Observational Study

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Infrared monitoring-based optimization of interventional lumbar sympathectomy outcomes evaluation in peripheral vascular disease patients

Experimental trial thermovision-guided lumbar sympathectomy

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Abstract

Chronic limb-threatening ischemia (CLTI) is associated with significant mortality and limb loss. The interventional lumbar sympathectomy (LS) is one of the supportive treatment options for CLTI patients, reducing pain intensity and peripheral arterial resistance. The use of LS has gradually declined despite its positive effects. The contradictory results of studies dealing with evidence of tissue perfusion improvement after LS are one of the possible explanations. We describe a new approach for the evaluation of LS efficacy in 2 CLTI patients and below-the-knee arteries pathology in our observational cohort experimental trial. We utilized the angiosome concept of foot. Angiography identified angiosomes with occluded source artery. The relationship between angiosomes and corresponding surface areas of angiosomes-dermatomes was identified. The infrared thermography was used for the measurement of thermal changes in dermatomes before and after LS. Based on the thermal changes in dermatomes and the relationship between angiosomes and their dermatomes, we estimated perfusion in angiosomes after the LS procedure. We found that the clinically relevant increase in temperature (>1°C) was presented only in dermatomes corresponding to angiosomes with occluded source artery. We hypothesize that LS opens up anastomoses between angiosomes, resulting in redistribution of blood flow between angiosomes that is associated with an increase in temperature in angiosomes with occluded source artery.

Abbreviations: ABI = ankle-brachial index, BTK = below-the-knee, CLTI = chronic limb-threatening ischemia, IRT = infrared thermography, LS = lumbar sympathectomy, PA = peroneal artery, PAD = peripheral arterial disease, PTA = posterior tibial artery.

Keywords: angiosome, chronic limb-threatening ischemia, microcirculation, sympathectomy, thermography

1. Introduction

Chronic limb-threatening ischemia (CLTI) represents the end stage of peripheral arterial disease (PAD). The accurate determination of CLTI epidemiology is not possible, particularly due to developing countries and secondarily due to a lack of high-quality data, especially from developing countries. In an analysis of the US MarketScan database, the prevalence and annual incidence of CLTI were estimated at 1.33% and 0.35%, respectively.[1] Another recently published study reported an

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estimated annual incidence and an estimated 2-year prevalence of 0.33% and 0.74%, respectively.[2] The prognosis of CLTI patients is alarming, resulting in significant mortality, limb loss, pain, and a diminished health-related quality of life.[3] Outcomes are even more devastating when revascularization is impossible.

There is a high risk of ischemic events in the CLTI population; thus, treatment must include optimal medical therapy consisting of lifestyle modifications, that is, smoking cessation, healthy diet, and weight loss, and pharmacological treatment, that is, antithrombotic therapy, antihypertensive therapy, lipid-lowering therapy, and diabetes management. In addition, rest pain, optimal wound care, and infection control should be managed. Exercise training is not recommended in patients with CLTI and wounds. The endovascular or surgical revascularization is recommended for the limb salvage when it is possible. Intermittent pneumatic compression or spinal cord stimulation can be considered in carefully selected patients (e.g., rest pain and minor tissue loss) in whom revascularization is not possible. Prostanoids can be considered selectively for patients with rest pain or minor tissue loss and in whom revascularization is not possible. The administration of vasoactive drugs (naftidrofuryl, pentoxifylline, and cilostazol) for these patients is not recommended.[4,5]

Although endovascular treatment has made remarkable progress in CLTI patient management, the risk of amputation persists even after successful revascularization. In the study by Baubeta et al[6], the amputation rate reached 12% during the first 6 months despite successful revascularization. According to another review of recent literature, amputation rates exceeded 15–20% within the first year.[7,8]

Persistent microvascular dysfunction may continue to exist even after successful endovascular treatment, and it may be a factor influencing wound healing.

Microvascular dysfunction is associated with impaired autoregulation of blood flow and vascular tone, leading to reduced oxygen delivery to the tissue, increased oxidative stress, and capillary rarefaction.[9,10]

The lumbar sympathectomy (LS) still represents one of the supportive treatment possibilities for CLTI patients. The interventional variant of LS is a minimally invasive procedure that irreversibly damages a part of the sympathetic trunk and adjacent ganglia between the L1 and L5 vertebrae, resulting in a reduction of peripheral resistance controlled by sympathetic activity. This potentially increases blood flow at the level of microcirculation. Decrease of pain intensity is another beneficial effect of LS.

Despite the positive facts mentioned above, the use of LS has gradually declined. One of the possible explanations for this can be contradictory results of studies dealing with evidence of tissue perfusion improvement after LS. However, one has to highlight that the relevance of commonly selected tests for perfusion assessment at the level of microcirculation after LS is debatable in studies.

In recent years, thermal imaging has been used to monitor and diagnose patients with PAD, primarily to assess blood circulation in the limbs. Several studies show that infrared thermography (IRT) can detect temperature changes in areas of impaired blood flow and can serve as a noninvasive indicator of improvement after treatment such as rehabilitation exercise or revascularization.

One of the relevant studies followed patients with PAD who underwent a home exercise program. IRT was used to measure the temperature of the foot before and after the exercise program. The results showed that exercise increased the average temperature of the foot, indicating an improvement in blood flow and thus peripheral perfusion, with no differences between genders.[11] Another study monitored the temperature of the feet of patients with critical limb ischemia before and after endovascular revascularization. The average difference in temperatures between less and more affected limbs was approximately 1.7°C before revascularization. It was found that after successful revascularization, there was a significant increase in temperature only in the more affected foot on average 2°C.[12] A systematic review of studies on the use of IRT in the diagnosis and monitoring of PAD confirmed that IRT can be an effective tool for the assessment of blood flow. However, it was pointed out the need for further development and standardization so that this technology can be effectively integrated into clinical practice.[13]

IRT offers a practical possibility of evaluating the success of endovascular revascularization in patients with critical limb ischemia,[11] in monitoring the temperature of the foot in patients with diabetic foot and PADs.[14]

The aim of our study is to determine the efficacy of lumbar sympathetic block on tissue perfusion evaluated by precise thermal measurements of skin zones (dermatomes) related to peripheral nerves and their associated angiosomes of the foot. In addition, another aim of this study is to find out whether there is any association between the patency of below-the-knee (BTK) arteries and temperatures of dermatomes before and after the LS procedure.

2. Methods

In the presented study, we measured changes of foot temperature in dedicated skin zones (dermatomes) using IRT before the LS procedure, and subsequently 10 and 20 minutes after LS in 2 CLTI patients (A, B) with chronic lower limb wound and ischemia at least grade 1 according to Wound, Ischemia, and foot Infection classification. We did not include patients with diabetes mellitus due to the potential sympathectomy-related risks associated with diabetic neuropathy.

The ultrasonographic examination of lower limb arteries was performed before admission to the hospital. The angiography of both lower limbs using a retrograde femoral approach was performed in all patients before LS. The side for the femoral approach was chosen based on prior ultrasonographic findings.

The presented study is experimental in nature; therefore, revascularization of the BTK arteries was not performed during angiography to avoid the influence of revascularization on the results of thermographic measurements before and after the LS procedure. Revascularization of the BTK arteries was performed using an antegrade femoral approach a few days later.

The LS procedure was performed at least 1 day after angiography and endovascular treatment of above-the-knee arteries. The measurement of foot temperature changes using IRT was performed a few minutes before the LS procedure, that is, at least 1 day after angiography and subsequently 10 and 20 minutes after the LS procedure.

Ethical approval to report this case series was obtained from the Ethics Committee of the East Slovak Institute of Cardiovascular Diseases, Košice (approval number 4/2023/VUSCH/EK) and was registered on clinicaltrials.gov with registration ID NCT06111599. Written informed consent was obtained from the patients for their anonymized information to be published in this article.

2.1. Technical aspects of a lumbar sympathetic blockade

The procedure was conducted under X-ray guidance. The position of the needle was controlled gradually in the anterior-posterior projection and was verified by a small amount of contrast. After visualizing the lumbar sympathetic structures with contrast, the medication (local anesthetic) was administered (Fig. 1).

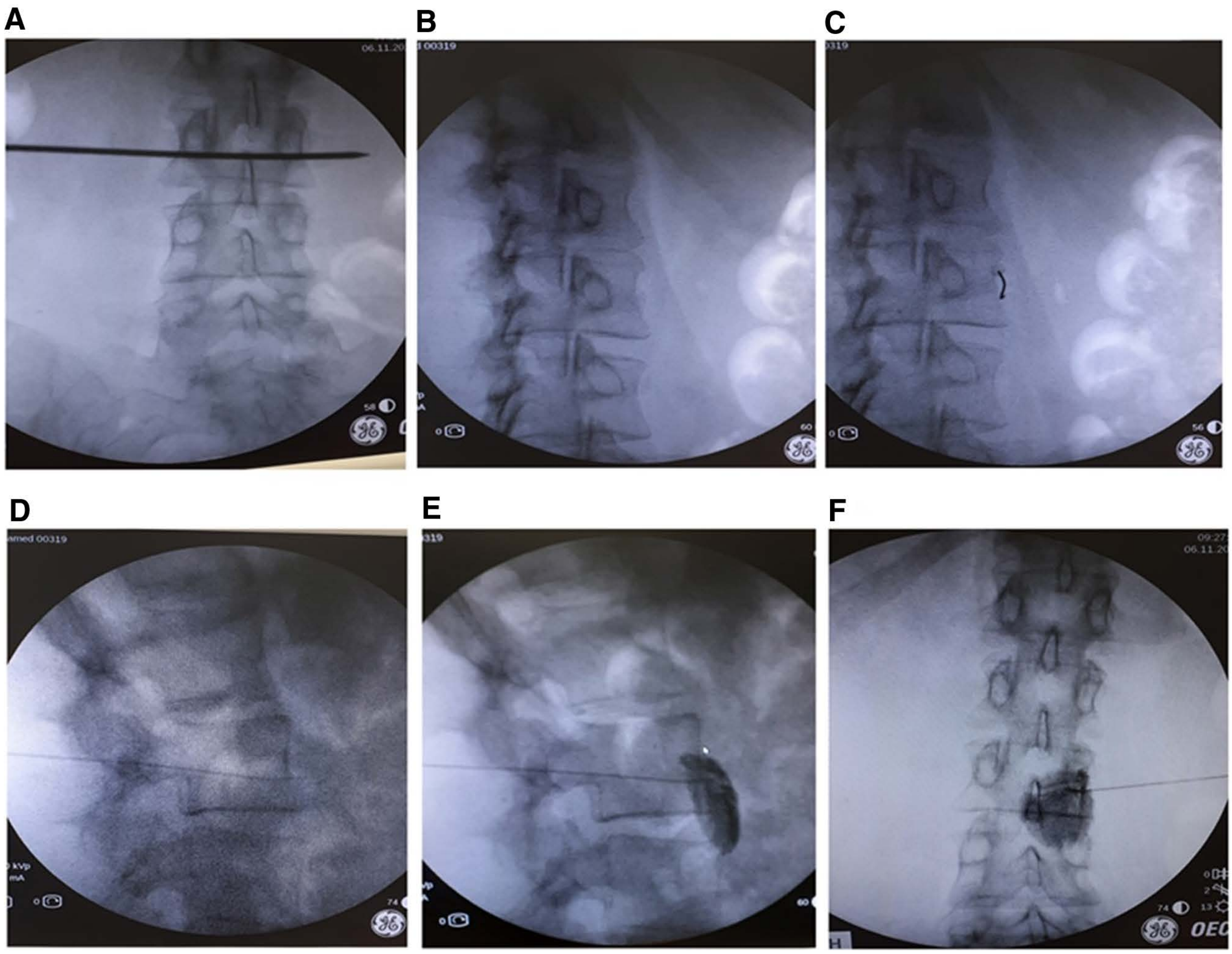

Figure 1. Technical aspects of lumbar sympathectomy. (A) Antero-posterior view of the patient in the prone position with squared vertebral endplates. (B) Oblique ipsilateral projection, where the spinous process overlaps the other side of the vertebral body. (C) The entry point for the needle is just below the transverse process, where more room is seen for needle guidance. (D) Lateral view to control the depth of the needle during guidance. (E) Contrast confirmation of the anatomical position of the lumbar sympathetic chain in lateral projection on the right side. (F) Contrast confirmation of the anatomical position of the lumbar sympathetic chain in anteroposterior projection on the right side.

2.2. Infrared thermography measurements—technical aspects

We utilized a FLIR SC660 thermal imaging camera (FLIR, Sweden, 640 × 480 pixels) to monitor temperature changes.

Thermal imaging with the camera was conducted before LS, 10 minutes after LS, and 20 minutes after LS. We observed temperature changes in selected areas of the foot, that is, dermatomes as depicted in Figure 2B. The patient was in a supine position during the scan and the measured area was exposed. The ambient temperature remained between 22°C and 23°C during the measurement.

The distance between the thermal imaging camera and the measured area was 0.7 to 0.8 meters. Subsequently, we evaluated the thermal imaging images using the FLIR Reporter program (FLIR, Sweden).

During the evaluation, the area of interest was outlined by a polygon, and the minimum, maximum, and average temperatures were assessed.

Clinically relevant change of temperature was arbitrarily considered an increase of more than 1°C after the LS procedure.

3. Pain intensity

We measured the intensity of pain before the operation and 20 minutes, 12 hours, 24 hours, and 48 hours after the lumbar sympathetic blockade procedure using a numerical rating scale (0–10).

All data generated or analyzed during this study are included in this published article [and its supplementary information files].

4. Results

The clinical characteristics of the treated patients are presented in Table 1. The assessment of pain in all patients showed the most significant improvement 12 hours after the procedure, as measured by the numerical rating scale, and this improvement persisted with only slight changes within 48 hours (Table 1).

The angiography showed stenosis of the superficial femoral artery, occlusion of anterior tibial artery and peroneal artery (PA) on the right limb, and occlusion of posterior tibial artery (PTA) on the left limb in Patient A. PTA artery was occluded on both limbs in patient B and in addition, PA was occluded on the right limb. The popliteal artery was stenosed on the left limb in patient B.

The distribution of lesions affecting the lower limb arteries in patients A and B is shown in Table 2 for better orientation. Figures 3 and 4 show the angiographic findings and distribution of lesions affecting BTK arteries in patients A and B.

The scoring balloon angioplasty of superficial femoral artery stenosis in patient A and popliteal artery in patient B was performed. BTK arteries were left without treatment.

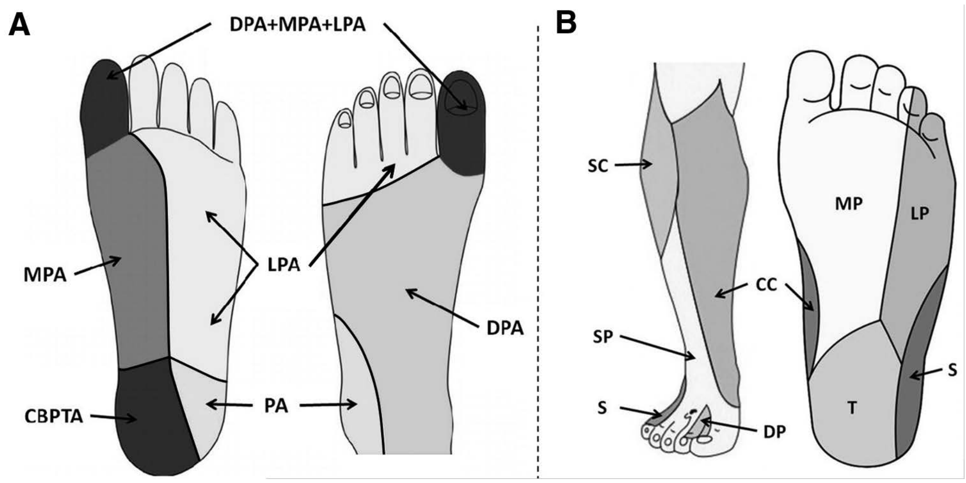

Figure 2. Anatomical relationship between angiosomes and dermatomes of the foot. (A) Angiosomes. (B) Dermatomes. ATA = anterior tibial artery, CBPTA = calcaneal branch of PTA, CC = saphenous medial crural cutaneous nerve (L3-4) , DP = deep peroneal nerve (L4-5) , DPA = dorsalis pedis artery—angiosome perfused by ATA, LP = dermatome of lateral plantar nerve (S1-2), LPA = lateral plantar artery, MP = dermatome of medial plantar nerve (L4-5), MPA = medial plantar artery, PA = peroneal artery, PTA = posterior tibial artery, S = dermatome of sural nerve (S1-2), SC = lateral sural cutaneous nerve (L5-S2), SP = superficial peroneal nerve (L4-S1), T = dermatome of tibial nerve (S1-2). MPA, LPA, and CBPTA create together one angiosome perfused by PTA; SP and DP create together surface area of DPA/ATA angiosome. LP, MP, and T create together the surface area of PTA angiosome. S is the surface area of PA angiosome.

Table 1

Patients characteristics.

	Patient A	Patient B
Age (years)	62	65
Gender male (M)/female (F)	F	F
Chronic obstructive pulmonary disease	No	Yes
Ischemic heart disease/heart failure	No	Yes
Chronic kidney disease	No	No
Diabetes mellitus	No	No
Ischemic stroke	No	No
Pain intensity (leg pain)		
NRS before procedure of lumbar sympathectomy	7	7
NRS 20 minutes after procedure	1	3
NRS 12 hours after procedure	2	2
NRS 24 hours after procedure	2	3
NRS 48 hours after procedure	2	3

NRS = numerical rating scale of pain intensity.

Table 2

Distribution of lesions affecting lower limbs arteries.

	Patient A		Patient B	
	Angiographic finding			
Artery of lower extremity	Right limb	Left limb	Right limb	Left limb
Iliac arteries	NA	NA	NA	NA
CFA	NA	NA	NA	NA
DFA	NA	NA	NA	NA
SFA	S	NA	NA	NA
PopA	NA	NA	NA	S
ATA	O	NA	NA	NA
PTA	NA	O	O	O
PA	O	NA	O	NA

ATA = anterior tibial artery, CFA = common femoral artery, DFA = deep femoral artery, NA = not affected, O = occlusion, PA = peroneal artery, PopA = popliteal artery, PTA = posterior tibial artery, S = stenosis, SFA = superficial femoral artery.

Comparing the left and right foot, the relevant increase of temperature was observed in patient A on the left foot in the dermatome of lateral and medial plantar nerve ranging from 1.4°C to 2.4°C (Figures 5–7 and Table 3), and on the right foot in the dermatome of the superficial peroneal nerve and sural nerve ranging from 1.7°C to 2.4°C (Figures 5–7 and Table 3).

In patient B, there was an apparent clinically relevant increase of temperature from 1.6°C up to 2.3°C in the dermatome of the lateral plantar, medial plantar, and tibial nerve on the left foot (Figures 5–7 and Table 3).

On the right foot, the clinically relevant increase of temperature ranging from 1.8°C up to 2.4 °C was found in the dermatome of the lateral plantar, medial plantar, tibial, and sural nerve (Figures 5–7 and Table 3). One month after the LS procedure all wounds on lower limbs were healed up.

5. Discussion

Denervation of the lumbar sympathetic ganglia increases blood flow to the lower limb by inducing vasodilation through the reduction of sympathetic tone. This, in turn, improves tissue oxygenation, reduces tissue damage, and alleviates pain.

Despite the positives of LS mentioned above, several randomized trials have failed to identify objective parameters for evaluating the effect of sympathectomy.

However, it is worth noting that the effectiveness of sympathectomy was assessed based on changes in pain intensity, wound healing (or amputations), and ankle-brachial index (ABI). Pain intensity is a highly subjective parameter. Although ABI is a fast, simple, and easily reproducible test, it is primarily intended for vascular screening.

In addition, ABI may be less useful in the settings of noncompressible vessels due to Mönckeberg medial calcific sclerosis.

However, among patients with diabetic foot ulceration, the measurement of skin perfusion pressures, toe pressures, and transcutaneous oxygen pressure appears to be more useful in predicting ulcer healing than ankle pressures or the ABI.[15–18]

IRT is an instrumental tool that is contact-free, noninvasive, low-cost, simple to use, and not influenced by the operator's experience.[19] It offers a fast, painless, and radiation-free method of photographically imaging temperature differences of the skin surface, allowing arbitrary repetitions of recording.[20,21]

Thermal imaging of the body surface can detect minute changes in the underlying tissues, which indicates neurological and vascular as well as metabolic pathologies. For this purpose, modern infrared thermal imaging cameras are used, which have a high-temperature sensitivity and produce high-resolution thermal images. Thermographic devices detect the infrared radiation emitted by the body surface, which is invisible to humans, convert it into electrical signals, and a thermogram can be created, which shows temperatures pictorially in different colors or gray tones.[21,22] Temperature emitted from the skin directly depends on the quality of tissue blood perfusion. A reduction in tissue blood perfusion due to arterial vessel obstruction compromises cellular metabolism, resulting in decreased heat production. IRT has proven to be a reliable tool for assessing the severity of atherosclerotic disease in a patient's limbs, showing lower temperature values in the less perfused limb. It is a safe, reliable, and easy-to-use tool, making it a valuable instrument for assessing the clinical condition and severity of foot blood perfusion in symptomatic patients with lower extremity arterial disease.[12] It has been demonstrated that thermographic measurements are associated with wound healing and can serve as an independent predictor for achieving 6-month freedom from major amputation in clinical practice.[23,24]

The angiosome concept, initially introduced in plastic surgery by Taylor and Palmer in 1987, was also adopted by vascular medicine for the purpose of targeted revascularization and this way improving wound healing.

It is defined as a three-dimensional network of vessels not only in the skin but also in all tissue layers between the skin and the bone. In the zones between adjacent angiosomes, 2 types of anastomotic arteries were identified: reduced-caliber ("choke") and similar-caliber ("true") anastomotic arteries. These "choke vessels" typically remain in a state of reduced caliber during routine circulation, essentially lying dormant.[25–27]

However, they have the capacity to dilate and become active during times of increased demand to facilitate greater blood flow.[25–27] Choke vessels can serve as crucial safety conduits, enabling one angiosome to receive blood from a neighboring angiosome in the event of an occlusion of the original source artery. These vessels are controlled by hormonal, nervous, or biochemical factors.[27–29]

In the most common angiosome model, the foot consists of 6 angiosomes originating from the 3 main BTK arteries, that is, anterior tibial artery, PTA, and PA (Fig. 2A).

In our pilot clinical trial, we decided to evaluate and compare temperature changes using IRT in dedicated skin areas—dermatomes on the foot in CLTI patients after the LS procedure adjusted to the patency of the source BTK artery. Dermatomes represent the surface area of angiosomes; therefore, it makes sense to evaluate perfusion in angiosomes by temperature changes in dermatomes. The anatomical relationship between dermatomes and angiosomes of the foot is shown in Figure 2A (Angiosomes) and Figure 2B (Dermatomes).

We observed a clinically relevant increase of temperature in patient A on the left foot in dermatome of lateral and medial plantar nerve that corresponds to the angiosome of PTA and in the dermatome of the superficial peroneal nerve and sural nerve on the right foot corresponding to the anterior tibial and PA. In patient B, a clinically relevant increase of temperature was documented in the dermatomes corresponding to PTA on both feet and PA on the right one.

Our results suggest that a clinically relevant increase of temperature was observed only in dermatomes corresponding to angiosomes with occluded source artery.

One potential explanation of this could be our hypothesis that alteration in sympathetic tone by the LS procedure could cause dilation and reorientation of flow in choke vessels, and this way the blood flow from the adjacent angiosome with patent source artery to angiosome with occluded source artery could increase.

This increase of blood flow could be objectified using IRT as an increase of temperature in dedicated dermatome corresponding to underlying angiosome.

Our study did not demonstrate the clinically relevant increase of temperature in all dermatomes of the foot after the LS procedure equally, but the area-specific increase of temperature

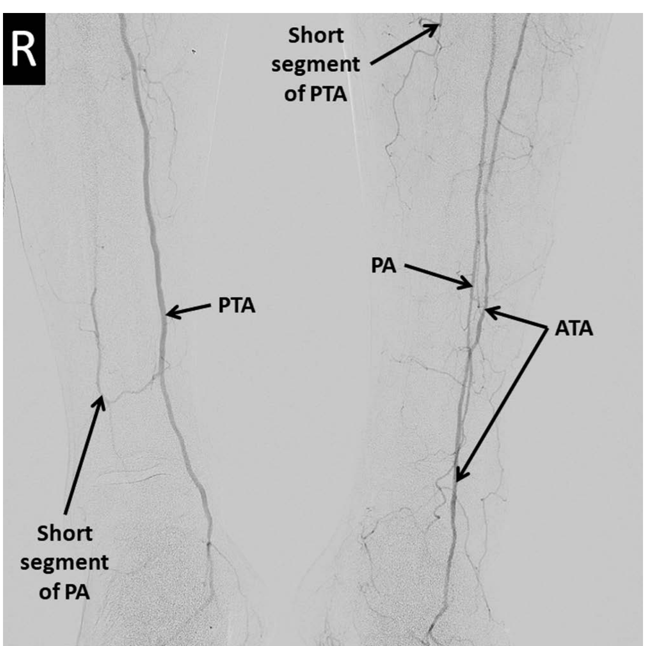

Figure 3. Angiography in patient A showing distribution of lesions affecting the below-the-knee arteries. ATA and PA are occluded; PTA is only sole run-off artery on the right side. The occlusion only of PTA was documented on the left limb. ATA = anterior tibial artery, PA = peroneal artery, PTA = posterior tibial artery, R = right side.

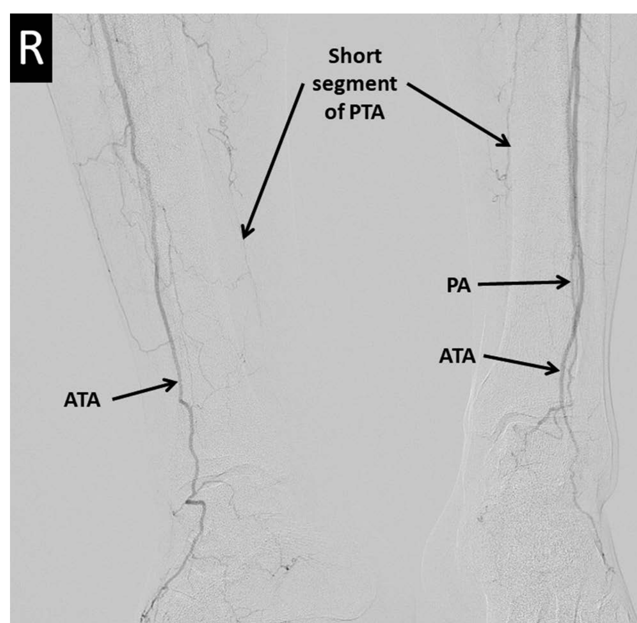

Figure 4. Angiography in patient B showing distribution of lesions affecting the below-the-knee arteries. The ATA is only sole run-off artery on the right side. The occlusion only of PTA was documented on the left limb. ATA = anterior tibial artery, PA = peroneal artery, PTA = posterior tibial artery, R = right side.

was found, that is, an increase of temperature in dermatomes corresponding to angiosomes without direct flow due to source artery occlusion.

This could be considered as further proof supporting the use of LS for CLTI patients without diabetes, especially when revascularization is not possible. In addition, LS provides a pain-relieving effect. Our results also suggest that IRT could be an effective and more appropriate method for evaluating LS procedure outcomes compared with commonly used hemodynamic tests.

On the other hand, the decision to use the increase of temperature in the dermatome of more than 1°C for the criterion of LS efficacy may be considered as the most disputable part of the presented study.[30] Two main arguments can be used for the explanation of this: technical parameters of thermal imaging cameras and results of other studies dealing with the use of IRT in medicine. First, the thermal sensitivity and accuracy of the FLIR SC660 thermal imaging camera used in the presented study is 0.045°C at 30°C and ± 1°C, respectively. Second, there is no wide consensus in the literature on what

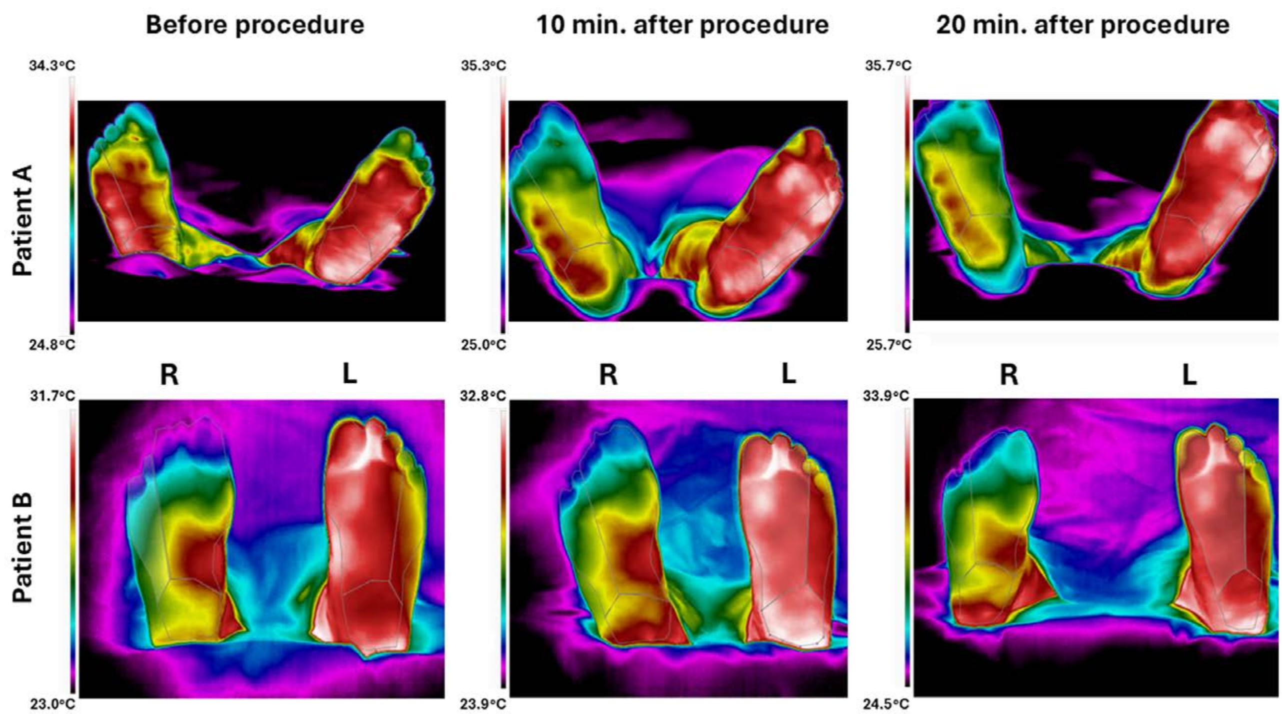

Figure 5. Images of thermal changes of the foot (plantar view) in patients A and B were taken by FLIR SC660 thermal image camera before, 10 minutes, and 20 minutes after the procedure with detailed area segmentation. L = left side, R = right side.

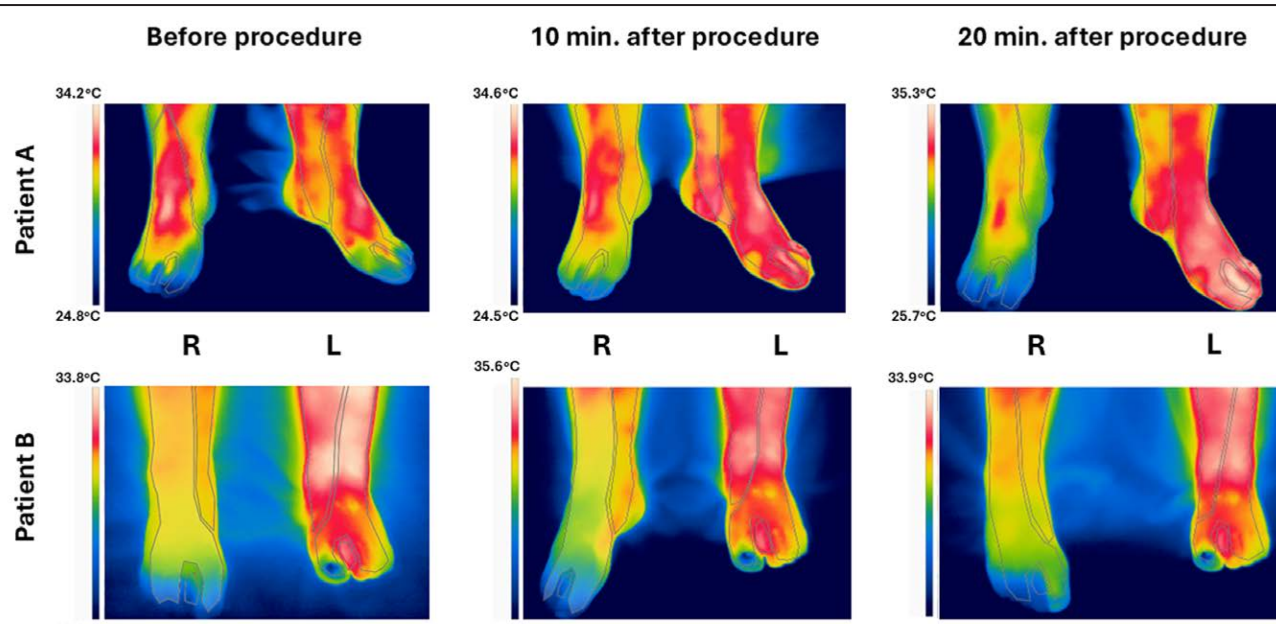

Figure 6. Images of thermal changes of the foot (anterior aspect) in patients A and B were taken by FLIR SC660 thermal image camera before, 10 minutes, and 20 minutes after the procedure with detailed area segmentation. L = left side, R = right side.

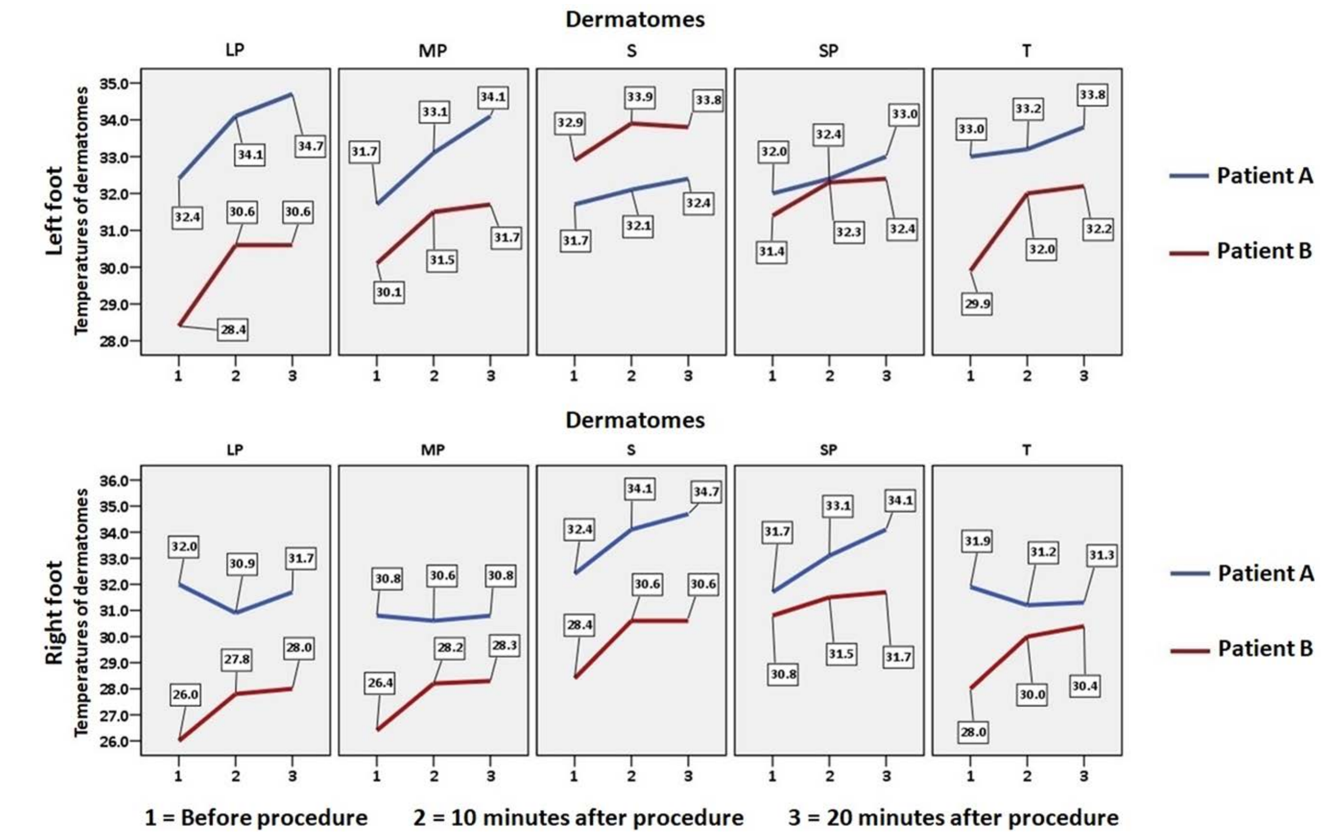

Figure 7. Line graphs showing changes of temperatures in each foot dermatome of all patients before, 10 minutes, and 20 minutes after the procedure (lumbar sympathectomy). LP = dermatome of lateral plantar nerve, MP = dermatome of medial plantar nerve, S = dermatome of sural nerve, SP = superficial peroneal nerve, T = dermatome of tibial nerve (S1-2).

Table 3

Temperature changes in dedicated dermatomes of foot before and after the lumbar sympathectomy.

		Average temperatures (°C)					
		Left foot			Right foot		
	Dermatomes	Before procedure	10 minutes after procedure	20 minutes after procedure	Before procedure	10 minutes after procedure	20 minutes after procedure
Patient A	LP	32.4	34.1	34.7	32	30.9	31.7
	MP	31.7	33.1	34.1	30.8	30.6	30.8
	T	33	33.2	33.8	31.9	31.2	31.3
	SP	32	32.4	33	31.7	33.1	34.1
	S	31.7	32.1	32.4	32.4	34.1	34.7
Patient B	LP	28.4	30.6	30.6	26	27.8	28
	MP	30.1	31.5	31.7	26.4	28.2	28.3
	T	29.9	32	32.2	28	30	30.4
	SP	31.4	32.3	32.4	30.8	31.5	31.7
	S	32.9	33.9	33.8	28.4	30.6	30.6

LP = dermatome of lateral plantar nerve, MP = dermatome of medial plantar nerve, S = Dermatome of sural nerve (surface area of peroneal artery angiosome), SP = Dermatome of superficial peroneal nerve (surface area of anterior tibial artery angiosome), T = Dermatome of tibial nerve (LP, MP and T create together surface area of posterior tibial artery angiosome).

exact value of temperature difference should be considered clinically relevant. The vast majority of studies just compared temperatures of healthy and affected limb/feet or more and less affected limb by the atherosclerosis at the rest, or mean increase of limb/feet temperatures before and after the revascularization procedure. The reported mean difference in temperature of feet in the studies varies approximately at the level of 0.7–1.3°C between the affected and nonaffected limbs by atherosclerosis at baseline,[13,31] and 0.7–1.7°C between more and less impaired limbs in patients with PAD.[11,12] The mean increase in temperature of feet before and after revascularization varies between 0.4 and 2.1°C in patients with PAD.[12,23,32,33]

6. Conclusion

In conclusion, our findings suggest that lumbar sympathetic blockade may be beneficial for CLTI patients, especially for those without diabetes.

However, it must be emphasized that the mentioned results are too preliminary, and further randomized trials are necessary to assess the effect of lumbar sympathetic blockade in CLTI patients for whom endovascular treatment or surgery is not feasible due to technical or medical reasons.

The use of new and progressive techniques of LS, like cryoablation or radiofrequency ablation, may potentially extend the duration of sympathetic denervation, and this way the short-term effect, that is, the most criticized shortcoming of LS, could be overcome.[34,35]

7. Limitations

The decision to consider the 1°C increase in temperature over time as a relevant factor for the evaluation of the effectiveness of LS represents a significant methodological limitation of this study that could be a potential source of bias. This could be considered as the main limitation of this study. We also identified 2 further limitations of our study: nonrandomized design and small sample size; thus the documented beneficial effect of LS is based mainly on our experimental hypothesis.

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Funding acquisition: Radovan Hudák.
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