain tolerance perception seems inescapable, although these patients did not report abnormality in unstimulated L_5L sensation postsurgically. We continue to monitor these patients' status at intervals and anticipate that this phenomenon may resolve with the other clinical signs in time.

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