Changes in Sympathetic Tone Associated with Different Forms of Transcutaneous Electrical Nerve Stimulation in Healthy Subjects

RITA A. WONG
and DIANE U. JETTE

The purpose of this study was to determine the effect of four different forms of transcutaneous electrical nerve stimulation (TENS) on sympathetic tone in healthy subjects. Twelve subjects received high frequency, low frequency, burst frequency, and placebo stimulation to one upper extremity. Treatments were given on different days. Ipsilateral and contralateral fingertip skin temperatures were measured at three intervals for each treatment: 1) after a 25-minute rest period before stimulation, 2) after a 25-minute treatment, and 3) 25-minutes posttreatment. High, low, and burst frequency TENS significantly increased sympathetic activity in the ipsilateral extremity immediately after treatment. Similar trends in temperature change were seen on the contralateral side. The effects of the three nonplacebo treatments did not differ from each other. Further research is needed to assess sympathetic effects of TENS on patient groups. The results suggest that monitoring skin temperature as part of a TENS assessment may be warranted, especially in patients with distal vascular impairments.

Key Words: *Electric stimulation, Physical therapy, Sympathetic nervous system.*

Three different forms of transcutaneous electrical nerve stimulation (TENS) are widely used in physical therapy: high frequency (40 to 150 pulses per second), low frequency (1 to 4 pulses per second), and burst frequency (short bursts of high frequency stimulation emitted 1 to 4 times per second). Although all three forms decrease pain, their comparative effectiveness is unclear.[1-4] With each form of TENS, the degree of pain relief may vary depending on the pain syndrome, electrode placements, type of stimulator, or different reactions of patients with the same pain syndrome. The choice of specific TENS characteristics is, therefore, arbitrary and is usually approached in an inefficient and time-consuming "trial and error" manner.

Evidence exists, however, that a patient who does not respond to one form of TENS may respond to another.[5,6] Additional information is needed about the effects of each form of TENS to delineate optimal choices of treatment. One important area that has not received adequate investigation is the effect of TENS on sympathetic activity.

The interrelationship between sympathetic nervous system activity and the sensation of pain is imprecisely defined. Most authors maintain that many pain-conducting nerve fibers enter the sympathetic ganglia, but their exact influence on sympathetic outflow is unclear.[7,8] Research does indicate a dynamic relationship in which painful sensations can lead to increased sympathetic tone and excessive sympathetic tone, in turn, can lead to pain.

This interrelationship may be the basis, as well as the key to treatment, of some pain syndromes. For example, stress is associated with increased sympathetically controlled peripheral vasoconstriction. In individuals with Raynaud's disease, this increase in sympathetic tone may result in pain, especially in the fingers and toes. This condition can be treated using thermal biofeedback. Pain relief is achieved by the patient's conscious efforts to increase distal skin temperature, thereby decreasing sympathetic activity.[9] Reflex sympathetic dystrophy, including causalgia, Sudeck's atrophy, and shoulder-hand syndrome, is characterized by severe pain and sympathetic vasomotor disturbances.[10] A sympathetic block always gives prompt relief of these symptoms and, indeed, is considered essential to confirm the diagnosis.[10]

In animal research, Wall demonstrated that neuromas in the intact sciatic nerve of rats were extremely sensitive to sympathetic amines.[11] He suggested that the excessive pain sometimes experienced in humans after peripheral nerve injury may be related to a similar excessive sensitivity of the pain fibers to sympathetic amines. Pain relief might result from maneuvers that decrease sympathetic activity, thereby decreasing excessive peripheral pain-fiber firing.

Despite this relationship between pain and sympathetic activity, only a few studies have investigated the effects of TENS on sympathetic activity.[12-15] Most of these studies have examined high frequency TENS only, and the results have been contradictory and inconclusive.[12-14] Only one study was found that investigated the effects of low frequency stimulation on sympathetic activity.[15] This study noted decreased sympathetic activity after low frequency TENS. The effects of any of the forms of TENS on sympathetic tone in healthy subjects without pain has not been established.

The purpose of this study was to determine the sympathetic response of healthy subjects to the application of

Ms. Wong was Special Instructor of Physical Therapy, Simmons College, 300 The Fenway, Boston, MA, at the time this paper was written. She is currently Assistant Professor of Physical Therapy, University of Connecticut, U101, Storrs, CT 06268 (USA).

Ms. Jette is Assistant Professor of Physical Therapy, Simmons College, 300 The Fenway, Boston, MA 02115.

This research was funded by the Simmons College Fund for Research, Grant #30170.

This article was submitted June 20, 1983; was with the authors for revision seven weeks; and was accepted November 22, 1983.

each of three forms of TENS to one upper extremity.

METHODS

Subjects

Twelve healthy women who were 18 to 35 years of age (mean, 20 years old) and who were unfamiliar with TENS devices participated in the study. All subjects refrained from strenuous exercise, cigarette smoking, and caffeine ingestion for two hours before the testing. Each subject signed an informed consent to participate. The procedure was approved by our institutional research review committee.

Materials

Electrical stimulation was provided with a Neuromod® Selectra™* model 7720 dual-channel stimulator connected to TENS electrodes (17 sq cm, each). Neuromod TENS electrode gel was used as the conducting medium. Skin temperature was measured with a Cyborg† J42 digital readout thermal biofeedback unit connected to standard reusable skin thermistors. A quiet environment was maintained in a room with an average temperature of 23°C with a range, 22°–24°C (73.4°F [71.6°-75.2°F]).

Procedures

We gave each subject the four treatments, each on a different day but at about the same time of day. Treatments were given according to a Latin square design. The four treatments, all given in the same manner and with electrodes affixed to the same upper extremity points, were 1) high frequency TENS, 2) low frequency TENS, 3) burst mode TENS, and 4) placebo TENS (Fig. 1). During the placebo stimulation, no electrical current was delivered.

For each appointment, one investigator applied TENS electrodes and skin thermistors to the subject and placed both of the subjects' hands in resting splints to maintain the fingers comfortably in the same position throughout the testing procedure. The investigator placed TENS electrodes over four acupuncture points commonly used for upper extremity pain (Fig. 2).[16,17] Acu-

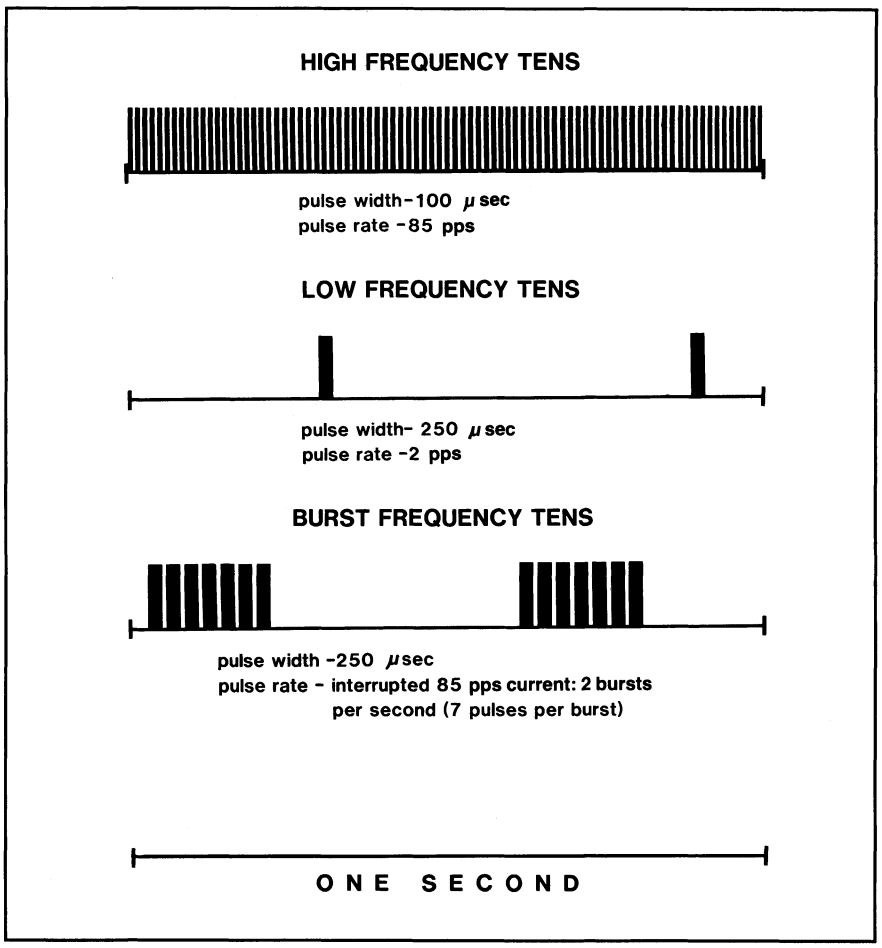

Fig. 1. Electrical characteristics of TENS used in treatments one, two, and three, respectively; pps = pulses per second.

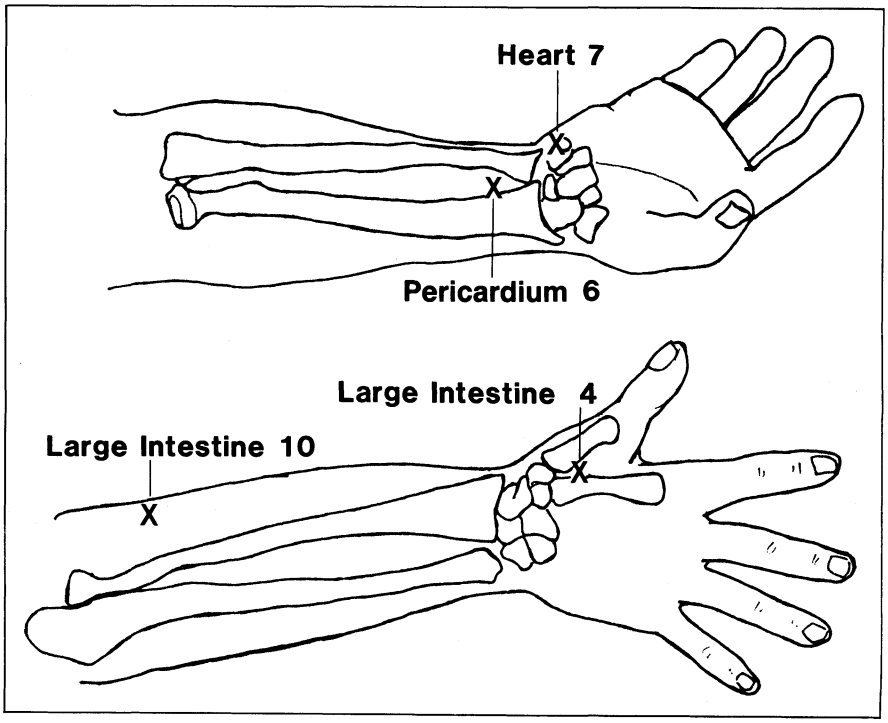

Fig. 2. Acupuncture points used for electrode placement.

* Medtronic, Inc, Neuro Division, 6951 Central Ave, NE, Minneapolis, MN 55440.

† Cyborg Corp, 55 Chapel St, Newton, MA 02158.

TABLE 1
Mean Skin Temperature Differences (C°) (N = 12)

Treatment	Immediate Effects $\bar{X}$	Immediate Effects *s*	Short-term Effects $\bar{X}$	Short-term Effects *s*
Ipsilateral Extremity				
High frequency	−2.73	2.08	−1.00	2.84
Low frequency	−3.44	2.88	−1.88	2.19
Burst frequency	−2.45	2.01	−0.12	3.28
Placebo	−0.13	1.13	−0.23	1.88
Contralateral Extremity				
High frequency	−1.50	1.85	−0.61	2.82
Low frequency	−2.27	1.59	−2.35	2.30
Burst frequency	−1.43	1.19	−0.26	1.55
Placebo	−0.46	1.28	−0.14	2.18

puncture points, Large Intestine 4 and Heart 7, constituted one channel; Pericardium 6 and Large Intestine 10 constituted the second channel.

The investigator secured skin thermistors to the tips of both index fingers. Skin temperature was recorded from this location because the blood flow through the fingertips is controlled almost entirely by sympathetic vasoconstrictor nerves.[18] Vasodilation occurs passively when sympathetic tone decreases. Therefore, increases or decreases in sympathetic vasomotor activity can be determined by the direction of the change in distal vasomotor tone. Stallworth et al in a study that included 1,200 subjects concluded that fingertip skin temperature accurately reflects cutaneous vasomotor activity.[19]

After we applied electrodes and thermistors, each subject relaxed for 25 minutes in the supine position. A 25-minute treatment session then followed. Each subject was given the same instructions, "You may or may not feel any sensation or experience muscle contraction from the treatment. You should relax and be comfortable during the session. Every 2 minutes during the first 10 minutes of the treatment session, the current intensity will be increased to your tolerance. The sensation should be comfortable, and the intensity will be increased either until you request that it be stopped or when a predetermined level is reached." The last statement was made to account for the lack of sensation from the placebo. During the treatments in which actual stimulation was given, all subjects experienced muscle contraction as well as electrical sensation. After the 25-minute treatment session, each subject again relaxed supine for 25 minutes.

One investigator applied the TENS device, and a second investigator, who was blind to the type of treatment being given, recorded three skin temperature scores: 1) after the 25-minute pretreatment period (baseline score), 2) after the 25-minute treatment session, and 3) after the 25-minute posttreatment period.

We calculated changes in skin temperature by determining the differences between the baseline temperature and 1) the temperature obtained immediately after the treatment (immediate effects) and 2) the temperature recorded at the end of the 25-minute posttreatment period (short-term effects). These calculations were performed separately for each extremity for each of the four treatments and were the scores used for data analysis.

Data Analysis

Data were analyzed using a two-by-four repeated measures analysis of variance (ANOVA). Ipsilateral and contralateral scores were analyzed separately. Newman-Keuls and simple effects tests were performed *post hoc*.

A two-way factorial design with repeated measures on both time and treatment was used because of the power of the analysis with a small number of subjects. We then had to assign treatments using a Latin square to control for sequence effects and carry-over effects.

RESULTS

The average temperature changes for all treatments are summarized in Table 1. Tables 2 and 3 contain the ANOVA summaries.

The main effects of treatment and time on temperature change were significant, and the interaction between the two for the ipsilateral side was significant ($p < .025$) (Tab. 2 and Fig. 3).

The simple effects of treatment at each time and the simple effects of time at each treatment were examined. Treatment had a significant effect in decreasing temperature at the immediate posttreatment time ($p < .01$), but the effect was not significant at the 25-minute posttreatment time. The change in tem-

TABLE 2
Analysis of Variance, Ipsilateral Extremity

Source	SS	*df*	MS	*F*	*p*
Main Effects					
1. Treatment	78.60	3	26.19	3.94	<.025
Error	219.60	33	6.65		
2. Time	45.79	1	45.79	7.98	<.025
Error	63.11	11	5.74		
3. Treatment x time	19.35	3	6.45	4.09	<.025
Error	52.00	33	1.58		
Simple Effects					
1. Treatment at immediate time	75.87	3, 48	25.29	6.14	<.01
2. Treatment at short-term time	13.83	3, 48	4.61	1.12	NS
3. Time at high frequency	50.55	1, 30	50.55	19.29	<.01
4. Time at low frequency	92.35	1, 30	92.35	35.25	<.01
5. Time at burst frequency	36.10	1, 30	36.10	13.78	<.01
6. Time at placebo	.41	1, 30	.41	1	NS

perature at the immediate posttreatment time was significantly different from the change in temperature at the 25-minute posttreatment time for the three nonplacebo treatments ($p < .01$).

Because the treatment effects were significant at the immediate posttreatment time on the ipsilateral extremity, a Newman-Keuls test was performed. The three nonplacebo treatments each differed significantly from the placebo treatment in their effects on skin temperature ($p < .05$), but they did not differ from one another.

The ANOVA for the contralateral side showed an effect of treatment only ($p < .025$) (Tab. 3). No significant interaction between time and treatment was observed. Because of this main effect and because Figure 4 suggests that a single treatment (low frequency) might account for the effect, we performed Newman-Keuls tests. At the immediate posttreatment time, we found no significant difference between any of the treatments. At the 25-minute posttreatment time, the low frequency treatment differed significantly from the placebo treatment and burst frequency TENS ($p < .05$) but not from the high frequency.

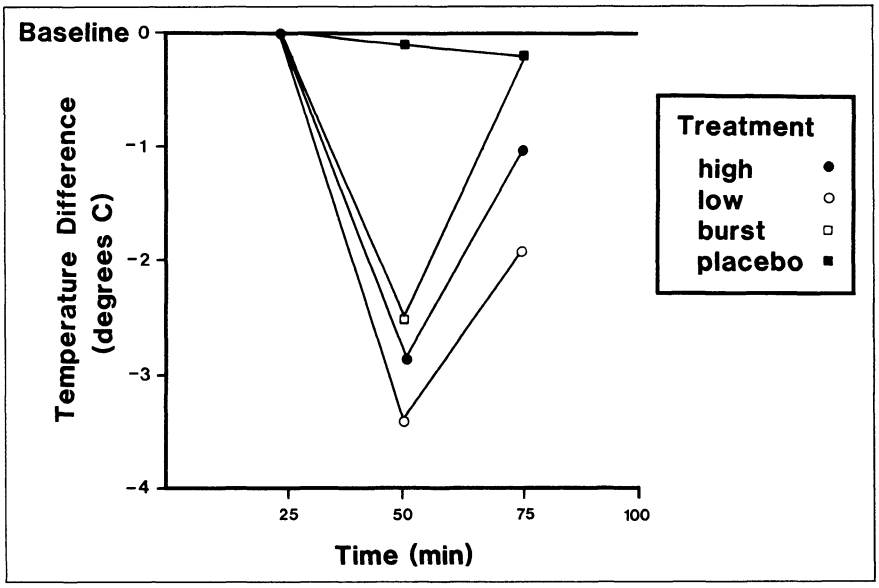

Fig. 3. Average differences from baseline in skin temperature over time on the ipsilateral extremity.

DISCUSSION

This study represents the first time, to our knowledge, that an attempt has been made to determine objectively and compare the effects of the various forms of TENS on sympathetic activity.

The interrelationship that exists between pain-fiber activity and sympathetic activity can lead logically to the assumption that TENS, in addition to decreasing sensitivity to pain, will decrease sympathetic activity. The studies by Abrams et al[12] and Kaada[15] support this assumption. Indeed, most clinicians using TENS whom we consulted believed TENS applied to the extremities would result in an increase in skin temperature indicative of vasodilation and decreased sympathetic activity.

The results of this study contradicted this assumption. The results revealed that, regardless of the form used, TENS treatment resulted in an increase in sympathetic activity evidenced by a fall in fingertip skin temperature. The skin temperature changes were temporary and returned toward baseline values 25 minutes after treatment completion. The changes were most marked on the ipsilateral extremity, although changes on the contralateral extremity followed similar trends. These findings indicate a local rather than generalized sympathetic effect of TENS.

Unfortunately, our results failed to give substantial information that could aid in selecting TENS characteristics. No significant differences were demonstrated among the three forms of TENS in their effect on sympathetic activity, with the exception of low frequency TENS and burst frequency TENS on the contralateral extremity 25 minutes after treatment completion ($p < .05$). We could not determine a reason for this occurrence. The evidence suggests that differences in pain relief obtained from each of the three forms of TENS were not related to changes in sympathetic activity and that one form of TENS was not a better choice than another if the patient had vascular problems.

We offer two possible explanations for the increase in sympathetic activity that occurred in this study: 1) sympathetic vasoconstrictor nerve fibers may have been directly stimulated by TENS or 2) vasoconstriction of superficial blood vessels may have occurred in response to an increased demand for blood by the muscles contracting from the TENS stimulation. Abrams et al,[12] Ebersold et al,[13] and Kaada[15] have reported results that conflict with our findings. These differences may be attributed to their use of subjects with various pain syndromes, abnormally low skin temperatures, sympathectomies, and other neurological deficits. Placement of electrodes and placement of skin thermistors also differed from our study.

Our results may have important clinical implications. Although more research is needed to justify generalization beyond healthy, young, female subjects, this study should alert clinicians that a potential for a decrease in skin temperature exists with use of TENS at certain extremity sites. Indeed, several subjects

TABLE 3
Analysis of Variance, Contralateral Extremity

Source	SS	*df*	MS	*F*	*p*
Main Effects					
1. Treatment	52.23	3	17.41	4.26	<.025
Error	134.71	33	4.08		
2. Time	7.94	1	7.94	3.02	NS
Error	28.92	11	2.63		
3. Treatment × time	5.64	3	1.88	1.43	NS
Error	43.48	33	1.32		

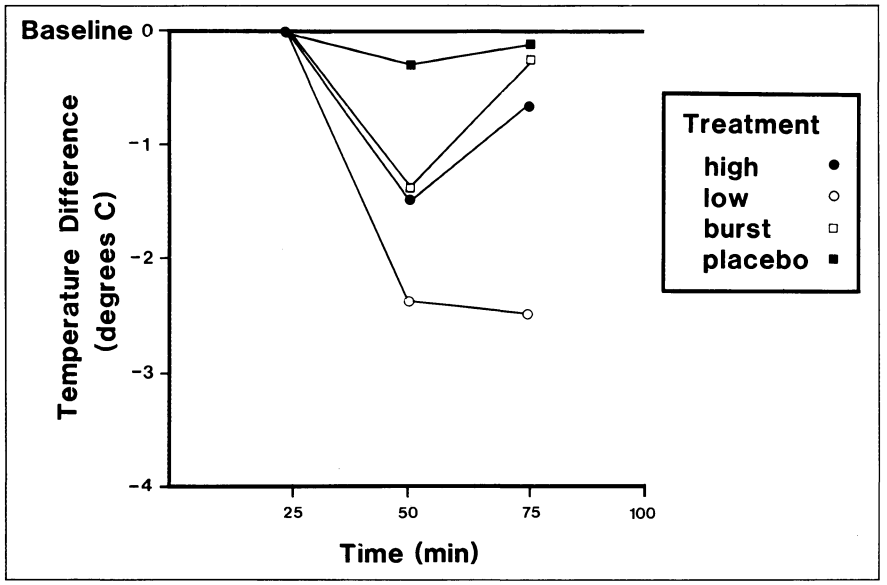

Fig. 4. Average differences from baseline in skin temperature over time on the contralateral extremity.

experienced decreases of 6° to 9°C (10.8°–16.2°F). Such large decreases in skin temperature emphasize the need to monitor skin temperature changes when assessing patients for TENS, especially patients with existing vascular disturbances.

More research is needed to document the sympathetic effects of TENS in clinical use to relieve acute and chronic pain syndromes. In this study, with subjects relaxed and not in pain, electrical stimulation was the only major factor affecting changes in sympathetic tone. This may not be the case in individuals for whom TENS is being used for pain control. Relief of pain may result in relaxation and, in turn, relaxation will result in decreased sympathetic tone. The combined effect of electrical stimulation and relaxation on sympathetic activity remains to be determined and will apparently be different according to stimulation sites used, pathological processes involved, psychological characteristics of the patient, and the amount of pain relief achieved during treatment. The effects of these variables should be investigated in controlled clinical studies.

CONCLUSION

In healthy subjects, the use of either high, low, or burst frequency TENS to one upper extremity was associated with increased sympathetic vasomotor tone, which was more pronounced on the ipsilateral than on the contralateral extremity. This increase in tone did not, however, substantially outlast the treatment. The effects of these three nonplacebo treatments were not different from each other. The results gave no clear basis for selection of TENS characteristics.

Until further clinically-based research is done, the results of this study suggest that clinicians who use TENS should monitor its effects on skin temperature, especially in patients with vascular impairments.

Acknowledgments. We wish to thank Medtronic, Inc for the donation of equipment used in this study. We are also indebted to Al Jette for his assistance with data anlysis.

REFERENCES

1. Meyer G, Fields H: Causalgia treated by selective large fibre stimulation of peripheral nerves. Brain 95:163–168, 1972
2. Fox E, Melzack R: Transcutaneous electrical stimulation and acupuncture: Comparison of treatment for low back pain. Pain 2:141–148, 1976
3. Melzack R: Prolonged relief of pain by brief, intense transcutaneous somatic stimulation. Pain 1:357–373, 1975
4. Long D, Hagfors N: Electrical stimulation in the nervous system: The current status of electrical stimulation of the nervous system on pain relief. Pain 1:109–123, 1975
5. Eriksson M, Sjolund B, Nielzen S: Long-term results of peripheral conditioning stimulation as an analgesic measure in chronic pain. Pain 6:335–347, 1979
6. Eriksson M, Sjolund B: Acupuncturelike electroanalgesia in TNS-resistant chronic pain. In Zotterman Y (ed): Sensory Functions of the Skin. New York, NY, Oxford University Press Inc, 1976, pp 575–581
7. Chusid JG: Correlative Neuroanatomy and Functional Neurology. Los Altos, CA, Lange Medical Publications, 1970, pp 145–158
8. Cotman CW, McGaugh JL: Behavioral Neuroscience: An Introduction. New York, NY, Academic Press Inc, 1980, pp 515–564
9. Freedman R, Lynn S, Ianni P, et al: Biofeedback treatment of Raynaud's disease and phenomenon. Biofeedback Self Regul 6:335–360, 1981
10. Bonica J: Causalgia and other reflex sympathetic dystrophies. Postgrad Med 53:143–148, 1973
11. Wall P: Ongoing activity in peripheral nerves: The physiology and pharmacology of impulses originating from a neuroma. Exp Neurol 43:580–593, 1974
12. Abrams S, Asiddao R, Reynolds A: Increased skin temperature during transcutaneous electrical stimulation. Anesth Analg 59:22–25, 1980
13. Ebersold M, Laws E, Albers J: Measurements of autonomic function before, during and after transcutaneous stimulation in patients with chronic pain and in control subjects. Mayo Clin Proc 52:228–232, 1977
14. Stilz R, Carron H, Sanders D: Case history number 96: Reflex sympathetic dystrophy in a 6 year old: Successful treatment by transcutaneous nerve stimulation. Anesth Analg 56:438–434, 1977
15. Kaada B: Vasodilation induced by transcutaneous nerve stimulation in peripheral ischemia (Raynaud's phenomenon and diabetic polyneuropathy). Eur Heart J 3:303–314, 1982
16. Mann F: Atlas of Acupuncture. London, England, Heinemann Medical Books, 1966
17. Castel C: Pain Management with Acupuncture and Transcutaneous Electrical Nerve Stimulation Techniques. Lake Bluff, IL, Pain Control Services, Inc, 1979, pp 21,23,27
18. Roddie I, Shephert J, Whelan R: The contribution of constrictor and dilator nerves to the skin vasodilation during body heating. J Physiol 136:489–497, 1957
19. Stallworth J, Horne J, Plonk G: A noninvasive method to assess sympathetic activity. Am Surg 47:333–337, 1981