Comparison of the Clinical Effectiveness Between Infrared Thermography and Electrophysiology Tests in Spinal Intradural Extramedullary Schwannoma

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ABSTRACT

Objective: Subjective pain is experienced differently by each patient; therefore, modalities that can objectify subjective symptoms are useful. Electrophysiology tests and infrared (IR) thermography can present subjective symptoms in an objective manner. This study aimed to compare the effectiveness of electrophysiology tests and IR thermography in patients with intradural extramedullary (IDEM) schwannoma and statistically analyze the results to verify the positive relationship between the subjective neurologic symptoms and test results.

Methods: We retrospectively analyzed the data from 23 patients, pathologically confirmed to have IDEM spinal schwannoma after surgery between January 2012 and December 2020. All patients were preoperatively examined using IR thermography and an electrophysiology test. IR thermography was conducted again a week after operation. The IR thermography results were classified as either positive or negative.

Results: Radiculopathy symptoms were reported in 16 cases and myelopathy in 7 cases. Among the radiculopathy patients, 9 out of 16 (56.2%) showed positive electrophysiology test results. Among the myelopathy patients, 2 out of 7 (28.5%) showed positive electrophysiology test results. In the radiculopathy group, 15 out of 16 (93.7%) patients showed positive IR thermography results. In the myelopathy group, 2 out of 7 (28.5%) patients showed positive IR thermography results. The correlation between the IR thermography and electrophysiology test was analyzed. In the radiculopathy group, positive electrophysiology test result was obtained in 8 out of 15 (53.5%) patients with positive IR thermography result. In the myelopathy group, 2 out of 7 (28.5%) patients showed positive IR thermography results. The correlation between the IR thermography and electrophysiology test was analyzed. In the radiculopathy group, positive electrophysiology test result was obtained in 8 out of 15 (53.5%) patients with positive IR thermography result.

Conclusion: In patients with IDEM schwannoma presenting radiculopathy symptoms, IR thermography is a complementary tool to objectify the neurological symptoms.

Keywords: Schwannoma; Electrophysiology; Thermography

INTRODUCTION

Solitary spinal schwannoma is the most common nerve sheath tumor of spine. The tumor typically arise from Schwann cells of a sensory nerve root; they appear as a globular, well-defined, encapsulated mass, well defined and separated from the other rootlets.
standard treatment for symptomatic spinal schwannomas is complete surgical resection, which stops symptoms progression, helps recovery in most patients, and decreases the rate of recurrence. Recent findings suggest that Ki-67 index might be related to the likelihood of recurrence. Schwannoma grow slowly and rarely develop into a malignant form. As schwannoma are usually located near the unilateral neural foramen, the most common symptom is radiculopathy. As the tumor grows, compression of the spinal cord induces myelopathy. The treatment requires surgical tumor excision for decompression.

Because pain is felt and expressed differently by each patient, modalities that can objectify and visualize this subjective symptom are useful for clinicians. The electrophysiology test and infrared (IR) thermography can objectify subjective symptoms. This study aims to compare the electrophysiology test and IR thermography in patients with intradural extramedullary (IDEM) schwannoma and to statistically analyze the positive relationship between neurologic symptoms and the test results.

**MATERIALS AND METHODS**

From January 2013 to November 2020, we reviewed 23 cases of pathologically proven IDEM schwannomas. The gender distribution of male to female subjects was 9:14, and their ages ranged from 19 to 77 years. Factors that can affect IR thermography test results, such as the presence of peripheral neuropathy, vasculopathy, and extremity disease, were examined and excluded before IR thermography. This study was approved by the Institutional Review Board of Inje University College of Medicine (2021-07-063-003).

Every patient was pre-operatively examined by IR thermography (DITI; Dorex Inc., Dallas, TX, USA; IRIS-XP Medicore, Hanam, Korea) and an electrophysiology study (Cadwell Sierra, Cadwell, Kennewick, WA, USA). The author performed unilateral hemilaminectomy and tumor removal in all patients. The IR thermography test result was classified as positive or negative. A positive test result was defined as more than 0.3°C of thermal asymmetry on the dermatome location of the affected nerve. Total tumor removal was performed in all enrolled patients. All patients received a follow-up IR thermographic study one week after the operation. For IR thermographic evaluation, the room temperature was maintained at 23°C–25°C. The study was done without heat supplementation. The room had a stable consistent airflow and adequate humidity. The patients were kept in the room for approximately 15–20 minutes without garments. The thermographic finding of the tumor lesion was analyzed by experienced professionals.

The electrophysiology test was done with needle electromyography and skin nerve conduction for all patients. A somatosensory evoke potential test was also done on patients presenting with a myelopathy symptom or lesions in the spinal cord. An electrophysiology test was done by highly trained technicians and interpreted by experts in the Department of Rehabilitation and Neurology. The categorical data was analyzed by Fisher’s exact test. The statistical analysis was performed using SPSS software version 22 (IBM, Armonk, NY, USA).
RESULTS

Patients’ information is listed in TABLE 1. Radiculopathy was reported in 16 cases and myelopathy in 7 cases (TABLE 2). In the patients with radiculopathy, 9 of 16 (56.2%) showed a positive electrophysiology test result. In those with myelopathy, 2 of 7 (28.5%) had a true positive somatosensory evoke potential test result (TABLE 2).

In the radiculopathy group, 15 out of 16 subjects (93.7%) (p-value=0.017) showed a positive IR thermographic test result (FIGURE 1, TABLE 3). In the myelopathy group, 2 of 7 subjects (28.5%) showed a positive IR thermography test (TABLE 3, FIGURE 2). We defined the pathologic thermographic test result based on standard skin temperatures in the Republic of Korea. We then analyzed the correlation between the IR thermography and electrophysiology test results. In the radiculopathy patients, a positive electrophysiology test result was shown in 8 out of 15 (53.5%) patients with a positive IR thermographic test result.

Postoperative IR thermography test result was listed (TABLE 4). In the radiculopathy group with positive preoperative IR thermography test result, 10 out of 15 subjects (66.6%) showed improved IR thermographic test result (TABLE 4). In the myelopathy group, no patient showed improvement of IR thermography test result.

### TABLE 1. Characteristics of 23 patients

| Sex | Age | Electrophysiology test | IR thermography | Radiculopathy | Myelopathy | Level |
|-----|-----|------------------------|-----------------|---------------|------------|-------|
| F   | 58  | Positive               | Positive        | Right leg     | Negative   | L2    |
| M   | 53  | Negative               | Positive        | Right leg     | Negative   | L4    |
| F   | 60  | Negative               | Positive        | Left shoulder, arm | Negative | C6    |
| F   | 23  | Positive               | Negative        | Negative      | Gait disturbance | T10–T11 |
| F   | 30  | Negative               | Positive        | Negative      | Gait disturbance | T12  |
| M   | 50  | Positive               | Positive        | Right leg     | Negative   | L5    |
| M   | 52  | Positive               | Positive        | Left arm      | Negative   | C5/6  |
| M   | 40  | Positive               | Positive        | Left leg      | Negative   | L3    |
| F   | 63  | Negative               | Negative        | Negative      | Fine motor deficit | C4/5 |
| M   | 49  | Positive               | Positive        | Right leg     | Negative   | L2    |
| F   | 47  | Negative               | Positive        | Right shoulder | Negative   | C4/5  |
| F   | 50  | Negative               | Positive        | Right leg     | Negative   | C5    |
| F   | 62  | Positive               | Positive        | Right leg     | Negative   | L4    |
| M   | 61  | Negative               | Positive        | Right arm     | Negative   | C7    |
| M   | 19  | Negative               | Positive        | Left leg      | Negative   | L3    |
| F   | 71  | Positive               | Positive        | Left leg      | Negative   | L2    |
| F   | 54  | Positive               | Positive        | Right leg     | Negative   | L3    |
| F   | 56  | Negative               | Positive        | Negative      | Fine motor deficit | C1/2 |
| M   | 53  | Positive               | Positive        | Right leg     | Negative   | L4    |
| F   | 64  | Negative               | Negative        | Negative      | Gait disturbance | T12  |
| M   | 45  | Negative               | Positive        | Right leg     | Negative   | L3    |
| F   | 64  | Negative               | Negative        | Right leg     | Negative   | L3/4  |
| F   | 77  | Positive               | Negative        | Negative      | Gait disturbance | C1/2 |

IR: infrared.

### TABLE 2. Type of neurologic symptom and electrophysiology finding

| Type of neurologic symptom | Electrophysiology test |   |
|----------------------------|------------------------|---|
|                            | Positive | Negative |
| Radiculopathy (n=16)       | 9 (56.2) | 7 (43.7)  |
| Myelopathy (n=7)           | 2 (28.5) | 5 (71.4)  |

Values are presented as number (%).
Comparing Sensitivity Between Different Diagnostic Modality in IDEM Tumor

TABLE 3. Type of neurologic symptom and IR thermography finding

| Type of neurologic symptom | IR thermography test |
|---------------------------|----------------------|
|                           | Positive | Negative |
| Radiculopathy (n=16)      | 15 (93.7) | 1 (6.2)  |
| Myelopathy (n=7)          | 2 (28.5)  | 5 (71.4) |

Values are presented as number (%).
IR: infrared.

FIGURE 1. In radiculopathy group, 15 out of 16 (93.7%) (p-value=0.017) show consistency with infrared thermographic test result. Nine out of 16 (56.2%) (p-value=0.371) show consistent electrophysiology test result.

TABLE 4. Type of neurologic symptom and postoperative change of IR thermography test result

| Type of neurologic symptom | Postoperative IR thermography change |
|----------------------------|--------------------------------------|
|                            | Improved | Unchanged |
| Radiculopathy (n=15)       | 10 (66.7)| 5 (33.3)  |
| Myelopathy (n=2)           | 0 (0)    | 100 (100) |

Values are presented as number (%).
IR: infrared.

FIGURE 2. Example of magnetic resonance imaging, thermography, electrophysiology test result in 63 years old female patient diagnosed with intradural extramedullary tumor. (A) Enhanced round shaped tumor was identified in T1 weighted enhanced axial image in L2/3 level. (B) Well enhanced round lesion was identified on right foramen between L2/3 level. (C) Preoperative infrared thermography show more than 0.3°C decreased in right leg.
DISCUSSION

IR thermography was widely used to diagnose and evaluate various spinal lesions. In patients with multiple disc herniations, thermographic findings show 88.6% sensitivity and 86.4% correlation with neurologic symptoms.\(^{19}\) Another study revealed consistency between dermatomal neurologic symptoms and thermographic test results in 78.5% of patients diagnosed with a herniated disc.\(^{20}\) Zhang et al.\(^{20}\) reported that thermal imaging can effectively visualize whiplash injury. The temperature of the neck and shoulder were 1°C–2°C higher than normal just after the injury. This gradually normalizes. In patients with multiple herniated cervical lesions, the distribution of the thermal change along the dermatome is reportedly an effective tool for diagnosing the radiculopathy origin.\(^{20}\) Dimitrijevic et al.\(^{21}\) examined the relationship between thermal deficit and clinical functional status. A strong positive relationship was found between thermal abnormalities and clinical severity in patients with unilateral lumbosacral radiculopathy.\(^{20}\) In this study, when comparing pre and post operative thermography change, radiculopathy group (66.6%) showed more improvement than myelopathy group (0%).

Few previous studies have examined the relationship between the presence of a spinal tumor and thermographic test findings. Zhang et al.\(^{11}\) reported such a relationship in 137 cases. The consistency between thermographic abnormalities and dermatome neurologic symptoms was reported at 81.1% for radiculopathy and 71.9% for myelopathy for patients with spinal tumors.\(^{11}\) Specifically in patients diagnosed with schwannoma, 78.6% of radiculopathy patients (11 out of 14) had symptoms and thermographic findings.\(^{11}\) An electrophysiology study was done in patients diagnosed with a spinal IDEM tumor, which showed positive test results in 36% (25 among 69) of cases.\(^{21}\) No previous study has compared electrophysiology test results and IR thermography test results in IDEM tumors.

The IDEM schwannomas usually arise from the dorsal root ganglion. As the dorsal root is comprised of the sensory somatic nerve, patients with IDEM schwannoma usually feature a single radiculopathy symptom.\(^{11}\) To compare the diagnostic value between different modalities, a single root involvement in IDEM tumors is adequate to analyze multiple nerve root lesions due to the fewer variables. We hypothesize that analyzing patients with an IDEM tumor can be very effective in comparing different diagnostic modalities.

As the spinal nerve root is a peripheral nerve, reviewing previous studies about various peripheral lesions can be meaningful. Specifically, comparison studies between electromyography and IR thermography in various diseases have been carried out. Among the 50 patients who were diagnosed with carpal tunnel syndrome, thermography shows a higher sensitivity in detecting the disease than electromyography, but specificity was higher on electromyography.\(^{16}\) Another study showed that thermographic abnormalities were revealed in 6 patients (43%) while electromyographic abnormalities were revealed in 10 of 14 patients (71%) diagnosed with cervical radiculopathy. Thermography was not superior to electromyography for cervical radiculopathy patients.\(^{24}\) A thermographic test was done on 431 patients diagnosed with chronic pain disease, with 70% of them showing positive findings.\(^{17}\) In 216 patients who underwent an electromyography study, 51% presented abnormalities.\(^{17}\) The author suggests that thermography is the most effective method for detecting chronic pain syndrome.\(^{17}\) In our study, in patients diagnosed with IDEM tumor, which presents with radiculopathy symptoms, thermography can be more useful to objectify subjective symptoms than an electrophysiology test.
We questioned how thermal change develops with pain and how the somatic pain distribution and thermatome coincide. One pathophysiological factor regarding thermal change concerns autonomic nerve disruption.\footnote{4,6,20} Sympathetic activation via the rami communicant by sinuvertebral nerve activation may be responsible for this pathophysiology.\footnote{14,20} The sympathetic innervation of the skin has 2 branches: the adrenergic vasoconstrictor and cholinergic vasodilator.\footnote{20} The adrenergic vasoconstrictor releases norepinephrine to bind the $\alpha$ receptors to induce vasoconstriction, which preserves the core temperature.\footnote{3,8} The cholinergic vasodilator increases skin blood flow to remove body heat from the core.\footnote{2,8} Vasoconstriction can induce relative hypothermia.\footnote{15}

The sympathetic nerves are distributed from the thoracic to lumbar spinal level. Below the L3 level, the sympathetic nerve fibers in the sinuvertebral nerve connect to the sympathetic ganglion in the upper lumbar and low thoracic levels through gray rami communicans and the sympathetic chain. They finally connect to the postganglionic nerve fiber.\footnote{22} Based on this anatomy study, we suggest that the thermographic changes due to disruption of the sinuvertebral nerve are insufficient to explain the dermatomal distribution of the thermatomal abnormalities. The sympathetic nerves below the L3 level mix with the upper lumbar and thoracic nerve fibers, indicating that the thermatomal changes at the specific dermatome lesion of each lumbar level cannot be fully explained.

Another pathophysiological factor to explain the correlation between the thermal change distribution and pain distribution is the local response due to the somatic nerve disruption. One study suggests that antidromic stimulation can explain the skin thermal changes.\footnote{10} Antidromic stimulation is the reverse transmission of an electric signal at the somatic sensory nerve, from the cord to the periphery.\footnote{10} Functional modulation can be expected by transmitting a reverse electric signal. This implies that the somatic nervous system also plays a role in skin thermal change.

Nerve fibers from the thermal receptor also pass through the dorsal root ganglion and enter the spinal canal.\footnote{3} We hypothesize that, due to a compressive lesion near the nerve root, disruption of the transmission of correct thermal data from the periphery to the brain may hinder adequate thermal regulation from the supraspinal area. One previous study about the supraspinal response to skin thermal stimuli used a positron-emission tomography study and observed cortical, thalamic, and hypothalamic responses.\footnote{9} Inadequate afferent thermal information may result in inadequate skin thermal autoregulation.

We suggest that thermal change was unspecific in the myelopathy group because of the mixed fibers in the different lesions. Involvement of the intermediolateral cell column where there are abundant sympathetic cell bodies may be crucial for thermal change. Lesions affecting a part of the intermediolateral cell column usually give no clear-cut symptoms because each vertebral ganglion receives fibers from more than one segment of the spinal cord.

This study has limitations that require further research. Because of the low incidence of IDEM spinal tumors, more patient data is required for further statistical analysis. Despite efforts to standardize the environment for IR thermography, it is difficult to control external variables such as atmosphere or humidity. To avoid bias induced by intraoperative procedures or post-operative medications, post-operative IR thermography was done one week after surgery. This is a preliminary study and a control group and analysis of casualty can extract meaningful results. In future study, extracting meaningful statistic result such as sensitivity and specificity can be considered for proving causality.
In conclusion, IR thermography is a valid neurophysiological diagnostic imaging procedure on IDEM spinal cord tumors. For patients diagnosed with an IDEM tumor with radiculopathy symptoms, thermography can be more sensitive for objectifying subjective neurologic symptoms than the electrophysiology test. This study implies that IR thermography can be useful when electrophysiology tests show false-negative results in patients with radiculopathy.

REFERENCES

1. Patapoutian A, Peier AM, Story GM, Viswanath V. ThermoTRP channels and beyond: mechanisms of temperature sensation. Nat Rev Neurosci 4:529-539, 2003
   PUBMED | CROSSREF
2. Wong BJ, Hollowed CG. Current concepts of active vasodilation in human skin. Temperature (Austin) 4:41-59, 2016
   PUBMED | CROSSREF
3. Roddie IC, Shepherd JT, Whelan RF. The vasomotor nerve supply to the skin and muscle of the human forearm. Clin Sci 16:67-74, 1957
4. Curt A, Nitsche B, Rodic B, Schurch B, Dietz V. Assessment of autonomic dysreflexia in patients with spinal cord injury. J Neurol Neurosurg Psychiatry 62:473-477, 1997
   PUBMED | CROSSREF
5. Dimitrijevic IM, Kocic MN, Lazovic MP, Mancic DD, Marinkovic OK, Zlatanovic DS. Correlation of thermal deficit with clinical parameters and functional status in patients with unilateral lumbosacral radiculopathy. Hong Kong Med J 22:320-326, 2016
   PUBMED | CROSSREF
6. Goodman PH, Murphy MC, Siltanen GL, Kelly MP, Rucker L. Normal temperature asymmetry of the back and extremities by computer-assisted infrared imaging. Thermology 1:195-202, 1986
7. Grant RT, Holling HE. Further observations on the vascular responses of the human limb to body warming: evidence for sympathetic vasodilator nerves in the normal subject. Clin Sci (Lond) 3:273-285, 1938
8. Hodges GJ, Kellogg DL, Johnson JM. Effect of skin temperature on cutaneous vasodilator response to the β-adrenergic agonist isoproterenol. J Appl Physiol (1985) 118:898-903, 2015
   PUBMED | CROSSREF
9. Egan GF, Johnson J, Farrell M, McAllen R, Zamarripa F, McKinley MJ, et al. Cortical, thalamic, and hypothalamic responses to cooling and warming the skin in awake humans: a positron-emission tomography study. Proc Natl Acad Sci U S A 102:5262-5267, 2005
   PUBMED | CROSSREF
10. Hobbins WB. Basic concepts of thermology and its application in the study of the sympathetic nervous system presented at The Second Albert Memorial Symposium. Washington, D.C.: Contemporary Issues in Chronic Pain Management, 1986
11. Zhang HY, Cho YE, Kim YS. Thermographic findings of spinal cord tumor. Pan Am J Med Thermol 1:55-67, 2014
   CROSSREF
12. Winn HR. Youmans neurological surgery, ed 6. Amsterdam: Elsevier, 2011
13. Lenti J, Anichini G, Landi A, Piciocchi A, Passacantilli E, Pedace F, et al. Spinal nerves schwannomas: experience on 367 cases-historic overview on how clinical, radiological, and surgical practices have changed over a course of 60 years. Neurol Res Int 2017:9508959, 2017
   PUBMED | CROSSREF
14. Mathias CJ, Frankel HL. Clinical manifestations of malfunctioning sympathetic mechanisms in tetraplegia. J Auton Nerv Syst 7:303-312, 1983
   PUBMED | CROSSREF
15. Grossmann M, Jamieson MJ, Kellogg DL Jr, Kosiba WA, Pergola PE, Crandall CG, et al. The effect of iontophoresis on the cutaneous vasculature: evidence for current-induced hyperemia. Microvasc Res 50:444-452, 1995
   PUBMED | CROSSREF
16. Hendler N, Uematsu S, Hungerford DS, Long D, Ono N. EMG vs. thermography to diagnose CRPS and radiculopathy. Electromyogr Clin Neurophysiol 21:165-182, 2020
17. Herrick RT, Herrick SK. Thermography in the detection of carpal tunnel syndrome and other compressive neuropathies. J Hand Surg Am 12:943-949, 1987

18. Nakamura SI, Takahashi K, Takahashi Y, Yamagata M, Moriya H. The afferent pathways of discogenic low-back pain. Evaluation of L2 spinal nerve infiltration. J Bone Joint Surg Br 78:606-612, 1996

19. Cho YE, Kim YS, Zhang HY. Clinical efficacy of digital infrared thermographic imaging in multiple lumbar disc herniations. J Korean Neurosurg Soc 27:237-245, 1998

20. LeBouef T, Yaker Z, Whited L. Physiology, autonomic nervous system. Treasure Island, FL: StatPearls Publishing, 2022

21. Yaşar S, Kırık A. Electrophysiologic assessment in spinal intradural tumors. Gulhane Med J 62:92-96, 2020

22. Kim YS, Cho YE, Oh SH. Digital infrared thermographic imaging (D.I.T.I.) in herniated lumbar disc patients. J Korean Neurosurg Soc 19:1303-1313, 1990

23. Lee YS, Paeng SH, Farhadi HF, Lee WH, Kim ST, Lee KS. The effectiveness of infrared thermography in patients with whiplash injury. J Korean Neurosurg Soc 57:283-288, 2015

24. So YT, Olney RK, Aminoff MJ. A comparison of thermography and electromyography in the diagnosis of cervical radiculopathy. Muscle Nerve 13:1032-1036, 1990

25. Zhang HY, Kim YS, Cho YE. Thermotomal changes in cervical disc herniations. Yonsei Med J 40:401-412, 1999