Palmar Skin Blood Flow and Temperature Responses Throughout Endoscopic Sympathectomy

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Thoracic surgical sympathectomy is often performed to treat primary palmar and axillary hyperhidrosis. An increase in palmar skin temperature is frequently used to identify the success of the procedure. Because changes in palmar skin temperature occur secondary to changes in skin blood flow, the objective of this study was to test the hypothesis that monitoring palmar skin blood flow would provide greater temporal resolution relative to monitoring palmar skin temperature. In 11 patients with palmar and/or axillary hyperhidrosis, we measured palmar skin temperature and blood flow (via laser Doppler flowmetry) throughout the sympathectomy procedure. Five minutes after the initial cautery, skin blood flow increased from 48 ± 7 perfusion units to 121 ± 17 perfusion units ($P < 0.001$), whereas no significant change in temperature was observed (31.0°C ± 0.5°C to 31.3°C ± 0.5°C; $P > 0.05$). The time required to reach peak skin blood flow (22 ± 3 min) was significantly less than the time required to reach peak skin temperature (34 ± 0.3 min; $P < 0.001$). Finally at 5, 10, and 15 min after the initial cautery, skin blood flow increased to a larger percentage of the total increase in relative skin temperature (all $P < 0.006$). These data suggest that monitoring skin blood flow provides greater temporal resolution when compared with monitoring skin temperature during thoracic sympathectomy. However, the initial cautery of the parietal pleura over the ganglion may result in increases in skin blood flow before physical disruption of the ganglion. This occurrence may limit the utility of skin blood-flow measurements in identifying the success of the procedure.

(Anesth Analg 2004;99:●●●–●●●)

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Primary palmar hyperhidrosis is a common disorder characterized by profuse sweating of the palms. This conditions has been reported to affect 0.6% to 1% of the Israeli population (1), and a recent report suggests a similar prevalence in the United States (2). Depending on the severity of the condition, palmar hyperhidrosis can be physically and emotionally debilitating in professional and social settings. A number of noninvasive or minimally invasive treatments are available for this condition, such as topical administration of aluminum chloride creams, water iontophoresis and, more recently, botulinum toxin injections (3). However, each of these treatments requires repeated application throughout the individual's life, often with limited effectiveness. For this reason, many individuals seek a permanent surgical solution of upper thoracic sympathectomy or sympathotomy to eliminate the effects of this condition and axillary hyperhidrosis (4–9). For treatment of these conditions, surgical disruption (i.e., resection, clipping, or disconnection via electrocautery) of the second and/or third thoracic ganglia is the most common procedure performed.

A number of intraoperative techniques for identification of a successful sympathectomy have been used. The most common technique is monitoring palmar temperature (6,10–14). The literature reports a wide range of increases in palmar skin temperature (0.4°C to 10°C) that are observed with a successful sympathectomy (4,6,11,14). The width of this range may be related to relatively slow changes in palmar temperature upon disruption of the ganglion, the time at which the investigator obtained the final reading, or an influence of the surgical suite temperature on palmar temperature. It is interesting that in a few cases successful sympathectomies were performed with inconsistent changes in palmar skin temperature (10).

Supported in part by National Institutes of Health Grants HL61388 and HL67422.

Accepted for publication June 24, 2004.

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DOI: 10.1213/01.ANE.0000139359.46635.2D

0003-2999/04

<ARTICLE DOCTOPIC="Article" DOCSUBJ="" DATE="December, 2004" VID="99" ISS="6" PPF="●●●" PPL="●●●" DOI="10.1213/01.ANE.0000139359.46635.2D">

Increases in palmar skin temperature during the surgical procedure occur secondary to increases in skin blood flow. In humans, neural modulation of blood flow to the glabrous skin of the palm is controlled solely by a sympathetic vasoconstrictor system, whereas neural control of nonglabrous skin is governed by a sympathetic vasoconstrictor system and a separate active vasodilator system (15–18). Upon neural disruption of glabrous skin during thoracic sympathectomy, large increases in skin blood flow have been reported (5,6,10,19). However, those studies limited their assessment of skin blood-flow responses to pre- and postsurgical periods. Therefore, little is known about the dynamic characteristics of skin blood flow, and how it relates to skin temperature, during the surgical procedure. Thus, the purpose of this study was to assess the utility of measuring intraoperative skin blood flow and to test the hypothesis that increases in palmar skin blood flow will precede increases in palmar skin temperature upon successful disruption of the ganglion. Such an outcome may demonstrate the usefulness, and perhaps the superiority, of intraoperative monitoring of skin blood flow over skin temperature during surgical sympathectomy for hyperhidrosis.

Methods

This study received approval from the IRB committees at both Presbyterian Hospital of Dallas and the University of Texas Southwestern Medical Center. The study design and associated risks of participation were explained to each subject, and each subject signed an approved consent form.

Eleven healthy subjects (four men and seven women; ASA class I) participated in this study. The average age of the subjects was 27 ± 3 yr, and they were of normal weight (77 ± 5 kg) and height (169 ± 4 cm). Ten subjects exhibited clinical manifestations of palmar and/or axillary hyperhidrosis, and one subject sought treatment for pronounced facial blushing and hyperhidrosis.

A peripheral IV catheter was placed, and 1–2 mg of midazolam was administered for sedation. The patient was transported to the operating room, where standard monitors were used, including a five-lead electrocardiogram, pulse oximetry, and automated oscillometry. The induction of general anesthesia was accomplished with 1 μg/kg fentanyl and 1.5 mg/kg propofol followed by 0.6 mg/kg rocuronium or 0.1 mg/kg cisatracurium to facilitate endotracheal intubation. A left-sided double-lumen endotracheal tube was placed, and its correct position was confirmed by fiberoptic bronchoscopy. Anesthesia was maintained with 1%–3% sevoflurane or 6%–7% desflurane at a fresh flow rate of 2 L/min. Up to 150 μg of supplementary fentanyl was administered if necessary.

Each subject was positioned with his or her arms supported anterior to the forehead. Uninsulated thermocouple temperature probes (Sable Systems, Las Vegas, NV) were placed on the thenar eminence of both palms. Integrated laser Doppler flowprobes (Perimed, Sweden) were positioned adjacent to the temperature probes. Care was taken to avoid placing the probes over superficial veins. Laser Doppler flowmetry is a widely used and accepted method of quantifying skin blood flow (5,6,10,19–24).

Each subject underwent bilateral endoscopic thoracic sympathectomy by the same surgeon (DMM). Three 3-mm incisions were made along the inframammary fold, through which thoracoscopic ports were inserted. Ganglia at the level of T2 ($n = 2$), T3 ($n = 7$), or T4 ($n = 2$) were identified and removed by using monopolar cautery. Periosteum over the adjacent ribs was cauterized to ablate any accessory nervous pathways. There were no differences in responses due to the level of ganglion removed, and thus data from all three levels were combined. In all cases, sympathectomy was first performed on the left side, followed by sympathectomy on the right side.

Each sympathectomy was treated as a unique observation. Experimental complications pertaining to either equipment or human error resulted in 19 sympathectomy procedures being analyzed. Skin blood-flow and temperature values were continuously sampled at 50 Hz via a commercial data-acquisition system (Biopac, Santa Barbara, CA). Baseline skin blood-flow and temperature values were obtained after the induction of general anesthesia and the insertion of endoscopic ports, but before any cautery was performed. In addition to baseline values, palmar skin blood flow and temperature were obtained at 5, 10, and 15 min after the initial cautery. Peak skin blood-flow and temperature responses were also obtained upon identification of a plateau of these responses. Four statistical analyses were performed on these data. 1) At each time point, responses for each variable (i.e., skin blood flow and temperature) were statistically analyzed via a one-way repeated-measures analysis of variance followed by a Student-Newman-Keuls *post hoc* test when a significant main effect was identified. 2) Differences in the duration from initial cautery to peak response between skin blood flow and temperature were statistically analyzed via a paired Student's *t*-test. 3) The percentage increase in the response of each variable at the aforementioned times was calculated relative to the total increase of that variable (i.e., the range) by using the following equation:

$$(X - \text{baseline response}) \times (\text{peak response} - \text{baseline response})^{-1} \times 100,$$

where *X* is the value at 5, 10, or 15 min after the initial cautery.

This calculation resulted in a value that represented a fraction of the total response at each of the listed times. At each time point, differences between these values for skin blood flow and temperature were statistically compared via a paired Student's *t*-test. 4) To assess the effect of sympathectomy on the variability of the oscillations in skin blood flow, the coefficients of variation (SD × mean^{-1} × 100) between baseline and peak skin blood-flow responses were obtained and statistically analyzed via a paired Student's *t*-test. The *P* value for statistical significance was set at 0.05. All data are presented as mean ± SEM.

Results

All subjects considered the surgery successful and reported a pronounced reduction in sweating in the affected areas after recovery. In each case, histological analysis of the removed tissue confirmed the tissue as ganglia. A typical response for the first 15 min after cautery is illustrated in Figure 1. Before cauterizing of any tissue, skin blood flow averaged 48 ± 7 perfusion units (PU), and temperature averaged 31.0°C ± 0.5°C. Five minutes after the initial cautery, skin blood flow increased to 121 ± 17 PU ($P < 0.001$), whereas no significant difference in skin temperature was identified (31.3°C ± 0.5°C; $P > 0.05$). Both skin blood flow and temperature were significantly increased from baseline 10 and 15 min after the initial cautery (Fig. 2). Peak skin blood flow and peak temperature after sympathectomy were 182 ± 17 PU and 33.8°C ± 0.3°C, respectively. However, the time required to reach peak skin blood flow (22 ± 3 min) after the initial cautery was significantly less than the time required to reach peak skin temperature (34 ± 0.3 min; $P < 0.001$).

To identify the delay between the increase in skin blood flow relative to the increase in skin temperature, the percentage increase in the respective value relative to the total range of that value was calculated at each time point and is depicted in Table 1. At 5 min postcautery, 45% ± 9% of the increase in skin blood flow had occurred, whereas only 11% ± 5% of the increase in skin temperature had occurred ($P = 0.002$). At 10 min postcautery, 68% ± 7% of the increase in skin blood flow had occurred, whereas 43% ± 7% of the increase in skin temperature had occurred ($P = 0.006$). Finally, at 15 min postcautery, 82% ± 4% of the increase in skin blood flow had occurred, whereas 59% ± 6% of the increase in skin temperature had occurred ($P < 0.001$).

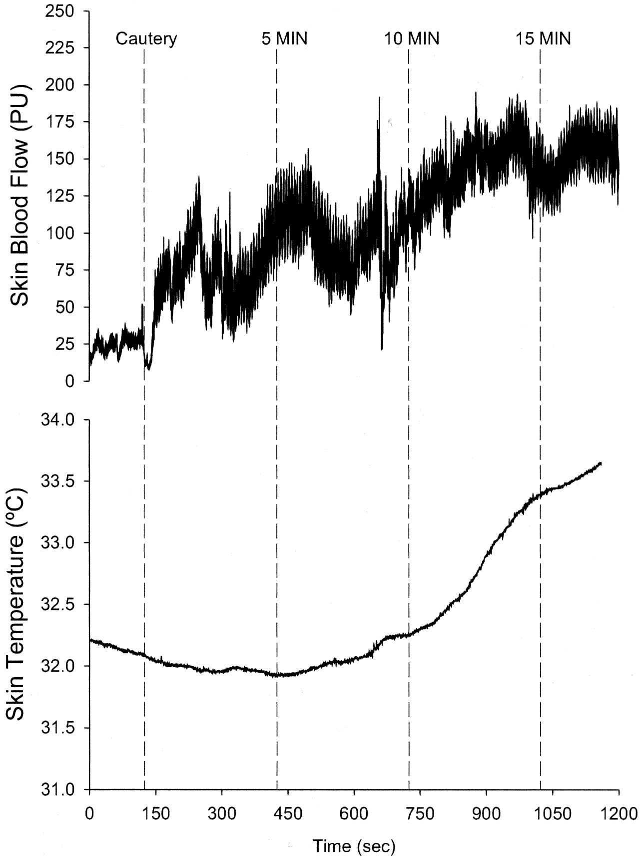

Figure 1. Typical palmar skin blood-flow and temperature responses during the sympathectomy procedure. The label indicated as "cautery" represents the initial cautery of the parietal pleura over the ganglion. The subsequent time points depict the time after this initial cautery. Notice the large increase in skin blood flow associated with the initial cautery. For this subject, the ganglion was sectioned ~5 min after the initial cautery. The increase in skin temperature lagged behind the increase in skin blood flow. PU = perfusion units.

At baseline and at peak blood flows, the coefficient of variation was calculated to identify the variability of blood-flow oscillations. At baseline, this value for palmar skin blood flow was significantly greater (28% ± 2%) relative to peak blood flow after sympathectomy (7% ± 1%; $P < 0.001$). It is interesting that at baseline oscillations in palmar skin, blood flow occurred at frequencies associated with Mayer waves (i.e., approximately 0.05 to 0.15 Hz) or appeared to be random. In contrast, after sympathectomy, these low-frequency oscillations were substantially minimized, whereas oscillations associated with the cardiac cycle were larger than at baseline (Fig. 3).

Discussion

The primary objective of this study was to assess the usefulness of intraoperative skin blood flow monitoring during surgical sympathectomy and to identify whether increases in palmar skin blood flow precede increases in palmar skin temperature. Although others have reported that palmar skin blood flow is increased

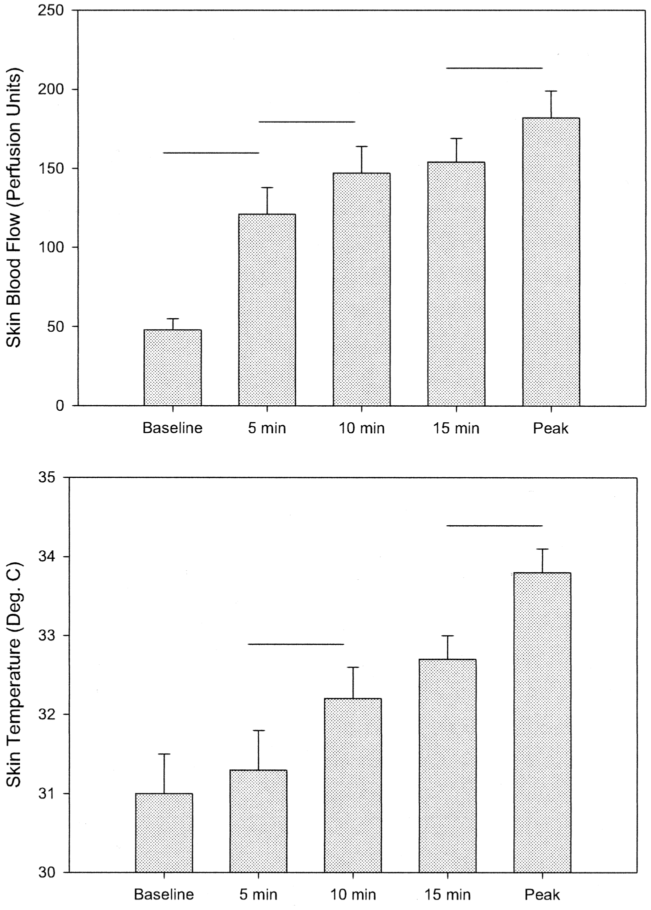

Figure 2. Average increases in palmar skin blood flow and temperature. Skin blood flow was significantly increased at 5 min postcautery and remained increased relative to baseline throughout data collection. In contrast, skin temperature at 5 min was not significantly different from that at baseline. Skin temperature was significantly more than baseline at 10 and 15 min after the initial cautery. Lines above the columns indicate statistical differences between adjacent periods ($P < 0.05$). Times depict the duration after initial cautery.

after sympathectomy (6,11,14), this study and companion studies (25) are the first to simultaneously record and compare palmar skin blood flow and temperature responses during the surgical procedure. Three primary, and related, findings confirm the hypothesis that skin blood-flow responses precede skin temperature responses during this operation. The first evidence is illustrated in Figures 1 and 2. In Figure 1, skin blood flow rapidly increased after the initial cautery, whereas skin temperature did not begin to increase until approximately five minutes later for this subject. In Figure 2, average data demonstrate that five minutes after the initial cautery, skin blood flow was more than twice the baseline value, whereas there was no significant change in skin temperature at this time. Second, the time after initial cautery to achieve a plateau of skin temperature was approximately 12 minutes after the plateau in skin blood flow. Third, the percentage increase in skin blood flow relative to the total increase in skin blood flow during surgery (i.e., peak − baseline) was significantly greater for each time point when compared with skin temperature (Table 1). Stated another way, at the observed time points, skin blood flow increased to a larger fraction of the total increase of this variable relative to skin temperature. Together, these data confirm that skin blood-flow responses preceded skin temperature responses throughout the procedure.

Palmar skin blood flow is primarily governed by a sympathetic vasoconstrictor system (15,18). When tonic sympathetic activity to the palm is disrupted, large increases in skin blood flow occur (26). Monitoring of palm or fingertip temperature has become the standard in identification of successful sympathectomy (6,10–14). Assuming that environmental temperature is constant, changes in palm or fingertip temperature during surgery will occur secondary to changes in skin blood flow. Thus, it is not surprising that these data support the hypothesis that changes in skin blood flow precede changes in skin temperature during this surgery. Nevertheless, by monitoring skin blood flow, the surgeon will be able to more rapidly identify whether the region being disrupted innervates the palmar area.

Despite the reported findings, enthusiasm for the use of laser Doppler flowmetry to assess the success of surgical sympathectomy must be tempered. For most subjects, increases in skin blood flow occurred in association with the initial cautery of the parietal pleura overlying the sympathetic chain. The point labeled as "cautery" in Figure 1 depicts the initial cauterization of pleural tissue. At this time, the sympathetic chain remained intact and was not physically disrupted by the cautery probe. However, it is likely that the current associated with cautery over the ganglion disrupted neural transmission at this location and that this disruption persisted through the period when the ganglion was sectioned. Once the sympathetic chain was cut, at approximately five minutes for the subject illustrated in Figure 1, a large fraction of the increase in skin blood flow had already occurred. If the initial cautery temporarily disrupts neural transmission in this area, a surgeon may incorrectly conclude that the initial increase in skin blood flow indicates a successful sympathectomy. Thus, a critical finding from this study is that an abrupt increase in palmar skin blood flow is insufficient to conclude that the sympathetic chain is permanently disrupted.

Another method to identify the success of the sympathectomy procedure may be to assess oscillatory characteristics of skin blood flow during the surgery. Before cautery, palmar skin blood flow showed typical fluctuations characteristic of glabrous skin (27–29). These fluctuations are primarily due to sympathetic modulation of arterial venous anastomoses, which are

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Table 1. Percentage Increase in the Measured Variable Relative to the Range of Increase as a Result of the Sympathectomy Procedure

Variable	Skin blood flow (increase relative to total range of increase)	Skin temperature (increase relative to total range of increase)	*P* value
5 min after initial cautery	45% ± 9%	11% ± 5%	0.002
10 min after initial cautery	68% ± 7%	43% ± 7%	0.006
15 min after initial cautery	82% ± 4%	59% ± 6%	<0.001

See text for the mathematical calculation used to obtain these data.

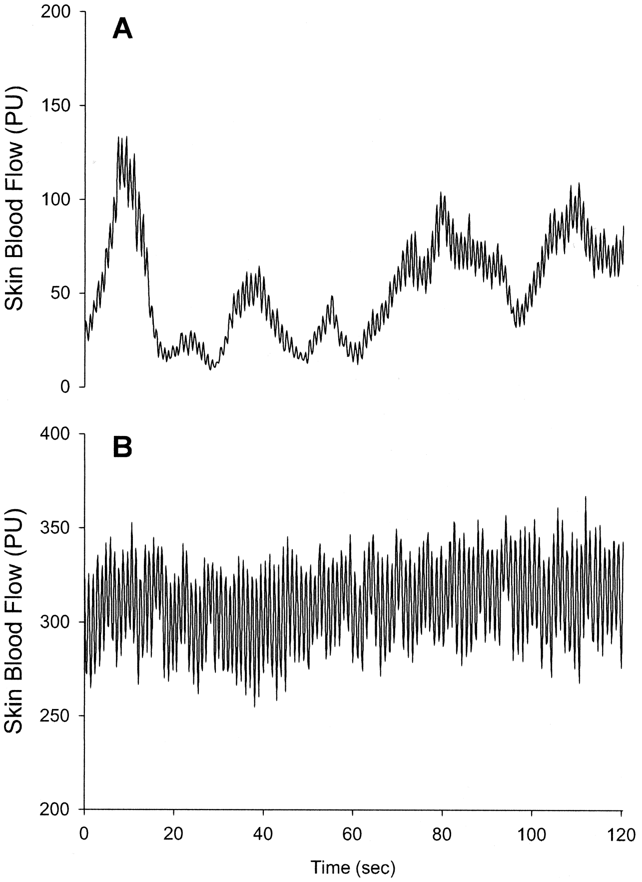

Figure 3. Palmar skin blood flow at baseline before cautery (A) and at peak response after sympathectomy (B) from a representative subject. Notice the large magnitude of low-frequency fluctuations before sympathectomy that was absent after sympathectomy. However, after sympathectomy, variation in skin blood flow associated with the cardiac cycle was greatly enhanced. PU = perfusion units.

numerous in glabrous skin (30). At baseline, the average coefficient of variation was quite large (28% ± 2%). Although insufficient baseline data were obtained to appropriately perform a spectral analysis of this response, the frequency of these oscillations was within the range previously reported from glabrous skin (29). After removal of the ganglion, these low-frequency fluctuations were abolished. However, it is interesting that blood-flow oscillations associated with the cardiac cycle became quite prevalent (Fig. 3). An increase in oscillations associated with the cardiac cycle may be related to an increase in the compliance of the vasculature upon removal of tonic sympathetic activity.

Although conclusions regarding the delay in skin temperature relative to skin blood flow during the surgical procedure are similar between this article and its companion (25), a few key differences are worth noting. The present surgical procedure, in which the desired ganglion is removed, is the more common technique. This is in contrast to the procedure of the companion study (25), in which the connection between the stellate ganglion and the T2 ganglion is permanently disrupted (sympathotomy). A detailed description of the differences of these surgical methods (i.e., sympathectomy and sympathotomy) to treat hyperhidrosis has recently been reported (4). A key limitation of the interpretation of our data is the possible confounding effects of the initial cautery leading to increases in palmar skin blood flow before physical disruption of the ganglion. Such a limitation may not exist or may be minimized with the sympathotomy procedure. It is likely that because the ganglion is not removed with the sympathotomy procedure, less cauterization occurs before disconnection of the T2 ganglion from the stellate ganglion. Thus, the abrupt increases in skin blood flow observed in the companion study (25) may be more an effect of interruption of the neural connection than an effect of application of current in this area when compared with this study.

Both studies report the time from cautery until the peak skin blood-flow and temperature responses. However, the values between these studies are quite different: this study reports an average duration of 22 minutes for skin blood flow and 34 minutes for skin temperature, whereas the companion study (25) reports an average duration for skin blood flow and temperature of approximately 1 and 5 minutes, respectively. Although in both studies skin blood-flow responses preceded skin temperature responses, differences in the duration to peak responses between these studies can only be speculated at this time and may be related to the aforementioned differences between the sympathectomy and sympathotomy procedures. For the sympathectomy procedure, the time from the initial cautery until physical disruption of the ganglion has the potential to be substantially longer than the sympathotomy procedure. The initial increase in skin blood flow and the associated increase in skin temperature during the sympathectomy procedure is likely due to the application of current. This would be followed by the physical disruption of the ganglion and subsequent further increases in skin blood flow and temperature. Moreover, given the possibility that the sympathotomy procedure may be performed quicker than the sympathectomy procedure, differences in the time to peak response between these studies may also be related to the duration that the responses are observed after the initial disruption of the ganglion.

In this study, the average increase in skin temperature associated with the procedure was ~2.8°C, whereas the companion study (25) showed an increase in skin temperature of ~1.2°C. These differences may be a factor of the duration after the initial cautery that the responses were observed. As previously discussed, it is likely that the time necessary to remove the ganglion (sympathectomy) was longer than the time required to disconnect the ganglion (sympathotomy). Given this, differences in temperature between studies may be related to the duration the responses were observed after the initial cautery. Another distinction between these studies is the location of the temperature probe. In this study, the temperature probe was placed as close as possible to the laser Doppler flowmetry probe, and both were located near or on the thenar eminence. This is in contrast to the companion study, in which the temperature probe was placed on the finger.

In conclusion, data from this study support the hypothesis that skin blood-flow responses, as measured via laser Doppler flowmetry, precede skin temperature responses during surgical sympathectomy. These findings suggest that monitoring skin blood flow may provide greater temporal resolution when compared with skin temperature during the surgical procedure. However, the surgeon needs to be aware that cautery of the parietal pleura over the ganglion may result in increases in skin blood flow without physical disruption of the ganglion, and this thus may limit the utility of skin blood-flow measurements in identifying the success of the procedure.

We would like to express appreciation to Kimberly Williams, RN, for her assistance with this project, as well as to the surgical support staff at St. Paul University Hospital at Southwestern Medical Center.

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