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Comparison of Sympathetic Skin Response and Digital Infrared Thermographic Imaging in Peripheral Neuropathy

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It is well known that the SSR (sympathetic skin response) is to evaluate the function of sudomotor activity and Digital infrared thermal imaging (DITI) is to evaluate the function of vasomotor activity of the sympathetic nerve. To assess the sympathetic nerve impairment in the patients with peripheral neuropathy, the SSRs and DITIs were tested in 35 cases. Twenty-four(68.6%) patients were abnormal on SSR test and twenty-nine (82.9 %) patients were abnormal on DITI test . In the relationship between DITI and SSR, 19 (54.3%) cases were abnormal and 1 case was normal finding in both of these two tests. And the remaining 25 (42.9%) patients were abnormal on only either one of both tests. Frequency of abnormal SSR and DITI findings were correlated with severity of axonal involvement in peripheral nerve lesion . The results of this study revealed DITI to be more sensitive test in assessing sympathetic dysfunction in peripheral neuropathy than the SSR. However DITI has very limited values in the patients with symmetrically involved peripheral neuropathy because thermal asymmetry is considered as abnormal on DITI. Therefore, in assessing the function of sympathetic nerve in peripheral neuropathy, combined tests of SSR and DITI are useful.

Key Words: Autonomic nervous system, peripheral neuropathy, sympathetic skin response, digital infrared thermographic imaging

It is well known that dysfunction of autonomic nervous system is frequent in peripheral neuropathy (Elie and Guiheneuc, 1990). Autonomic function in peripheral neuropathy such as diabetic polyneuropathy have been investigated by many researchers (Fagius and Wallin 1980, Knezevic and Bajada 1985, Soliven *et al.* 1987, Niakan and Harati 1988). In 1984, on evaluating sympathetic function in peripheral neuropathy with the sympathetic skin response (SSR) and morphometric methods, Shahani *et al.* concluded that abnormalities of the SSR did not correlate well with clinical evidence of dysautonomia, but were a reliable indicator of disorders affecting unmyelinated axons. However many other studies noted that SSR is a noninvasive, and sensitive method for early detecting and monitoring autonomic function (Fagius and Wallin 1980, Knezevic and Bajada 1985, Soliven *et al.* 1987, Niakan and Harati 1988).

In recent years, DITI has been employed not only in the field of industry, but also in medicine. Thermographic devices can measure the change of temperature at the body surface which is controlled by sympathetic nervous system. Therefore measuring skin temperature with thermographic devices is thought to be a useful method to assess sympathetic function (Uematsu, 1985).

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The aim of this study is to investigate sympathetic nerve function of peripheral nerve in the patients with peripheral neuropathy using the SSR and DITI and to compare the results of the SSR with thermographic findings.

MATERIALS AND METHODS

Thirty-five patients with peripheral neuropathy, 23 men and 12 women are tested. The age of the patients range from 11 to 67 years with a mean age of 36.2 years. The age and sex distribution of the patients is illustrated in Table 1.

Skin temperature with Digital infrared thermographic imaging system (DITI) is measured in the thermographic laboratory room, which has no window and is maintained at a temperature of 19 to 21℃ and humidity below 50 %. The setting for DITI is illustrated in Table 2. The patients were prepared for the DITI test (Table 2) 24 hours before the examination and on the day of the test the patients were disrobed and asked to remain in the thermographic room for 15 minutes in order to equilibrate their body surface temperature to the room temperature. Temperature difference (△ T) between corresponding sites of the body is measured and thermal asymmetry of more than 0.3℃ is considered as abnormal .

The SSR with the Medelec MS 60 EMG machine is tested with the patients lying supine in a comfortable relaxed position. Electrical stimuli of 150 to 200 V intensity are applied to median nerve at the wrist or tibial nerve at the ankle. To avoid habituation, 5 times stimuli were delivered at irregular rates, with intervals longer than 15 seconds apart. The responses are taken from both palms and soles with surface electrodes. The setting and procedure for the SSR is illustrated precisely in Table 3. Among 5 consecutive responses, a well-defined response is chosen and peak-to-peak amplitude is measured. The results are compared to that of normal control group on previous study in our hospital (Kim *et al.* 1989). A response is defined as absent if no reproducible deflection could be recorded after

Table 1. Age and sex distribution

Age(yrs)\Sex	Male	Female
10~19	4	1
20~29	5	0
30~39	9	5
40~49	1	1
50~59	3	3
60~69	1	2
Total	23	12

Table 2. Patient preparation and setting for digital infrared thermographic imaging

Patient preparation
1. The patient should shower or bathe on the day of the examination but no talcum powder, lotions, deodorants
2. Alcoholic beverages should not be consumed
3. Procedures such as electromyography, acupuncture, nerve block or myelography should be deferred until after thermal graphic examination
4. Any physical therapy should not be permitted
5. Patient should not smoke for at least two hours prior to the study

Setting for DITI
- Dorex DITI System
- Windowless room
- Air flow; uniform and constant
- Room temp; 19~21℃
- Humidity; below 50%

Table 3. Setting for sympathetic skin response

- EMG Machine: Medelec MS 60
- Stimulation intensity: 150~200V
- Frequency filter: 8~800 Hz
- Sweep speed: 500 msec/div
- Amplification: 200 μV/div
- Stimulation: median and tibial nerve
- Recording site: both hands and feet
- Recording electrode: surface electrode

Table 4. Conduction block index and axon loss index

$$\text{Conduction Block Index} = \frac{\text{CMAP}^1 \text{ distal(invol.)} - \text{CMAP proximal(invol.)}}{\text{CMAP distal(uninvol.)}} \times 100$$

$$\text{Axon Loss Index} = \frac{\text{CMAP distal(uninvol.)} - \text{CMAP distal(invol.)}}{\text{CMAP distal(uninvol.)}} \times 100$$

1. CMAP: Maximal compound muscle action potential negative peak area

5 consecutive stimulations. SSR finding is considered as abnormal when the response is absent or when the amplitude of SSR is less than 2 standard deviation of normal mean on Kim's results.

Conduction block and axon loss index suggested by Brown and Watson (1991) and Watson and Brown (1992) are used for defining the severity of peripheral nerve lesion. After motor nerve conduction study is performed in median or tibial nerve, conduction block and axon loss index are calculated by the formula illustrated in Table 4. Also we performed conventional needle EMG study in all of the patients and considered the grade of positive sharp wave(Kimura, 1989) as severity of axonopathy. Statistical analysis was performed using Fisher's exact test.

RESULTS

Disease distribution of the patients is illustrated in Table 5. Among the 35 patients, 21 are lumbar or cervical radiculopathy; 8 , traumatic peripheral neuropathy; 4, diabetic neuropathy and 2, Guillain-Barre syndrome, respectively.

The SSR is abnormal in 24 of the 35 patients (68.6%). All of the patients with peripheral polyneuropathy such as DM and Guillain-Barre syndrome have abnormal findings on SSR (Table 6).

DITI shows hypothermia in 21 cases and hyperthermia in 8 cases among 35 patients with peripheral neuropathy and there are no significant thermal asymmetries in the remaining 6 patients who have bilateral peripheral nerve involvements of DM and Guilain-Barre syndrome (Table 7). The absense of thermal asymmetry with these patients is mainly due to symmetrical involvement of peripheral nerves. Therefore DITI is a more sensitive test to detect sympathetic dysfunction in peripheral neuropathy than SSR, however it is not helpful in symmetrically involved peripheral polyneuropathy. Meanwhile SSR is very helpful in symmetrically involved peripheral polyneuropathy such as diabetic polyneuropahty and Guillain-Barre syndrome.

In the relationship between DITI and SSR,

Table 5. Disease Distribution

Disease	No. of cases
Lumbar Radiculopathy	12
Cervical Radiculopathy	9
Traumatic Peripheral Neuropathy	8
Diabetes Mellitus	4
Guillain-Barre Syndrome	2

Table 6. Findings of sympathetic skin response

Disease	No. of cases(%)	
	Normal	Abnormal
Radiculopathy	8(22.8)	13(37.2)
Peripheral Polyneuropathy	0(0.0)	6(17.0)
Traumatic Peripheral Neuropathy	3(8.6)	5(14.3)
Total	11(31.4)	24(68.6)

Table 7. Findings of digital infrared thermographic imaging

Disease	No. of cases(%)		
	Hypothermia	Hyperthermia	Isothermia
Radiculopathy	16(76.2)	3(14.3)	2(9.5)
Peripheral Polyneuropathy	1(16.7)	1(16.7)	4(66.6)
Traumatic Peripheral Neuropathy	4(50.0)	4(50.0)	0(0.0)
Total	21(60.0)	8(22.9)	6(17.1)

Table 8. Relationship between digital infrared thermographic imaging and sympathetic skin response

		No. of cases(%) DITI[2]		Total
		Normal	Abnormal	
SSR[1]	Normal	1(2.8)	10(28.6)	11(31.4)
	Abnomal	5(14.3)	19(54.3)	24(68.6)
Total		6(17.1)	29(82.9)	35(100.0)

(X^2= 0.13886, p=0.7094)

1. Sympathetic skin response
2. Digital infrared thermographic imaging

19 cases are abnormal (54.3%) and 1 case is normal on both of these two tests. DITI and/or SSR show abnormal findings in almost all of the patients except for 1 case. Five (14.3%) patients show abnormal findings on only the SSR test and ten (28.6%) patients have abnormal findings on only the DITI test. The results of DITI test are not related to that of SSR test ($p>0.05$, Table 8).

The patients are divided into mild, moderate and severe group according to the scores of the axon loss index. In the mild group, the SSR is abnormal in 7 of the 15 patients and DITI is abnormal in 13 of the 15 patients. In the severe group, all of the patients show abnormality on SSR and DITI (Table 9). However, it is very limited to generalize the results by statistical analysis because of the small number of cases ($p>0.05$).

The patients are also divided into three groups according to scores of conduction block index. In the mild group, incidence of abnormal finding was 60.0% on SSR and 92.0% on DITI (Table 10). These results showed that DITI is a more sensitive test than the SSR ($p<0.05$). Conventional needle EMG study is done in all of the patients. The patients are grouped according to the grade of positive sharp waves. All the patients without positive

Table 9. Sympathetic skin response and digital infrared thermographic imaging findings according to axon loss Index

	No. of cases(%) Axon Loss Index		
	Mild (0~25)	Moderate (26~50)	Severe (51~100)
Abnormal SSR[1]	7/15(46.7)	4/5(80.0)	2/2(100.0)
Abnormal DITI[2]	13/15(86.7)	5/5(100.0)	2/2(100.0)

1. Sympathetic skin response
2. Digital infrared thrmographic imaging

$p>0.05$

Table 10. Sympathetic skin response and digital infrared thermographic imaging findings according to conduction block index

	No. of cases(%) Conduction Block Index		
	Mild (0~25)	Moderate (26~50)	Severe (51~100)
Abnormal SSR[1]	15/25(60.0)*	1/1(100.0)	1/1(100.0)
Abnormal DITI[2]	23/25(92.0)*	1/1(100.0)	1/1(100.0)

1. Sympathetic skin response
2. Digital infrared thrmographic imaging
*. p=0.0215

Table 11. Digital infrared thermographic imaging findings according to grade of positive sharp wave

Grade of positive sharp wave	No. of cases(%) DITI[1]	
	Normal	Abnormal
Grade 0	2(100.0)	0(0.0)
Grade 1~2	11(44.0)	14(56.0)
Grade 3~4	0(0.0)	8(100.0)

$X^2=11.34$, p=0.0034
Grade by Kimura method
1. Digital infrared thermographic imaging

sharp waves on needle electromyographic study have normal findings on DITI, but 56 % of the patients who have positive sharp waves of grade 1 or 2 have abnormal findings on DITI, and all the patients with positive sharp waves of grade 3 or 4 have abnormal findings on DITI. These results suggest that abnormal DITI findings are related with the grades of positive sharp waves ($p<0.05$, Table 11).

DISCUSSION

In 1890, Tarchanoff described different kinds of sensory or emotional stimulation which induced a change of skin potential. This phenomenon was originally called galvanic skin reflex. Carmichael *et al.* (1941) recorded sympathetic activity using faradic shock, and called it the skin resistance response. The dependence of the skin resistance response on the activity of the sympathetic nervous system was illustrated experimentally by the abolition of the response with a combination of the effects of atropinization and devascularization. They concluded that the change in skin resistance to a given stimulus resulted from activity of the sympathetic nervous system.

In 1972, Hagbarth *et al.* reported that SSR's were recorded with microelectrodes inserted percutaneously into the skin nerve fascicles in alert adult subjects and identified that the signals were abolished by sympathetic ganglionic blocking agents and by lidocaine nerve blocks proximal to the recording site. They concluded that their study agreed with the notion that there were certain inherent rhythms prevailing in the central sympathetic structures governing the vasoconstrictor and sudomotor outflow to skin, rhythms which can be modified by a variety of influences (Koepchen 1962, Weidinger and Leschhorm 1964). However, this method is time-consuming, require skilled experienced operators, and is invasive, making the routine use impratical.

Shahani *et al.* (1984) has introduced the technique for evoking the sympathetic skin response. They measured the sympathetic skin responses in patients and normal controls using surface electrodes placed on the palm and dorsum of the hand, and on the sole and dorsum of the foot. The simplicity of Shahani *et al's* technique of eliciting the sympathetic skin response makes it particularily suitable in the autonomic nervous system evaluation during routine EMG sessions.

The sympathetic skin responses can be easily induced by any internal or external stimuli. These stimuli include cough or deep inspiration, startling or painful stimuli or electrical impulses applied to peripheral nerves. An electrical stimulus over a peripheral nerve was found to be the most reliable method of evoking a reproducible response. And also this

reproducible response is easily recorded in all normal subjects (Knezevic and Bajada 1985). A normal sympathetic skin response is usually biphasic potential of larger amplitude and shorter latency in the upper limb than the lower limb. The physiologic mechanisms underlying the production of the response are still poorly understood. The potential is thought to originate from sudomotor activity of the synchronized sympathetic activation (Shaver *et al.* 1962, Torebjork HE 1974, Hagbarth *et al.* 1972). In a while Shahani *et al.* (1984) reported that the absence of sympathetic skin response correlated best with disorders that preferentially affected unmyelinated axons and abnormalities of sympathetic skin response did not correlate with clinical evidence of dysautonomia. It seems likely that a diffuse, "dying back" type of peripheral neuropathy would affect many small, distal sudomotor fibers and thereby alter sympathetic skin activity long before other sympathetic or parasympathetic fibers were damaged sufficiently to cause orthostatic hypotension or other signs of dysautonomia. For this reason they concluded that sympathetic skin response was a better marker of peripheral neuropathies than of dysautonomia and could document axonal pathology, especially when unmyelinated axons were involved, but did not assess autonomic function. After that, in the majority of studies the SSR in patients with diabetic neuropathies was evaluated to demonstrate the involvement of the autonomic nervous system and concluded that the SSR is a noninvasive, quantitative and sensitive test for early detecting and monitoring autonomic function (Knezevic and Bajada 1985) and correlated with other autonomic function tests and the degree of sensorimotor peripheral neuropathy (Fagius and Wallin 1980, Soliven *et al.* 1987, Niakan and Harati 1988).

Fagius and Wallin studied SSR in 47 diabetic patients selected for the presence of symptoms and clinical signs of peripheral neuropathy and in 24 normal control subjects. They reported that the SSR was present in all controls but was absent at the foot in 60% and at the hand in 27.7% of the diabetic patients and absence of SSR did not correlate with the severity of the peripheral demyelination as measured by the slowing of conduction velocity nor with the severity of axonal damage as indicated by a decreased amplitude of the compound muscle and nerve action potentials. This is at variance with the report by Shahani *et al.* who found the SSR to be more frequently abnormal in axonal neuropathies than in demyelinating neuropathies. Fagius and Wallin's subsequent study of 18 patients with more severe diabetic neuropathy, absence of SSR appeared to correlate with signs of axonal involvement such as reduced amplitude of sensory nerve action potential and/or compound muscle action potentials. In other studies SSR in diabetic patients was absent at the foot in 66% and at the hand in 27.7% of the diabetic patients by Soliven *et al's* report, at the foot only in 46% and at the hand and foot in 37% by Niakan *et al's* report and at the foot 58.5% and at the hand in 34.1% by Lee's report.

In this study, SSR is abnormal in 68.6% and this study reveals that SSR is more frequently abnormal in the groups with higher axon loss index and with the high grade of positive sharp waves which is implied more axonal involvement and supported the Shahani *et al's* report. And also this study is designed to assess the SSR in the patients with demyelinating diseases, conduction block index which is implied as an index for severity of demyelinating neuropathy was used by Brown & Watson's (1991) method. However, the cases and the distribution of conduction block index in this study is not sufficient for statistical analysis subject to any conclusion. Further study in the patients with demyelinating disease is required to determine the relationship between SSR and demyelinating neuropathies.

Digital infrared thermal imaging records the dermal blood flow as skin temperature and of less than 5 mm depth. This method of blood flow measurement is considered most accurate at the present time. The sympathetic nervous system controls the microcirculation of the dermis. The DITI is a useful method to evaluate the vasomotor function of sympathetic nerves in the peripheral nerves of the extremities as well as within the blood vessels

(Brelsford & Uematsu 1985, Hobbins 1986 Uematsu, Uematsu *et al.* 1988).

Skin temperature varies widely from time to time and with alteration of the vasomotor function, but it has been revealed that there is almost no temperature variation between corresponding sites on different sides of an individual's body. Several studies (Uematsu 1976, Feldman and Nickoloff 1984) have documented that symmetry of the extremities and trunk dictates that neither side will differ from the other along a dermatome or thermatome by more than 0.3℃ and this documentation has been applied as the criteria for abnormal thermal asymmetry in this study. Other researchers considered as abnormal finding on DITI when the thermal asymmetricity is more than 0.62℃ by Goodman *et al's* report (1986), 0.7℃ by Cho *et al's* report (1991), and 0.5℃ by Park *et al's* report (1993). And Kim *et al.* (1990) defined abnormal DITI finding when thermal asymmetry is more than 0.5℃ or when thermal asymmetry is more than 0.2℃ if the area of thermal asymmetry is compatible with the area where the patient complains of pain.

The detection of a significant temperature difference between corresponding sites on opposite sides of the body is highly suggestive of sympathetic nerve impairment in the peripheral nerve (Uematsu, 1985). As the reproducible thermal asymmetry is of greatest importance in the interpretation of the thermographic findings, there is a significant limitation in the diagnosis of symmetric involvement of peripheral nerve such as diabetic neuropathy or Guillain-Barre syndrome.

Thermography in the detection of carpal tunnel syndrome and other compressive neuropathies were conducted by Herrick *et al* (1987). They reported that the sensitivity of thermography is very high to 96% and therefore concluded that thermography offers a painless, reproducible, objective method of determining the presence or absence of carpal tunnel syndrome and other compressive neuropathies of the upper extremities. Uematsu (1985) divided the patients into two groups of complete loss of sensation in the skin segment relating to the damaged nerve (Group A) and partially traumatized nerve injury (Group B), acccording to the status of their sympathetic nerve function. The skin temperature of the damaged side averaged 1.92℃ higher in group A and 0.83℃ colder than the opposite intact segment of the limb than the opposite intact side. Since there is not complete peripheral nerve injury in our study, any difference of thermographic finding in complete and incomplete peripheral nerve injury can not be evaluated, but there are both hyperthermic and hypothermic changes over the skin area relating damaged nerve that is different from that of Uematsu report. There are many studies of DITI findings in patients with lumbar radiculopathy due to herniated lumbar disc. Fisher *et al* (1983) reported that diagnositic sensitivity of DITI in radiculopathy is 77%. And by Uematsu *et al's* (1988) report that is 85.6%. There are some reports about the diagnostic sensitivity of DITI in our country. Kim *et al* (1990) reported the sensitivity is 79% and that of DITI in the patients with lumbar herniated disc is 76% by Cho *et al* (1991) and 70% by Park *et al* (1993).

SSR and DITI were studied in the patients with peripheral nerve injury to evaluate the function of sympathetic nerve in the peripheral nerves in this study. There are only abnormal SSR in 14.3%, only abnormal thermographic finding in 28.6% and the result of SSR and DITI is correlated in 57.1%. All the patients who had only abnormal SSR had symmetrically involved polyneuropathies such as diabetic neuropathy and Guillain-Barre syndrome.

In our study, the sensitivity of DITI is 82.9% in the patient with peripheral neuropathy and therefore DITI is a very sensitive test to detect the function of sympathetic nerves in the peripheral nerves, but is of a limited value in detecting the symmetric involvement of peripheral nerves.

REFERENCES

Brelsford KL, Uematsu S: Thermographic presentation of cutaneous sensory and vasomotor activity in the injured peripheral nerve. *J Neurosurg 62:711-715, 1985*

Brown WF, Watson BV: Quantitation of axon loss and conduction block in peroneal nerve palsies. *Muscle Nerve 14: 237-244, 1991*

Carmichael EA, Honeyman WM, Kolb LC, Stewart WK: A physiological study of the skin resistance response in man. *J Physiol 99: 329-337, 1941*

Cho J, Moon CT, Nah JH, Cho BI, Chang SK, Lee YC: Postoperative evaluation of lumbar disc herniation using digital infrared thermographic imaging. *J Kor Neurosurg Soc 20: 528-532, 1991*

Elie B, Guiheneuc P: Sympathetic skin response: normal results in different experimental conditions. *Electroenceph Clin Neurophysiol 76: 258-267, 1990*

Fagius J, Wallin BG: Sympathetic reflex latencies and conduction velocities in patients with polyneuropathy. *J Neurol Sci 47: 449-461, 1980*

Feldman F, Nickoloff EL: Normal thermographic standards for the cervical spine and upper extremities. *Skeletal Radiol 12: 235-249, 1984*

Fischer AA, Chang CH, Kuo JC: Value of thermography in diagnosis of radiculopathy as compared with electrodiagnosis. *Arch Phys Med Rehabil 64: 526, 1983*

Goodmann PH, Murphy MG, Siltanen GL, Kelly MP, Rucker L: Normal temperature asymmetry of the back and extremities by computer-assisted infrared imaging. *Thermology 1: 195-202 1986*

Hagbarth KE, Hallin RG, Hongell A, Torebjörk HE, Wallin BG: General characteristics of sympathetic activity in human skin nerve. *Acta Physiol Scand 84: 164-176, 1972*

Herrick RT, Herrick SK: Thermography in detection of carpal tunnel syndrome and othe compressive neuropathy. *J Hand Surg 12A: 943-949, 1987*

Hobbins WB: Basic concept of thermology and its application in the study of the sympathetic nervous system. *(2nd Albert Memorial symposium) Sep. 17, 1986*

Hoeldtke RD, Davis KM, Hshieh PB, Gaspar SR, Dworkin GE: Autonomic surface potential analysis: assessment of reproducibility and sensitivity. *Muscle Nerve 15: 926-931, 1992*

Kim CT, Cho MJ, Chun SI: Electrodiagnostic study of sympathetic skin response. *J Korean Acad of Rehabilitation. 13: 221-226, 1989.*

Kim YS, Cho YE, Oh SH: Digital infrared thermographic imaging in herniated lumbar disc patients. *J Kor Neurosurg Soc 19: 1303-1313, 1990*

Kimura J: Type of abnormality: *Electrodiagnosis in diseases of nerve and muscle* 2nd ed. Philadelphia, F.A.Davis Company *1989, pp 249-274*

Knezevic W, Bajada S: Peripheral autonomic surface potential: a quantitative technique for recording sympathetic conduction in man. *J Neurol Sci 67: 239-251, 1985*

Koepchen HP: Die Blutdrunck-rhytmik Dr. D Steinkoff Verlag Damrstadt *1962*

Lee IS, Kim HS, Ahn KH: Sympathetic skin response in diabetes mellitus. *J Kor Acad Rehab Med 17: 165-176, 1993*

McLeod JG: *Evaluation of the autonomic nervous system,* in Aminoff MJ(ed); *Electrodiagnosis in clinical neurology, 3rd ed. New York, Churchill Livingstone 1992, pp 421-432*

Niakan E, Harati Y: Sympathetic skin response in a diabetic peripheral neuropathy. *Muscle Nerve 11: 261-264, 1988*

Park GY, Chun SI, Park CI, Yim SY, Kim AY, Shin DB: Comparison of CT-myelography, electromyography and digital infrared thermographic imaging in lumbar herniated nucleus pulposus. *J Kor Acad Rehab Med 17: 42-50, 1993*

Shahani BT, Halperin JJ, Boulu P, Cohen J: Sympathetic skin response-a method of assessing unmyelinated axon dysfunction in peripheral neuropathies. *J Neurol Neurosurg Psychiatry 47: 536-542, 1984*

Shaver BA, Brusilow SW, Cooke RE: Origin of the galvanic skin response. *Proc Soc Exp Biol 110: 559-564, 1962*

Shin JB, Chon JS, Ha KH, Chun SI: The habituation phenomenon of sympathetic skin response. *J Kor Acad Rehab Med 15: 40-46, 1991*

Soliven B, Maselli R, Jaspan J, Green A, Gra249ziano H, Petersen M, Spire JP: Sympathetic skin response in diabetic neuropathy. *Muscle Nerve 10: 711-716, 1987*

Tarchanoff J: Uver die galvanicschen erscheinungen an der Haut des Menschen bei Reizung der Sinnersorgane und bei verschiedenen formen der physischen Th tigkeit. *Pflaüger's Arch Ges Physiol 46: 46, 1890*

Torebjörk HE: Afferent c units responding to mechanical, thermal and chemical stimuli in human non-glabrous skin. *Acta Physiol Scand 92: 374-390, 1974*

Uematsu S: Thermographic imaging of cutaneous sensory segment in patients with peripheral nerve injury. Skin-temperature stability between sides of the body. *J Neurosurg 62: 716-720, 1985*

Uematsu S, Edwin DH, Jankel WR, Kozikowski J,

Trattner M: Quantification of thermal asymmetry. Part 1: Normal values and reproducibility. *J Neurosurg 69: 552-555, 1988*

Uematsu S, Jankel WR, Edwin DH, Kim W, Kozikowski J, Rosenbaum A, Long DM: Quantification of thermal asymmetry Part 2: Application in low-back pain and sciatica. *J Neurosurg 69: 556-561, 1988*

Uematsu W, Long D: *Thermography in chronic pain.* In Uematsu et. *Medical thermography theory and clinical application.* Los Angelas Brentwood Co. *1976, pp52-67*

Uncini A, Pullman SL, Lovelace RE, Gambi D: The sympathetic skin response: normal values, elucidation of afferent components and application limits. *J Neurol Sci 87: 299-306, 1988*

Wang GH: The galvanic skin response. A review of old and recent work from a physiologic point of view. *Am J Phys Med Part I 36: 295-320, 1957*

Watson BV, Brown WF: Quantitation of axon loss and conduction block in acute radial nerve palsies. *Muscle Nerve 15: 768-773, 1992*

Weidinger H, Leschhorn V: Sympathische Tonisierung and rhythmische Blutdrucks-Schwankungen. *Kreisl Forsch 53: 985-1002, 1964*

Yokota T, Matsunaga T, Okiyama R, Hirose K, Tanabe H, Furukawa T, Tsukagoshi H: Sympathetic skin response in patients with multiple sclerosis compared with spinal cord transection and normal control. *Brain 114: 1381-1394, 1991*