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Photoplethysmographic Signals to Predict the Success of Lumbar Sympathetic Blockade for Lower Extremity Pain and Cold Hyperalgesia

냉통각과민성 일측 하지통증 치료를 위한 요부 교감신경블록의 성공을 예측하기 위한 광체적흡광도 신호분석

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The Department of Medicine
(Biomedical Engineering)
Seoul National University
Soo Young Park

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위 원 장 이 상 철 (인)

부위원장 박 광 석 (인)

위 원 김 희 찬 (인)

위 원 김 용 철 (인)

위 원 김 고 근 (인)

Studies on roles of Photoplethysmographic Signals to Predict the Success of Lumbar Sympathetic Blockade for Lower Extremity Pain and Cold Hyperalgesia

by

Soo Young Park

A thesis submitted to the Department of Biomedical Engineering in partial fulfillment of the requirements for the Doctor of Philosophy in Medical Science at Seoul National University College of Medicine
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Approved by Thesis Committee:

Chairman	Sang Chul Lee
Vice chairman	Kwang Suk Park
Member	Hee Chan Kim
Member	Yong Chul Kim
Member	Ko Keun Kim

Abstract

Photoplethysmographic Signals to Predict the Success of Lumbar Sympathetic Blockade for Lower Extremity Pain and Cold Hyperalgesia

Soo Young Park

Department of Medicine, Biomedical Engineering

The Graduate School

Seoul National University

Background: Although lumbar sympathetic blockade (LSB) is a valuable modality to manage pain in the lower extremities, it is difficult if LSB will result in pain alleviation before the procedure. In this study, we investigated how signals of photoplethysmography (PPG) change during LSB. Furthermore, we established which patients would respond to LSB through a power spectrum analysis (PSA).

Methods: A prospective, observational study was performed with 38 patients who had single leg pain with cold hyperalgesia. Bilateral temperature and PPG signals were recorded during LSB. PPG data including low- (LF) and high-frequency (HF) DC signals were analyzed blindly by a technician. The PSA was attempted using a fast Fourier transform periodogram blindly by a technician.

Results: Eight (22.1%) patients had excellent pain-relieving response to LSB, and they were considered as having sympathetically mediated pain (SMP). AC signal changes of PPG occurred immediately after drug administration even before temperature changes were noted. DC signals were decreased slowly with a linear fashion. The PSA of DC signals showed that significantly lower LF/HF ratios in SMP than in sympathetically independent pain (SIP), both before LSB (2.81 ± 1.60 vs. 4.99 ± 3.12, P = 0.038) and after LSB (1.77 ± 0.82 vs. 3.21 ± 2.03, P = 0.023).

Conclusions: PPG can be used as an early indicator of a successful LSB in the clinical setting. Indeed, PPG signals can be used to distinguish SMP from SIP before performing LSB.

Keywords: Lumbar sympathetic blockade, Photoplethysmography, Power spectrum analysis, Sympathetic mediated pain

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Introduction

Lumbar sympathetic block (LSB) is known as a useful non-surgical procedure to manage various medical conditions involving the lower extremities.[1, 2] In this procedure, local anesthetic is injected percutaneously around the lumbar sympathetic ganglia; this results in temporary sympathectomy.[3] When sympathetic blockade results in substantial pain relief, the presence of predominantly sympathetically mediated pain (SMP) is assumed.[4-6] Sufficient pain relief can help patients to restore and improve their daily living functions. However, it is difficult to predict that the patient's response to sympathetic blockade before procedure.

The success of LSB can be assessed easily by monitoring vasodilation.[2, 7] Since temperature is largely dependent on blood flow, skin temperature monitoring at the plantar surface of the foot is the most commonly used technique during LSB.[8-12] And also, photoplethysmography (PPG) can be used as a good alternative to detect blood volume changes in the microvascular bed of tissue.[13] PPG signals can provide valuable information about the cardiovascular system which is represented by a pulsatile 'AC' waveform, and the autonomic function, which is represented by a slowly varying 'DC' baseline.[14, 15] In particular, the DC component of PPG reflects sympathetic activity and thermoregulation.[15]

A recent report recommends the use of LSB not as a single modality for pain management, but as a component of multimodal treatment of complex regional pain syndrome (CRPS); the authors also advise that its long-term use should be limited, especially in case of non-CRPS neuropathic pain.[16] Several medical conditions, however, involve neuropathic pain comprising a clear sympathetically mediated component. Because pain relief is extremely subjective and very individual, it is important to discriminate between SMP and sympathetically independent pain (SIP) unlike objective tests of blockade including increasing skin temperature due to increased blood flow.[12, 17] This raises the question: should diagnostic sympathetic blocks always identify SMP?[18]

Although PPG signals are still not fully understood yet, we assumed that signal changes both in the AC and in the DC component of PPG would occur around the onset of LSB which had already been reported through our paper.[12] The aim of the present study was to investigate how PPG signals change during unilateral LSB and whether these changes can serve as a tool to predict for SMP.

Methods

1.Patients

After written informed consent was obtained from each patient, unilateral LSBs were performed in consecutive patients for the diagnosis or treatment of pain with self-reported cold hyperalgesia at the Pain Centre, Seoul National University Hospital, Seoul, Korea, between December 2009 and April 2011. Those who were eligible for inclusion were classified as either level I or II according to the American Society of Anesthesiologist's Physical Status Classification, and had no significant cardiac, pulmonary or systemic disease. Patients who were not willing to participate, those with contraindications to regional anesthesia, and those in whom it was not possible to monitor foot temperature and PPG signals, for example, patients with previous foot amputation, were excluded. Patients aged below 19 or above 70 were also excluded. Pain intensity was measured twice using a 11-points numeric rating scale (NRS; 0 = no pain to 10 = the worst imaginable pain) before LSB and 1 week later.[19] The study protocol was approved by the Institutional Review Board of the Seoul National University Hospital.

2. Lumbar Sympathetic Blockade

LSBs were performed using same method as our previous study,[12] that is only at the upper third of the L3 vertebra without any pre-medication.[20] Patients were placed in a prone position with a pillow under the lower abdomen to reduce lumbar lordosis, and their backs were covered with sterile drapes to avoid the influence of the ambient temperature, which was constantly maintained within 23-24°C.[21-23] Only the areas of skin required for the procedure remained exposed. The target lumbar vertebra was identified by anteroposterior fluoroscopic imaging (OEC® 9800 Plus; GE Medical Systems, Salt Lake City, UT, USA) and the fluoroscopic C-arm was then adjusted 30° laterally to avoid the transverse process over the needle pathway.

The skin entry point was infiltrated using 1% lidocaine. A curved 21-guage, 15-cm Chiba needle (Cook Inc., Bloomington, IN, USA) was then advanced toward the anterolateral edge of the target lumbar vertebra under fluoroscopic guidance using the tunnel vision (coaxial) technique.[20, 24] After confirming the needle position with anteroposterior, lateral and oblique views, and verifying negative aspiration for blood, 3 ml of iopamidol (Iopamiro®, Bracco, Milan, Italy) was administered incrementally, followed by 10 ml of 0.25% levobupivacaine (Chirocaine®, Abbott, Elverum, Norway).

3. Temperature Monitoring

As an index of the efficacy of sympathetic blockade, skin-surface temperatures were monitored with small adhesive thermocouple probes (accuracy of ±0.1°C) (Dash 4000; GE Healthcare, Milwaukee, WI, USA) attached bilaterally to the plantar surface of the feet using transparent patches (Tegaderm™; 3M Health Care, St Paul, MN, USA).[2, 12] The baseline temperature was obtained immediately after placement of sterile surgical drapes. Temperatures were measured at 1-min intervals and recorded automatically from the time of administration of the local anesthetic onwards.[12] Assessments were continued for a maximum of 20 min.

LSB was considered successful when changes in temperature met the following 2 criteria: unilateral difference in temperature on the target side was more than 2°C within 20 min after the injection of the local anesthetic,[25] and the rate of temperature change of the skin was 0.4°C/min at the onset of sympathetic block.[12]

4. Photoplethysmography

A commercially available pulse oximetry sensor (DS-100A Nellcor® R-Cal; Nellcor™, Mansfield, MA, USA) was used at wavelength 890 nm with transmission mode. For PPG recording, a device of our own design was used.[26] The output signal from pulse oximetry sensor was converted into a voltage and amplified; then it was filtered with a band-pass of 0.05–10 Hz to separate the pulsatile AC signal, and with an analog low-pass cutoff at 1 Hz to separate the DC signal. A constant current source circuit was used to drive the LED, and the amplification ratio was kept constant. The PPG waveform was continuously collected from the right and left second toes. An electrocardiogram (ECG) was also obtained simultaneously using a patient monitor (Dash4000; GE Healthcare, Milwaukee, WI, USA) for analyzing heart rate variability. All analog signals, namely, AC and DC signals from PPG and ECG, were digitized at a sampling rate of 200 Hz with 12-bit resolution using a Biopac data acquisition system (BIOPAC; BIOPAC System Inc., Goleta, CA, USA). At the end of study, the PPG waveforms were analyzed 'off-line' blindly by a technician (HJ Baek) using Matlab® 7.1 (The Mathworks™ Inc., Natick, MA, USA).

Several points were set according to events occurring during the procedure: the surgical drape (event 1), local infiltration for skin anesthesia (event 2), deep muscle infiltration (event 3), contrast media injection (event 4), initiation of local anesthetic injection at the target point (event 5), completion of local anesthetic injection (event 6), cut-off point of temperature and needle withdrawal (event 7) and the end of study (event 8).

5. Data analysis

1. Analysis in Time Domain

To investigate changes in PPG signal amplitude during LSB, data collected after event 6 were selectedand normalized with respect to subject-specific value by dividing the selected PPG signal by mean value. Beat-to-beat amplitude of AC signal was derived by detection of normalized PPG pulse peaks and valleys, and their differences during each heart cycle. The difference between successive pairs of peak and valley was considered the peak-to-peak pulse amplitude of the PPG AC signal. Then, beat-by-beat amplitude was averaged within 1-min time windows. Amplitude of DC signal was also calculated by averaging of normalized DC signal samples within 1-min time windows. Data were compared between the target and control (contralateral without pain symptom) sides.

2. Analysis in frequency domain

DC signals are composed of low-frequency band (LF = 0.04–0.15 Hz), and high-frequency band (HF = 0.15–0.40 Hz), which vary according to sympathetic activities controlling the peripheral circulation (LF), and parasympathetic activities mostly related to respiratory consequence to cardiac output (HF), respectively. The LF/HF ratio reflects the balance between the sympathetic and parasympathetic tone.[27-31]

Power spectral density was calculated directly from the DC signal of PPG and ECG using non-parametric method: fast Fourier transform (FFT) periodogram function in Matlab for investigating how the power of a time series PPG DC signal is distributed with frequency. The periodogram is the Fourier transform of the autocorrelation sequence. Consider the signal $x_N(n)$ of finite length *N*, the estimate of power spectrum can be determined by taking the Fourier transform to autocorrelation sequence and applying the convolution theorem as:

$$\hat{P}_{per}\left(e^{j\omega}\right) = \frac{1}{N} X_N\left(e^{j\omega}\right) X_N^*\left(e^{j\omega}\right) = \frac{1}{N}\left|X_N\left(e^{j\omega}\right)\right|^2$$

Where $X_N(e^{j\omega})$ is the discrete time Fourier transform of the N point data sequence $x_N(n)$:

$$X_N(e^{j\omega}) = \sum_{n=-\infty}^{\infty} X_N(n)e^{-jn\omega} = \sum_{n=0}^{N-1} x(n)e^{-jn\omega}$$

The input of the periodogram function was PPG DC signal itself and pre-processed RR-interval data from ECG.

Spectral parameters, total power (TF; ≤0.4Hz), LF (0.04-0.15Hz) and HF (0.15-0.40 Hz) were obtained by the sum of the power in the relevant frequency range in the spectrum. Spectral parameters were also extracted from heart rate variability (HRV) for comparison. To obtain the power spectrum, regularly sampled data are required. However, RR-interval data from ECG is irregularly sampled. Therefore it should be interpolated and re-sampled to obtain regularly sampled RR-interval data. In this study, RR-interval data was interpolated using cubic spine method and re-sampled at 4Hz, which adequate satisfy the Nyquist theory.[32] Then, PSD was calculated using periodogam method.

Finally, we investigated differences in spectral parametersof PPG DC and ECG including TF, LF, HF and LF/HF between pre- and post-phase.

To avoid interference due to transition period of sympathetic blockade, the periods between event 1 and 5 and between 7 and 8 wereconsidered as pre- and post-phase of LSB, respectively. Data were compared between phases (pre/post) and sides (target/control).

6. Statistical Analysis

Data were presented as *n*, means ± SD or mean ± 95%CI. Statistical comparisons of parametric data were performed using the paired *t*-test, and comparisons of non-parametric data were performed using the chi-square test, Fisher's exact test, or Mann–Whitney *U*-test.

A receiver operator characteristic (ROC) curve was constructed using a pre-phase LF/HF ratio of target side as a diagnostic test to predict SMP. A ROC curve is a graph of the true positive rates [sensitivity (%)] versus the false positive rates [100 – specificity (%)], which corresponds to each possible cut-off point for a diagnostic test.

Data were analyzed using SPSS version 19.0 (IBM SPSS Statistics, CA, USA). A value of $P < 0.05$ was considered statistically significant.

Results

1. LSB in the Target vs. Control Side

1. Demographics

Demographic data are summarized in Table 1. Initially, 50 patients were enrolled in this study, but 12 were excluded because LSB was not considered successful (9 patients) or DC signals were not detected entirely (3 patients) (Fig 1). Finally, 38 patients were included for this study: 18 cases of CPRS type I; 3, CRPS type II; 11, CRPS-NOS that were not covered by the Budapest criteria for CRPS from the International Association of the Study for Pain;[33] 1, herniated nucleus pulposus; 1, paraplegia; 1, postherpetic neuralgia; 2. pheripheral neuropathies; and 1, Raynaud disease. Compared to the pre-procedural state, overall pain intensity was decreased after LSB ($P < 0.01$). Complications as well as sensory or motor blockade were not observed in any of the patients during LSB.

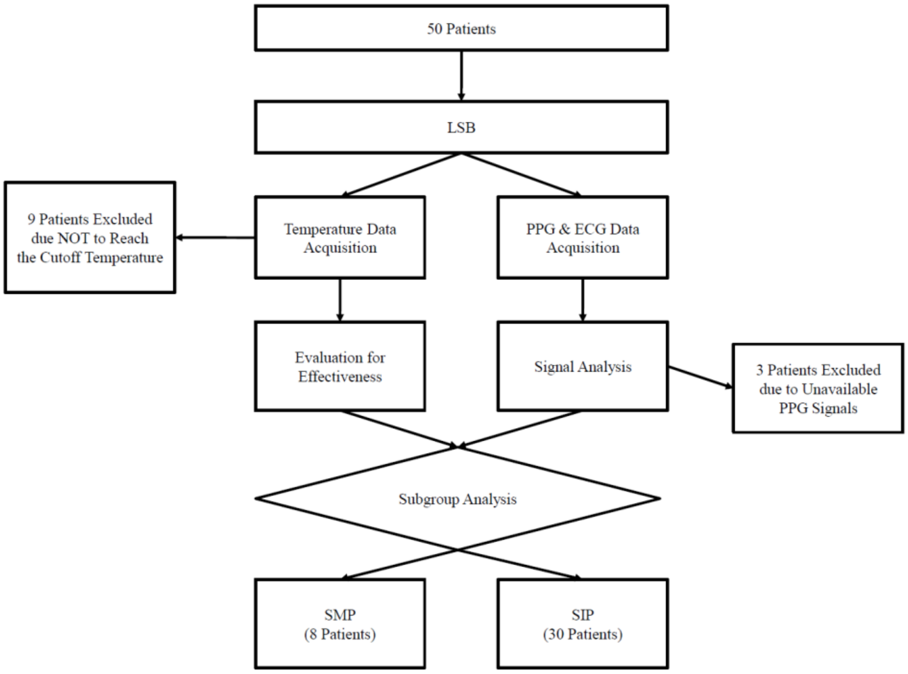
Table 1. Demographics

	Total (n = 38)	SMP (n = 8)	SIP (n = 30)	P-value
Sex (m/f)	26/12	4/4	22/8	0.232
Age (yr)	37.24 ± 15.32	34.50 ± 14.75	37.97 ± 15.63	0.747
Height (cm)	169.39 ± 8.70	169.50 ± 5.78	169.37 ± 9.41	0.844
Weight (kg)	64.53 ± 12.18	65.50 ± 11.23	64.27 ± 12.59	0.958
Duration (mo)	15.03 ± 26.92	19.88 ± 40.71	13.73 ± 22.72	0.323
Side (Lt/Rt)	20/18	6/2	14/16	0.238
NRS (before)	7.13 ± 1.91	5.88 ± 2.53	7.47 ± 1.59	0.090
NRS (1 week later)	4.74 ± 2.49	1.50 ± 0.53	5.60 ± 2.05	< 0.01*
Diagnosis				
CRPS I	18	4	14	
CRPS II	3	0	3	
CRPS-NOS	11	3	8	
Others	6	1	5	

Demographic and clinical characteristics of patients with unilateral lower extremity pain and self-reported cold hyperalgesia, included in a study to investigate the diagnosis of sympathetically mediated pain via photoplethysmography during unilateral lumbar sympathetic blockade, stratified according to the reported degree of pain relief.

Data are presented as mean ± SD, frequencies. SMP: sympathetically mediated pain, pain intensity decreased below 2 for ≥ 1 week; SIP: sympathetically independent pain; NRS: numeric rating scale; CRPS: complex regional pain syndrome; CRPS-NOS: complex regional pain syndrome not otherwise specific. Others include postherpetic neuralgia, herniated nucleus pulposus, diabetic peripheral neuropathy, paraplegia and Raynaud disease.

Figure 1. Study Flow Chart.



LSB: lumbar sympathetic blockade; PPG: photoplethysmography; SMP: sympathetically mediated pain; and SIP: sympathetically independent pain.

2. Temperatures

In the total patient group, time to reach the onset of LSB was 5.11 ± 2.56 min after injection of local anesthetics which was similar to the results obtained in our previous study (5.16 ± 3.25 min).[12] The temperatures of the target side were lower than the control side until 2 min before the onset ($P < 0.01$), but the temperatures surpassed those of the control from 1 min after the onset ($P < 0.01$) (Fig. 2). There were no differences at 1 min before the onset ($P = 0.087$) or at the onset point ($P = 0.326$).

3. PPG

1) Changes in AC and DC Amplitude over Time

From the time of drug administration, the amplitude of the AC signal increased as sympathetic block-induced vasodilation. At first, the AC amplitude of the target was lesser than that of the control until 60 seconds after the drug administration ($P < 0.018$). Inversion of amplitude occurred between 120 seconds and 180 seconds, and then the AC amplitude of the target was greater than that of the control from 240 seconds after drug administration ($P < 0.037$; Fig. 2b).

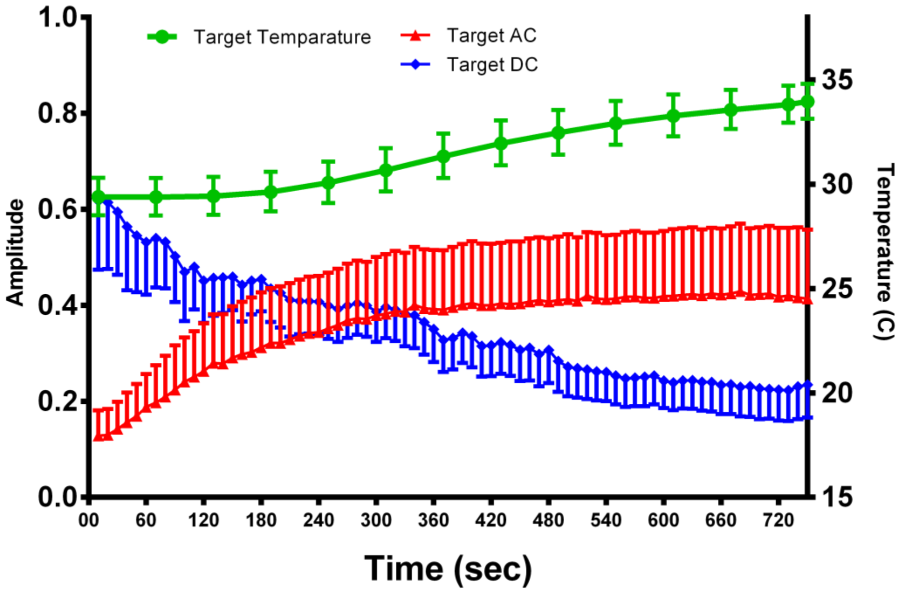
The value of the DC signal was decreased over time in a linear fashion. The DC value of the target was greater than that of the control until 120 seconds after the drug administration ($P < 0.039$). Inversion of value occurred between 180 seconds and 240 seconds, and then the DC value of the target was lesser than that of the control from 480 seconds after drug administration ($P < 0.027$). Even though the AC amplitude of the control was unchanged during LSB, the DC increased slightly (Fig. 2c). Compared with changes in temperature, changes in PPG signals occurred at an earlier time point (Fig 2a).

2) Power Spectrum Analysis of PPG DC signals and ECG

On ECG, there were no difference in each TF, LF, HF or LF/HF ratio (3.39 ± 2.01 vs. 2.76 ± 2.47, $P = 0.229$) between the pre-phase (events 1-5) and the post-phase (events 7-8). Similarly, there were no differences in TF, LF, or HF as determined by PPG DC signals at the target and control sides (all $P > 0.05$). However, LF/HF ratios of DC signals were significantly changed: before drug administration, LF/HF ratio of the target and the control sides was 4.53 ± 2.99 and 6.19 ± 6.42 respectively; at the post-phase, LF/HF ratio was 2.91 ± 1.93 and 5.07 ± 4.66, respectively (Table 2). Even though there was no difference in LF/HF ratio between the target and control sides at the pre-phase ($P = 0.153$), a significant difference was observed at the post-phase ($P = 0.009$). In addition, there was a significant difference between the pre-phase and post-phase LF/HF ratio at the target side ($P < 0.001$), but not at the control side ($P = 0.194$).

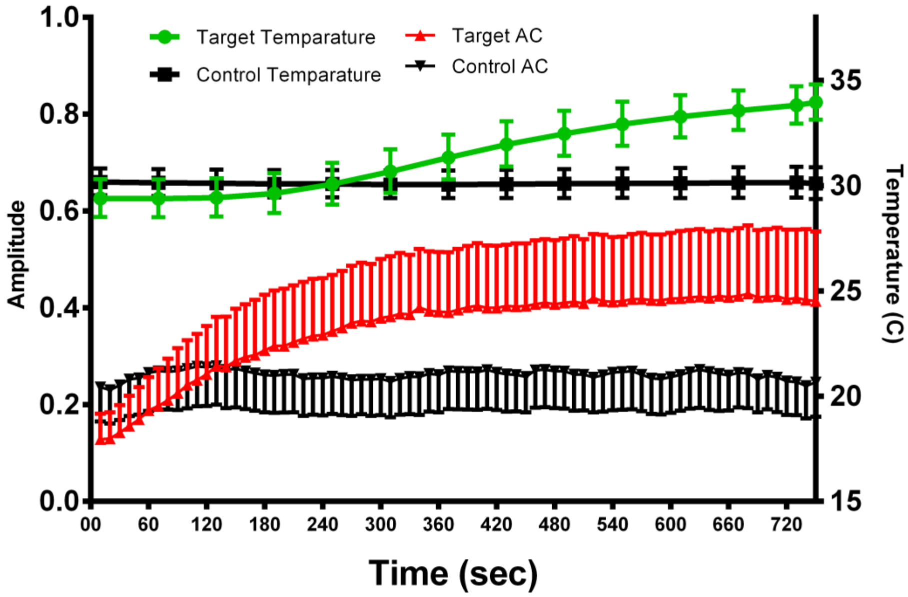
Figure 2. Time Course of the Temperature and Signals of Photoplethysmogray (PPG) after Drug Administration.

(a) Changes at target side



Data are presented as means ± 95% CI.

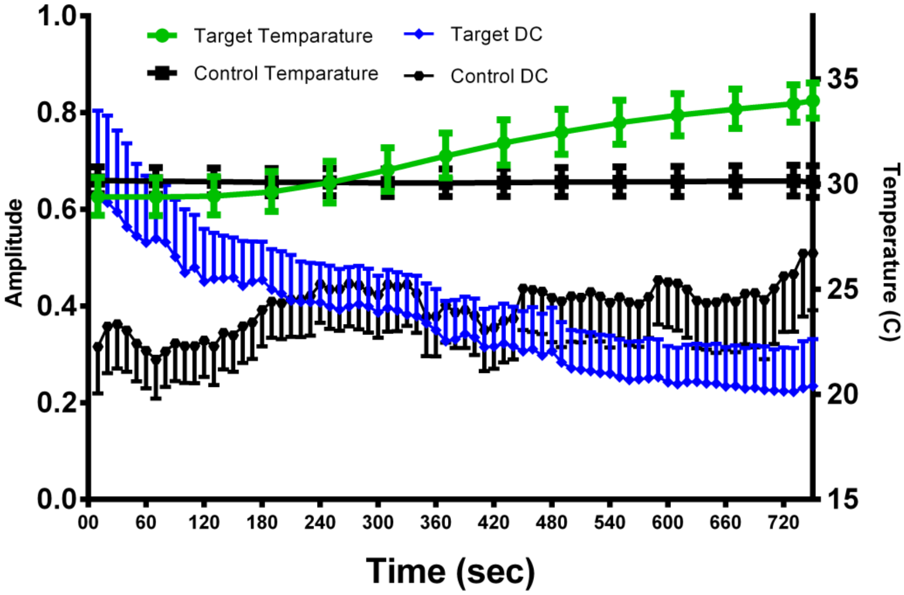
(b) Changes in AC signals of PPG in both target and control (contralateral) sides



Data are presented as means ± 95% CI.

PPG; photoplethysmography

(c)Changes in DC signals of PPG in both target and control (contralateral) sides



Data are presented as means ± 95% CI.

PPG; photoplethysmography

2. Sympathetically Mediated Pain vs. Sympathetically Independent Pain

According to the reported degree of the pain relief, we stratified patients into 2 groups: the sympathetically mediated pain (SMP) group, whose pain intensity decreased below 2 for at least 1 week; and the sympathetically independent pain (SIP) group (Table 1). Eight patients (21.1%) were stratified into the SMP group.

There were no difference in temperature changes over time between patients with SMP and SIP, including initial temperature (P = 0.686), the onset time (P = 0.712), and the final temperature (P = 0.739). Hematologic components, including red blood cells (P = 0.745), hemoglobin (P = 0.260), hematocrit (P = 0.347), total bilirubin (P = 0.940), albumin (P = 0.220) and total protein (P = 0.251), which could disturb the absorption of light[14] were not different between groups either.

On power spectrum analysis, there were significant differences in the LF/HF ratio of PPG DC signals at pre-target (P = 0.038), pre-control (P = 0.034), and post-target (P = 0.023) (Table 2). However, there were no differences in TF, LF, or HF between pre-phase and post-phase at the target or at the control side between the 2 groups (all P > 0.05).

Figure 3 shows the ROC curve for LF/HF ratio in predicting SMP. At a cut-off value of 2.92, the area under the curve (AUC) was 0.742. At this point, the sensitivity, specificity, positive likelihood ratio were 75.0%, 76.7%, and 3.21 [1.5 – 6.9], respectively (Fig 3).

Table 2. Comparison of LF/HF Ratio Between Subgroups

PPG LF/HF Ratio		Total (n = 38)	SMP (n = 8)	SIP (n = 30)
Target	Pre-phase	4.53 ± 2.99	2.81 ± 1.60	4.99 ± 3.12*
	Post-phase	2.91 ± 1.93†‡	1.77 ± 0.82	3.21 ± 2.03*
Control	Pre-phase	6.88 ± 1.95	6.88 ± 1.95	6.00 ± 7.17*
	Post-phase	6.84 ± 7.48	6.84 ± 7.48	4.60 ± 3.63

Photoplethysmography low frequency/high frequency (LF/HF) ratio before (pre-phase) and after (post-phase) administration of local anesthetic in unilateral lumbar sympathetic blockade, for patients with unilateral lower extremity pain and self-reported cold hyperalgesia, stratified according to the reported degree of pain relief: sympathetically mediated pain (SMP; pain intensity decreased below 2 for ≥ 1 week); sympathetically independent pain (SIP)

Data are presented as means ± SD.

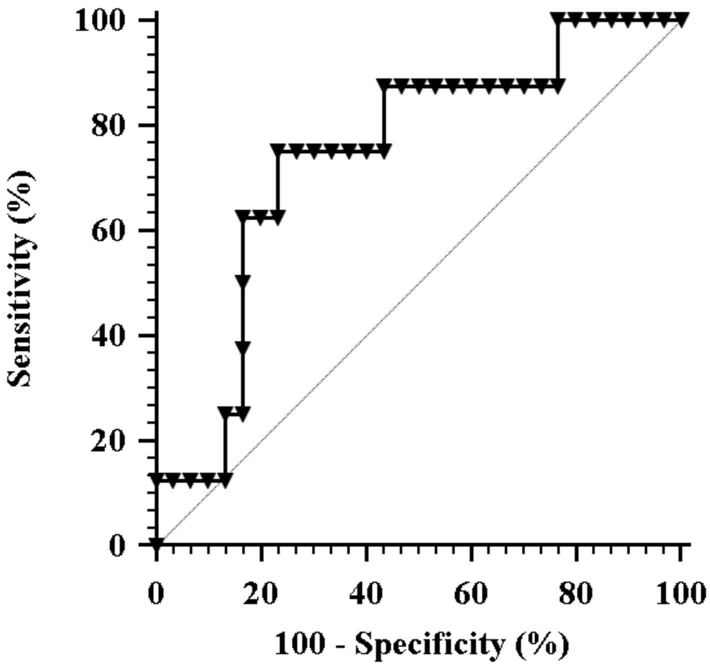
PPG: photoplethysmography; Target: affected limb; Control: contralateral limb

*$P < 0.05$ vs SMP group; Mann-Whitney *U*-test

†$P < 0.001$ vs target pre-phase; paired *t*-test

‡$P < 0.01$ vs control post-phase; paired *t*-test

Figure 3. Receiver operating characteristic (ROC) curve for sympathetic mediated pain (SMP).



This graph is showing the true positive(sensitivity (%)) and false positive (100 – specificity (%)) rates at the best cut-off point of LF/HF ratio (below 2.92) for SMP. The 45°dotted line represents the point at which the test is no better than chance. The area under the ROC curve (AUC) measures the performance of the test (0.742).

Discussion

The present study showed that PPG signals are more useful than temperature monitoring for earliest assessment of the successful LSB. Further, PPG signals proved valuable for predicting the involvement of SMP and the associated success of LSB. In our study population, the frequency of patients diagnosed with SMP was 21.1% (eight of 38 patients) including 22.2% of CRPS type I; 27.3%, CRPS-NOS; 1 case of Raynaud disease, which was similar to that found in another study (25%) using quantitative sensory testing after sympathetic blockade.[18]

The pulsatile AC signal of PPG is related to the pumping action of the heart and the average of blood flow within the sample.[14, 15] Before administration of local anesthetics, the temperature and AC amplitude of PPG are lesser in the symptomatic limb than in the normal limb; this may be related to decreased blood volume due to vasoconstriction derived from high sympathetic tone. After initiation of LSB, blood volume increases as a consequence of vasodilation in both arteries and veins.[34] In this study, the time gap between the initiation of AC signal change and temperature change was approximately 180 seconds.

In the present study, the onset time was similar to that found in our former study (5 min), in which only temperature monitoring was performed.[12] However, AC signals of PPG began to change within 60 seconds after injection of local anesthetics. Indeed, amplitude inversions of AC signals of PPG appeared approximately 3 minutes before the onset of LSB, as estimated based on temperature changes. Although sympathetic denervation can increase blood influx and affect PPG signals by decreasing resistance of arterioles and increasing venous volume, the time gap between changes in PPG signals and temperature elevation (due to blood perfusion) may explained by the fact that sympathetic nerve fibers are not distributed to the capillaries.[35] Our findings indicate that similar to pulse oximeter perfusion index of PPG, AC signals of PPG can be used as an early assessment tool for successful LSB.[34,36]

The slowly varying DC signals of PPG in the range of 0.01–0.40 Hz are related to sympathetic nervous system activities, which include relative vascularization and blood pooling within sampling site.[14] In the present study, the value of DC signals at target side was greater than that at the control side, but it decreased gradually after administration of local anesthetics, and ultimately became lesser than that at the control side. Although inversion of value of DC signals progressed slowly, it occurred around the time of temperature change, suggesting that sympathetic activity decreased unilaterally as LSG progressed. In addition, on power spectrum analysis, the LF/HF ratio significantly decreased after the onset of LSB at the target side. Because the

LF/HF ratio is used to indicate balance between sympathetic and parasympathetic tone,[27,29] a decrease in this score may indicate a decrease in sympathetic tone. These findings show that DC signals of PPG can also be used as a tool for determining the success of LSB. However, LF/HF ratio derived from ECG was not statistically significant. This suggests that unilateral lumbar sympathetic blockade does not affect the heart rate in patients with normal cardiac function in the present study.

Overall pain intensity diminished from 7.13 to 4.74 (33.5%) in this study population, indicating that LSB was not always effective to manage pain in patients with self-reported cold hyperalgesia; therefore, we assumed that pre-procedural pathophysiologic conditions are related to individual responses to LSB. Generally, the efficacy of LSB is assessed on basis of at least 50% of pain relief.[16,37,38] Because PPG has not been established as a predictor of pain relief, we established the stringent NRS score ≤ 2 for 1 week. With reference to present study result, pre-procedural LF/HF ratio was paradoxically lesser at the target side than at the control side in spite of lesser temperature and lesser amplitude of AC signal. In other words, blood flow was diminished although sympathetic activities were maintained at a lower level on the affected side. This phenomenon was observed in the entire patient population, but it was especially notable in the SMP group. Compared with the SIP group, the SMP group had a lower LF/HF ratio at the affected side. This may be related to a local compensatory mechanism of blood flow.

The blood flow to each tissue is usually regulated according to the tissue's requirement and is divided into acute control and long-term control.[39] In the acute phase of disease, local vascularity is increased to favor the healing process. Angiogenesis causes this increased blood flow to persist after healing, inducing local heat loss. This phenomenon encourages proximal vasoconstriction to decrease blood flow influx, ultimately promoting a vicious cycle in which distal sympathetic activities are decreased and local heat loss is increased.[38] In ischemic pain, sympathetic blockade increases blood flow through blockade at proximal level, facilitating oxygen delivery to tissues and removal of pain-mediating substances from tissue. Because the effect of this artificial acute control by local anesthetic diminishes over time, repetitive sympathetic blockades may be required for such patients.

A recent report showed that there were no signs or symptoms could predict an effective sympathetic blockade before the procedure.[40] Allodynia and hypoesthesia rather played roles as negative responsible factors in CRPS type I. In present study, 78.9% of patients did not response to LSB sufficiently despite a diagnosis of cold hyperalgesia. These patients, belonging to the SIP group, appeared to have an abnormal physiologic compensatory mechanism for circulation; in these cases, sympathetic blockade should be used as an accessory treatment option. However, we cannot agree with complete prohibition of sympathetic blockade for SIP patient because not even spinal cord stimulation can guarantee increased blood flow.[41]

The limitations of the present study include non-randomized analysis of PPG signals. However, a double-blinded process between independent signal analysis and statistical investigation according to the flowchart could counterbalance this limitation. Another limitation was the small sample size of the SMP population, which hindered the definition of a clear cut-off LF/HF ratio value for diagnosis. Notwithstanding the need for further studies with larger sample sizes, we suggest that sympathetic blockade is helpful for pain relief when the LF/HF ratio on the affected side is below 2.92, approximately half the value of that on the normal side.

In conclusion, PPG can be used as an early indicator for a successful lumbar sympathetic block since its AC signal changes happen earlier than temperature rising after local administration. Indeed, it can be useful as a determining tool for the assessment as well as will be helpful to distinguish the sympathetic mediated pain from the sympathetic independent pain before lumbar sympathetic blockade. And also, further studies should be focused on finding the cut-off value for diagnosis of sympathetic mediated pain.

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초 록

서론: 요부 교감신경절 블록술은 하지의 동맥과 정맥혈관에 분포되는 교감신경을 국소마취제 작용시간 동안 블록하여, 혈관을 확장시키고 순환 혈류량을 증가시킴으로써 다양한 하지 통증을 치료하기 위한 좋은 중재적 시술방법이지만, 시술 시 요추 척추체 앞쪽 옆까지 바늘을 삽입하는 비교적 침습적인 시술이기 때문에, 드물게 출혈이나 신장손상, 요통유발 등의 합병증을 발생시킬 수 있어 주의를 요한다. 임상적으로 하지의 시린 통증이나 냉통각과민 증상이 있는 환자를 대상으로 이 블록술을 시행하지만, 요부 교감신경절 블록술을 시행한다 하더라도 통증완화 효과가 없는 경우도 있는데, 시술을 시행하기 전에 이러한 결과를 예측하는 것은 현재까지 불가능하였다. 따라서, 이 연구에서는 요부 교감신경절 블록술을 시행하는 전 기간 동안 광체적 흡광도 신호를 취득하여, 그 변화를 조사하고 스펙트럼분석을 통해 어떤 환자가 요부 교감신경절 블록술을 통하여 완연한 통증완화 효과가 있을지 예측해 보고자 하였다.

방법: 냉통각과민을 동반한 일측 하지 통증을 호소하는 환자 50명을 대상으로 요부 교감신경절 블록술을 시행하는 동안 양하지 온도와 광체적흡광도 신호를 취득하고, 설정된 연구 제한기준에 맞는 38명에

대하여 분석을 시행하였다.

결과: 광체적 흡광도의 AC 신호는 하지 온도가 상승하기 전, 약물주입 직후부터 변화하기 시작하였으며, DC 신호는 천천히 감소하는 양상을 나타내었다. 38명중 8명(22.1%)이 통증점수 2점 이하의 매우 훌륭한 통증경감 효과를 보여 교감신경 매개성 통증으로 분류되었다. 푸리에 분석을 이용한 교감신경계 활성도를 나타내는 DC 신호의 저주파영역과 고주파영역 비는 교감신경 매개성 통증으로 분류된 군에서 오히려 시술 전과(2.81 ± 1.60 vs. 4.99 ± 3.12, P = 0.038) 시술 후(1.77 ± 0.82 vs. 3.21 ± 2.03, P = 0.023) 모두 낮게 측정되었다.

결론: 광체적 흡광도 신호는 요부 교감신경절 블록술의 성공여부를 온도변화보다 빨리 감지할 수 있는 방법일 뿐만 아니라, 시술 시행 전에 미리 신호분석을 통해 해당 환자에서 통증완화 효과를 보일 수 있을지 예측할 수 있는 도구로 사용될 수 있다.

주요어: 광체적흡광도, 교감신경매개통증, 요부교감신경블록술, 스펙트럼분석

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