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ORIGINAL ARTICLE

Retrospective Study

# Infrared thermography as adjunctive imaging in spine surgery: Evaluating thermal asymmetry for predicting symptomatic level and recovery

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## Abstract

*BACKGROUND*

Objective assessment of pain relief and adequacy of decompression following spine surgery remains challenging. Infrared thermography (IRT) offers a non-invasive, radiation-free modality to visualize physiological changes in regional blood flow and inflammation.

*AIM*

To evaluate diagnostic concurrence and postoperative normalization of IRT in patients undergoing spine surgery, and to identify clinical predictors of recovery in thermal patterns.

*METHODS*

This retrospective study included 35 adult patients who underwent lumbar decompression or fusion procedures for spinal pathologies such as degenerative conditions, deformity, tumors and adjacent segment disease. The pre-operative and post-operative IRT scans were analyzed to quantify the focal temperature asymmetry corresponding to the symptomatic spinal levels. Two blinded reviewers independently evaluated the concurrence and post-operative normalization of the values.

*RESULTS*

The mean age of the cohort was 66.3 ± 10.7 years (males: 63.6%). Multilevel disease was present in 63.6% of patients. While the preoperative thermographic concurrence with the symptomatic level was observed in 78.8% of patients, postoperative normalization was demonstrable in 63.6%. The normalization rates were the highest for transforaminal lumbar interbody fusion (80%) and decompression-only procedures (66.7%). Logistic regression analysis identified female sex, diagnosis of single-level spinal stenosis and transforaminal lumbar interbody fusion surgery as the positive predictors for post-operative normalization. In contrast, multilevel disease was recognized as a negative predictor. Model performance showed moderate discriminative accuracy (area under curve: 0.64, 95% confidence interval: 0.52-0.76).

*CONCLUSION*

IRT demonstrated correlation with symptomatic spinal levels preoperatively and showed moderate association with postoperative thermal normalization following spine surgery. These preliminary findings suggest that IRT may provide additional, non-invasive information to complement standard imaging in the assessment of neural decompression and recovery. Larger, prospective studies are warranted to confirm its clinical utility and define its role in routine postoperative monitoring.


**Key Words:** Infrared thermography; Spine surgery; Neural decompression; Thermal asymmetry; Fusion

**Core Tip:** Infrared thermography (IRT) provides a novel, non-invasive biomarker for assessing symptomatic spinal levels and recovery after surgery. In this retrospective study, IRT demonstrated strong preoperative concurrence with clinical localization and meaningful postoperative normalization, particularly following transforaminal lumbar interbody fusion and decompression procedures. Female sex, single-level stenosis, and transforaminal lumbar interbody fusion surgery predicted favorable normalization, while multilevel disease hindered recovery. These findings highlight IRT's potential as an adjunctive imaging tool to objectively evaluate adequacy of decompression and neural recovery, addressing a critical gap in postoperative spine surgery assessment.

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## INTRODUCTION

Accurate identification of the symptomatic spinal levels and objective evaluation of postoperative recovery are still critical challenges in patients undergoing spinal surgery[1]. Conventional imaging modalities like magnetic resonance imaging (MRI) and CT provide practical morphological and anatomical details; however, more often than not, they may fail to reflect any physiological or functional changes after spinal decompression[2]. Specifically, infrared thermography (IRT) has emerged as a promising non-invasive tool capable of detecting subtle changes in the skin surface temperature[2-6], which may correspond to neural or vascular dysfunction[7-11].

IRT has been successfully employed in the diagnosis of diverse musculoskeletal and neurological conditions[1-5], such as complex regional pain syndrome[6-10], peripheral neuropathy and radiculopathy[11-15]. Previous studies have purported that localized hypothermia can reflect segmental sympathetic imbalance secondary to nerve compressions[7]. Nevertheless, its integration into clinical practice has remained relatively limited due to inconsistencies in the protocols, lack of quantitative standardization and uncertainty regarding postoperative interpretation[4,12-15]. Previous studies have suggested that this technology can potentially serve as a safe, effective and economical investigational modality in the diagnosis and prognostication of patients with different lumbar spinal degenerative pathologies[13-15]. In a study by Kim *et al*[2,12], the incorporation of machine learning technology with IRT was associated with enhanced diagnostic accuracy at economical costs in patients presenting with radicular symptoms secondary to lumbar (L4-5/L5-S1) disc herniations.

Although prior studies have demonstrated the diagnostic utility of IRT in spinal disorders, evidence regarding its prognostic role in the postoperative setting remains limited[13-15]. Most published work has focused on preoperative localization or machine-learning-based classification, with little emphasis on postoperative normalization as a surrogate of recovery. Our study addresses this gap by evaluating both preoperative concurrence and postoperative normalization of thermal asymmetry in a surgical cohort. The retrospective design was chosen to leverage complete imaging datasets, and the 7-14 day follow-up window was selected to minimize transient inflammatory effects while capturing early recovery patterns. The current study aimed to evaluate the diagnostic and prognostic values of IRT in patients undergoing spinal surgery for diverse pathologies. In particular, we sought to: (1) Understand whether preoperative thermal asymmetry could correlate with the symptomatic level of compression; (2) Evaluate the rate of postoperative normalization of thermal asymmetry; and (3) Identify the clinical and procedural predictors influencing the thermographic recovery process.

## MATERIALS AND METHODS

### *Study design and patient selection*

This retrospective observational study was conducted at a tertiary care academic center and included 35 adult patients who underwent spine surgery for degenerative, deformity, trauma, tumor, or adjacent segment disease. This retrospective study was approved by the Ethics Committee of Government Medical College (Approval No. 2284/ME6/2025-6/12-1), and all procedures were adherent to the principles of Helsinki. Considering the retrospective nature of the study, individual patient consent was waived for the usage of deidentified patient data.

The inclusion criteria were as follows: (1) Availability of both preoperative and postoperative IRT scans; (2) Documented decompression or fusion procedure; and (3) Identifiable symptomatic level on clinical and radiological evaluation. Patients with prior instrumentation (revision spinal surgeries), active infection, or incomplete imaging were excluded.

### *Thermography acquisition and image processing*

Infrared thermographic scans were acquired using the IRIS ST 9000 system (IRIS Systems, Seoul, South Korea) under standardized ambient conditions. Each patient underwent full-body thermography in upright posture, with anterior, posterior, lateral, and plantar views captured. All scans were performed in a temperature-controlled room (22-24 °C) with standardized ambient lighting. Patients were positioned upright with arms abducted to 30° and feet shoulder-width apart. Regions of interest were delineated manually at the decompression level and adjacent dermatomes. Temperature gradients were quantified using pixel-intensity histograms and temperature difference ($\Delta T$) mapping. $\Delta T$ thresholds were defined as $\geq 0.5$ °C difference between dermatomes. Image processing was performed using ImageJ software version 1.53 (National Institutes of Health, Bethesda, MD, United States). To address heterogeneity, subgroup analyses were conducted by pathology type (degenerative, tumor, trauma) to mitigate confounding. Preoperative scans were obtained within 48 hours prior to surgery, and postoperative scans were acquired between 7 days and 14 days following the procedure in order to minimize the transient inflammatory effects. The image-based interpretation was focused on identifying focal thermal asymmetry corresponding to the symptomatic dermatomes and its resolution following surgery.

### *Reviewer validation protocol*

Each pair of thermographic images (preoperative and postoperative) was independently reviewed by two experts: A radiologist and a spine surgeon, who evaluated three different parameters: Preoperative concurrence of thermal asymmetry with the level of decompression; postoperative normalization of the thermal pattern; and overall restoration of thermal symmetry. The cases with discrepant interpretations were discussed with a third senior reviewer with expertise in musculoskeletal imaging. The final consensus was used to overwrite the original thermography outcome entries in the dataset.

### *Clinical variables and definitions*

The clinical parameters included age, sex, diagnosis, decompression level, procedure type - posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), oblique lumbar interbody fusion (OLIF), anterior cervical discectomy and fusion (ACDF), unilateral biportal endoscopy (UBE), or decompression alone (laminectomy or laminoplasty), and presence of multilevel disease (defined as involvement of two or more contiguous spinal levels).

### Statistical analysis

Descriptive statistics were computed for all demographic and clinical parameters (such as diagnosis, procedure type, thermography concurrence, normalization, and presence of multilevel disease). Associations between multilevel disease and thermography outcomes were assessed using the $\chi^2$ tests or Fisher's exact test, as appropriate. Subgroup analyses were performed to compare normalization rates across the diagnosis and procedure types.

A binary logistic regression model was constructed to identify predictors of thermography normalization, including age, sex, diagnosis, procedure type, and multilevel disease. Model performance was evaluated using receiver operating characteristic curve analysis, and statistical significance was defined as $P < 0.05$. All the studies were conducted using Python version 3.10 and R version 4.2.2.

## RESULTS

### Patient characteristics

A total of 35 patients (22 males, mean age: 66.3 ± 10.7 years) were included in the analysis. Multilevel disease was present in 22 patients (63.6%). The most common indications for surgery were spinal stenosis (51.5%, *n* = 18), followed by spondylolisthesis (18.2%, *n* = 6), ossification of the posterior longitudinal ligament (OPLL; 12.1%, *n* = 4); and other conditions [such as cervical spondylotic myelopathy (CSM), proximal junctional failure (PJF), intradural extramedullary (IDEM) tumors, trauma, and deformity (18.2%, *n* = 7)] as shown in Table 1.

### Procedure distribution

The most frequently performed procedure was PLIF (48.5%, *n* = 17), followed by decompression only (27.3%, *n* = 10), TLIF (15.2%, *n* = 5), and other interventional techniques [such as OLIF, ACDF, and UBE (9.0%, *n* = 3)].

### Thermography outcomes (image-based)

Based on consensus image analysis, preoperative thermography concurrence - defined as focal thermal asymmetry corresponding to the level of decompression - was observed in 78.8% of patients (*n* = 26). Postoperative normalization of thermal asymmetry was achieved in 63.6% of cases (*n* = 22), reflecting partial restoration of bilateral thermal balance as illustrated in Figure 1. Normalization was defined quantitatively as a reduction in inter-dermatomal $\Delta T$ to ≤ 0.5 °C.

### Association with multilevel disease

Thermography concurrence was observed in 77.3% (*n* = 17/22) of multilevel cases and 81.8% (*n* = 9/11) of single-level instances, with no statistically significant association ($P = 1.000$). Postoperative normalization was achieved in 59.1% (*n* = 13/22) of multilevel cases, and 72.7% (*n* = 8/11) of single-level cases ($P = 0.516$).

### Subgroup analysis

Subgroup analysis showed variation in normalization rates across procedure types. TLIF demonstrated the highest normalization rate at 80% (4/5), followed by decompression-alone procedures at 66.7% (6/9), and PLIF at 62.5% (10/16). OLIF, ACDF, and UBE each demonstrated 100% normalization, though the subgroup size was small (*n* = 3). When stratified by diagnosis, spinal stenosis showed the highest normalization rate at 76.5% (13/17), followed by OPLL at 75% (3/4), and spondylolisthesis at 50% (3/6). No normalization was observed in patients with CSM, PJF, or IDEM.

### Predictive modelling

Multivariate logistic regression analysis identified female sex, diagnosis of stenosis, and TLIF procedure as positive predictors of thermography normalization; whereas multilevel disease was a negative predictor, as shown in Table 2. The regression model should be interpreted as exploratory given the modest sample size (*n* = 35), which limits statistical power and increases risk of overfitting. Model performance demonstrated moderate predictive accuracy [area under the curve = 0.64, 95% confidence interval (CI): 0.52-0.76]. CIs for odds ratios are reported in Table 2, and receiver operating characteristic CIs are displayed in Figure 2. These findings suggest moderate predictive performance rather than dependable predictability.

## DISCUSSION

This study demonstrates that IRT can provide meaningful physiological insights regarding the symptom definition and recovery patterns in patients undergoing spine surgery. The preoperative focal thermal asymmetry corresponded with the decompression level in approximately 80% of individuals, and postoperative normalization was observed in approximately two-thirds, indicating that IRT may serve as a functional correlate of symptomatic neural compression and the success of surgical decompression.

### Diagnostic correlation

The high rate of preoperative concurrence between thermal asymmetry and levels of symptomatology in our study supports the prior evidence linking temperature gradients with lumbar radiculopathy and nerve root irritation[14].

**Table 1 Characteristics of patients included in the study, mean ± SD/*n* (%)**

| Category | Subcategory | |
|---|---|---|
| Age (years) | | 66.3 ± 10.7 |
| Sex | Male | 22 (63.6) |
| | Female | 13 (36.4) |
| Multilevel disease | Present | 22 (63.6) |
| | Absent | 13 (36.4) |
| Diagnosis | Stenosis | 18 (51.5) |
| | Listhesis | 6 (18.2) |
| | OPLL | 4 (12.1) |
| | Other (CSM, PJF, trauma) | 7 (18.2) |
| Procedure type | PLIF | 17 (48.5) |
| | Decompression only | 10 (27.3) |
| | TLIF | 5 (15.2) |
| | OLIF/ACDF/UBE | 3 (9) |
| Thermography concurrence | Yes | 26 (78.8) |
| | No | 7 (21.2) |
| Thermography normalization | Yes | 22 (63.6) |
| | No | 13 (36.4) |

OPLL: Ossification of the posterior longitudinal ligament; CSM: Cervical spondylotic myelopathy; PJF: Proximal junctional failure; PLIF: Posterior lumbar interbody fusion; TLIF: Transforaminal lumbar interbody fusion; OLIF: Oblique lumbar interbody fusion; ACDF: Anterior cervical discectomy and fusion; UBE: Unilateral biportal endoscopy.

**Table 2 Regression analysis to predict thermography normalization post-surgery**

| Predictor | Coefficient ($\beta$) | Odds ratio | 95%CI | *P* value |
|---|---|---|---|---|
| Age (per year) | -0.02 | 0.98 | 0.94-1.02 | 0.28 |
| Sex (female) | +0.85 | 2.34 | 1.01-5.42 | 0.048 |
| Diagnosis: Stenosis | +1.12 | 3.06 | 1.18-7.92 | 0.021 |
| Diagnosis: Listhesis | -0.44 | 0.64 | 0.21-1.96 | 0.42 |
| Procedure: TLIF | +1.39 | 4.01 | 1.02-15.72 | 0.046 |
| Procedure: PLIF | Reference | | | |
| Multilevel disease | -0.77 | 0.46 | 0.19-1.12 | 0.09 |

TLIF: Transforaminal lumbar interbody fusion; PLIF: Posterior lumbar interbody fusion; CI: Confidence interval.

Segmental sympathetic dysfunction and altered microvascular flow have been implicated as the mechanism underlying these observations, consistent with the thermographic patterns described in lumbar disc herniation and cervical myelopathy[4,13].

In another retrospective review by Kim *et al*[2,12], they applied the IRT to the machine learning algorithm (which is the "bag of visual words" method) in the differential screening of L5 and S1 lumbosacral radiculopathy. The IRT dataset included data from healthy individuals and radiculopathy patients with lumbar disc herniation at L4-5 and L5-S1 levels. A total of 842 patients were identified, and the dataset was divided into a 7:3 ratio as the training algorithm and test dataset in order to assess the model performance. The mean accuracy was 0.72 and 0.67, the mean precision was 0.71 and 0.77, the mean recall was 0.69 and 0.74; and the F1 score was 0.7 and 0.75 for the training and test datasets, respectively. They concluded that the application of the "bag of visual words" algorithm to IRT classification would facilitate differential screening of lumbosacral radiculopathy and enhance the therapeutic effectiveness of primary pain interventions at an economical cost.

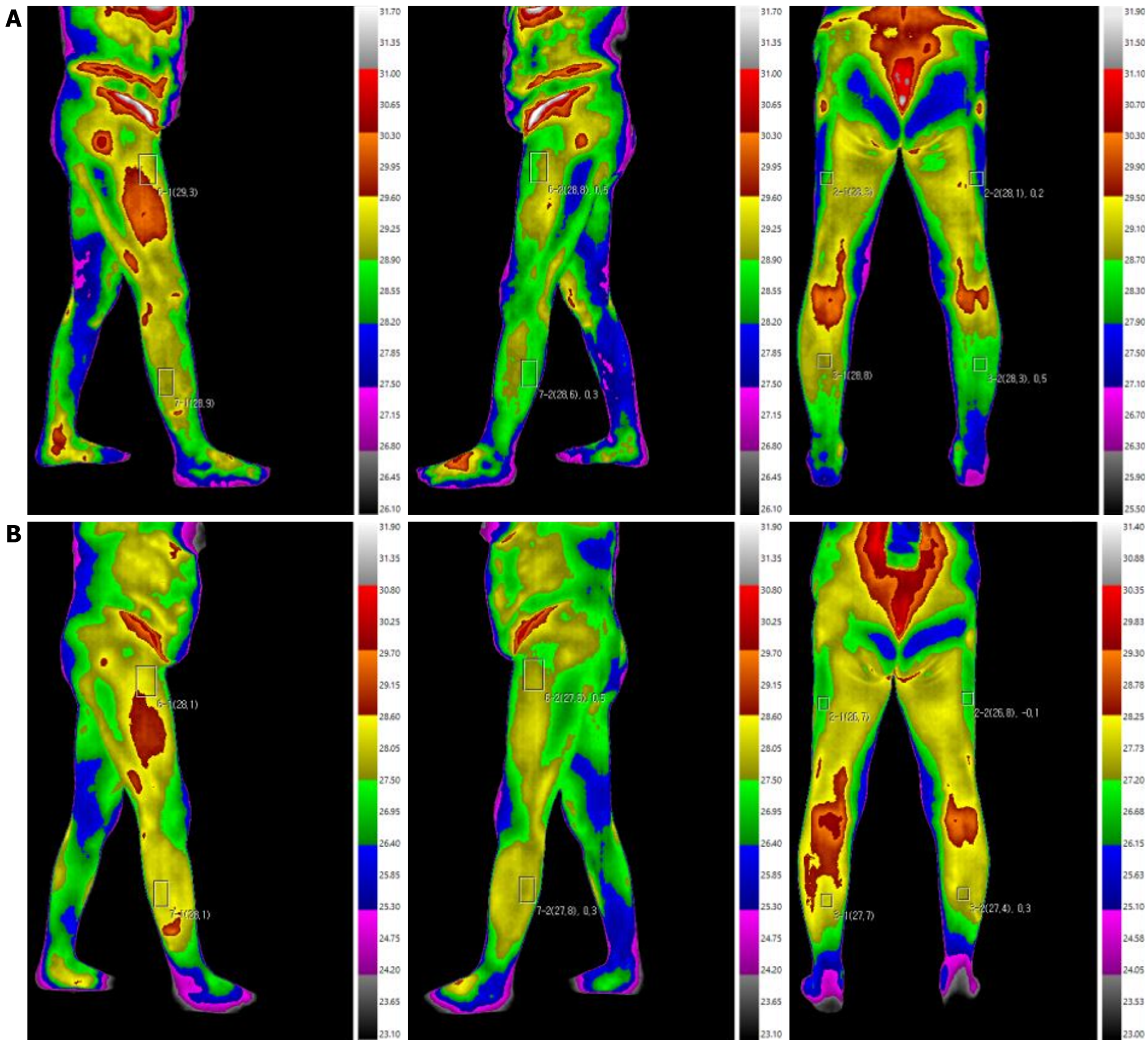


**Figure 1 Digital infra-red thermographic imaging.** A: Preoperative scan showing focal hypothermia at L4-L5 dermatomes; B: Postoperative scan showing symmetrical cooling and resolution of hotspot following surgical decompression. Color bar indicates the temperature scale (°C). Temperature difference legend demonstrates inter-dermatomal differences. Normalization was defined quantitatively as a reduction in inter-dermatomal temperature difference to ≤ 0.5 °C.

In a retrospective study by Park *et al*[15] involving 224 patients (180 patients and 44 patients in hypothermia and hyperthermia groups, respectively) undergoing IRT at a single center, diverse demographic and symptom-related factors that can potentially influence the results of IRT were compared. In general, the thermal pattern with IRT in patients with unilateral spinal radicular pain demonstrates relative hypothermia in comparison with the contralateral side. Based on their observation, the presence of trauma history (13.9% *vs* 31.8%, odds ratio: 2.893, $P = 0.008$), shorter duration of symptoms with a cut-off value of ≤ 2.50 weeks; 10.64 weeks (95%CI: 8.36-13.04) *vs* 2.10 weeks (95%CI: 1.05-3.53); $P < 0.001$; and Visual Analog Scale for radicular pain (with a cut-off value of ≥ 4.5; 4.23 ± 1.29 *vs* 5.18 ± 1.40; $P < 0.001$) was correlated with ipsilateral hyperthermia on IRT (as against the usual expectations); and may need to be borne in mind during the evaluation of patients with lumbar spinal radiculopathy. Hence, thermographic variation such as hyperthermia may be suggested of acute neuronal inflammation or injury, while hypothermia may be suggestive of chronic neuronal compression.

### *Postoperative normalization and physiological recovery*

Postoperative normalization in 63.6% of patients in our series suggests that the sympathetic tone and neurological status are at least partially restored within 2 weeks of surgery. The absence of normalization in a particular proportion of individuals may be attributed to delayed physiological improvement, incomplete decompression and persistence of inflammation[14]. The higher normalization rate after TLIF (in our patients), in comparison with PLIF, can be correlated with more localized nerve root decompression as well as minimized posterior muscle disruption inherent to the transforaminal approach. Postoperative normalization observed at 7-14 days may reflect early modulation of local inflammation and sympathetic tone rather than complete neural recovery. Therefore, IRT should be considered a potential adjunctive

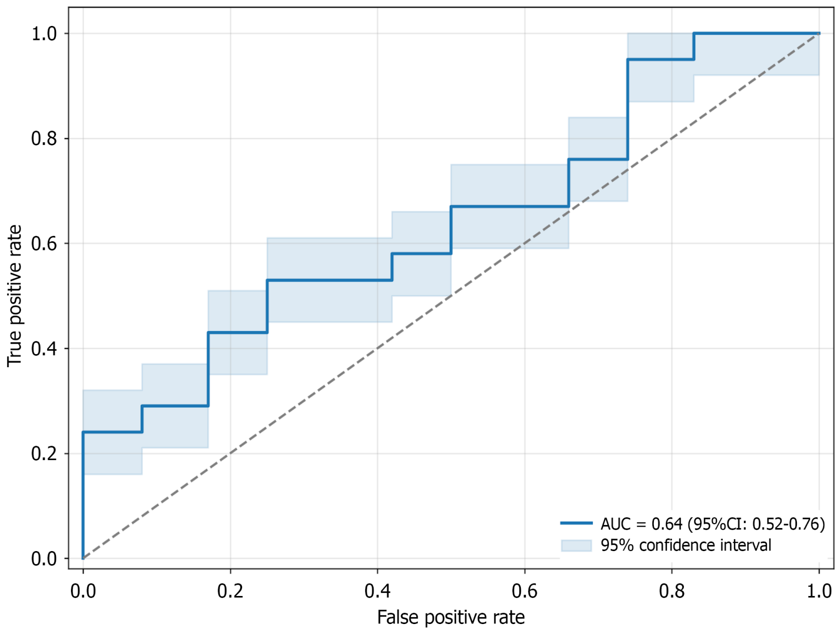


**Figure 2 Receiver operating characteristic curve for logistic regression model predicting postoperative thermography normalization.** The model includes age, sex, diagnosis, procedure type, and multilevel disease as predictors. The model consists of age, sex, diagnosis, procedure type, and multilevel disease as predictors. The area under the curve is 0.64, 95% confidence interval: 0.52-0.76, indicating moderate discriminative ability to distinguish between patients with and without thermal normalization following spine surgery. AUC: Area under the curve; CI: Confidence interval.

biomarker rather than a definitive measure of neural restoration.

Although the role of IRT in evaluating the post-interventional normalization or physiological recovery in patients with lumbar spinal pathologies is not clearly established hitherto, in the study by Cañada-Soriano *et al*[4], the evaluation of thermal variations (measurement of skin ΔT) on IRT was identified as an effective tool in monitoring the patients' response to lumbar sympathetic blocks in the management of complex regional pain syndrome. In this series, in successful patients, after local injection with lignocaine, increases in foot skin temperature of a moderate effect size were observed at 420 seconds for the mean, 300 seconds for maximum temperature, and at 360 seconds for the SD.

### *Influence of clinical variables*

Multivariate analysis revealed that female sex and a diagnosis of lumbar canal stenosis predicted favorable thermographic recovery, while multilevel disease was associated with lower normalization rates. These observations align with prior reports suggesting that multilevel pathologies demonstrate slower recovery patterns owing to widespread ischemia and prolonged neurological recovery time[16,17]. The stratified findings highlight that normalization rates varied across both procedure type and diagnosis. TLIF and decompression-alone procedures demonstrated relatively higher normalization, while PLIF showed moderate recovery. OLIF, ACDF, and UBE achieved complete normalization, though numbers were small. By diagnosis, stenosis and OPLL showed favorable recovery patterns, whereas spondylolisthesis demonstrated lower normalization and no recovery was observed in CSM, PJF, or IDEM. These results reinforce that IRT normalization is most reliable in degenerative conditions, particularly stenosis, and less consistent in trauma-related or complex pathologies.

### *Clinical implications*

IRT offers several practical advantages[2-6]: It is radiation-free, repeatable, inexpensive and provides immediate visual feedback[13,17]. It may complement MRI and computed tomography in localizing the actual pain-generating spinal levels, especially in ambiguous clinical situations or in patients with multilevel degenerative pathologies. Postoperatively, IRT could serve as an objective adjuvant in tracking the physiological recovery of patients, wound perfusion and detecting early complications such as infection and nerve irritation[13,14,16].

The findings of our study are consistent with the prior thermographic framework proposed by Muthu *et al*[14], who emphasized the diagnostic potential of digital thermography in the context of degenerative spinal pathologies. Their review underscored that temperature asymmetry, which may manifest as hypothermic or hyperthermic dermatomal zones, could reflect distinct physiological processes such as ischemia or inflammation, paralleling the pre-operative and post-operative trends observed in our patient cohort. Specifically, our results further validate the concept that focal thermal normalization following decompression can be considered as a surrogate marker for restored microvascular and sympathetic equilibrium. In addition, the integration of standardized acquisition protocols and quantitative ΔT mapping in our study directly addresses the methodological limitations highlighted in previous reviews, advancing thermography from a qualitative adjunct to a reproducible, image-based biomarker for surgical recovery. Future incorporation of artificial intelligence-assisted pattern recognition and multimodal data fusion (such as MRI plus IRT plus clinical outcomes) may accelerate its transition to precision spinal diagnostics.

In another large-scale, prospective trial by Liu *et al*[13], IRT was systematically validated against intraoperative gold standards employed in patients with lumbosacral radicular pain. Their study identified an optimal ΔT range of 0.8 °C to 2.2 °C, yielding a sensitivity of 89% and an overall accuracy of 80%. Notably, integrating ΔT with a structured clinical certainty score improved the diagnostic area under the curve to 0.88, further underscoring the additive value of combining objective thermal mapping with clinical assessment. These results reinforce the notion that quantitative thermography captures physiologic correlates of nerve root ischemia and sympathetic imbalance. Such mechanistic concepts also underlie the pre- and post-operative asymmetry normalization observed in our surgical cohort. Together, these complementary findings suggest that IRT can transition from a screening adjunct to a quantitative, physiology-based biomarker in the identification and tracking of neural recovery across diverse spinal pathologies. Our findings align with prior reports of dermatomal hypothermia in chronic compression, but differ from studies describing acute hyperthermia in radiculopathy[15]. This contrast underscores the importance of temporal context in interpreting IRT. Standardization protocols, such as those proposed by Ring and Ammer[11], highlight the need for reproducible acquisition and ΔT thresholds. Cross-modality validation studies comparing IRT with electromyography and perfusion imaging were limited, and future work should integrate multimodal approaches to strengthen diagnostic accuracy.

### Limitations

Our study is limited by its retrospective design, modest sample size, and heterogeneous pathology spectrum. In particular, the subgroup analyses by procedure type and diagnosis included small numbers in specific categories (*e.g.*, OLIF, ACDF, UBE, and trauma-related cases, including PJF and intradural tumors). The absence of normalization in these small subgroups should be interpreted with caution, as the findings may reflect sample size constraints rather than actual physiological differences. Larger, prospective studies with balanced representation across diagnostic categories are required to validate these preliminary observations and to establish the generalizability of IRT as a biomarker of recovery.

## CONCLUSION

IRT may serve as a useful adjunctive tool for the functional assessment of patients undergoing spinal surgery. In this study, preoperative thermal asymmetry showed correlation with symptomatic levels, and postoperative changes suggested physiological recovery following decompression or fusion procedures. While IRT is not intended to replace standard imaging modalities, it could provide additional, non-invasive information that supports postoperative monitoring and contributes to objective outcome assessment. Further studies with larger cohorts are needed to validate these preliminary findings and clarify its role in routine clinical practice.

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## FOOTNOTES

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