CLINICAL MANAGEMENT

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Infrared Skin Thermometry: An Underutilized Cost-effective Tool for Routine Wound Care Practice and Patient High-Risk Diabetic Foot Self-monitoring

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This continuing educational activity will expire for physicians on January 31, 2016.

PURPOSE:

To provide information about the use of infrared skin thermometry for routine wound care practice and patient high-risk diabetic foot self-monitoring.

TARGET AUDIENCE:

This continuing education activity is intended for physicians and nurses with an interest in skin and wound care.

OBJECTIVES:

After participating in this educational activity, the participant will be able to:

1. Describe infrared thermometer use and the authors' study findings.

2. Summarize studies that have evaluated the use of infrared thermometers for measuring skin temperature of the diabetic foot.

ABSTRACT

The aim of this article is to provide practitioners with an overview of infrared skin thermometry for everyday wound care practice. Thermometers have the potential for home use by patients with neuropathy to self-detect damage from repetitive trauma that will increase the risk of foot ulceration.

KEYWORDS: infrared thermometers, wound infection, diabetic foot monitoring, Charcot foot

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The measurement of increased skin temperature with infrared thermometry has been utilized clinically for detecting altered metabolic activity. Skin thermometry facilitates clinician and patient assessment of:

- increased skin temperature associated with systemic fever,
- monitoring of repetitive trauma–associated increased risk of neurotropic foot ulceration,
- localized sign of deep inflammation (an acute Charcot joint), and
- periulcer (local) signs of deep and surrounding infection.

PRINCIPLES OF INFRARED THERMOMETRY

Simple thermodynamic principles can explain the physics of infrared thermometry. All objects at a temperature greater than absolute zero release infrared radiation.[1] Similarly, in the human body, heat released by inflammation, fever, and infection is a form of infrared radiation. When this infrared radiation is perceived by a sensor in the infrared thermometer, the sensor converts this energy into a specific electrical signal that corresponds to a given temperature. The higher the temperature, the greater the infrared radiation received by the sensor, which displays a higher temperature reading.

There are many different types of commercially available infrared thermometers, and most can be categorized as either "contact" or "noncontact." Numerous studies have compared the accuracy of noncontact infrared thermometers with contact infrared thermometers and mercury thermometers for detecting elevated skin surface temperatures associated with systemic fever in children.[2–4] Noncontact infrared thermometers have equivalent or better diagnostic accuracy when compared with mercury-in-glass thermometers and contact infrared thermometers. Furthermore, noninvasive/noncontact thermometers are more comfortable, especially for children. Although rectal thermometry remains the most reliable method of obtaining a child's temperature, Teran et al[3] recently reported the superior diagnostic accuracy of a noncontact infrared thermometer compared with traditional rectal thermometers.

This article reviews the key indications for use of noncontact infrared thermometry:

- to detect periwound deep and surrounding infection,
- in patients with peripheral neuropathy (including patients with diabetes),
  - repetitive foot trauma and an increased risk of a foot ulcer, and
  - inflammation associated with an acute Charcot joint.

Diabetic ischemic limbs can lose their normal symmetrical arterial blood flow owing to asymmetrical plaque formation and blockages in the arterial system. The resultant impedance to the normal symmetry of the arterial blood supply affects the proximal as well as the distal arterial circulation. This asymmetrical and ischemic vascular supply may also result in measurable temperature differences. Limb ischemia results in lower regional, local, and side-to-side variability in temperatures. Using the handheld thermometer, the operator is able to essentially map out an unequal vascular supply by measuring the temperatures proximal and distal to the wound. In addition, by measuring the temperatures of the contralateral limb at the exact anatomical points of measurement locations of the ipsilateral limb, a "mirror image" or temperature map may be constructed and correlated with other studies, digital subtraction angiography, arteriograms, ultrasound, and Doppler studies.

If the bilateral limb temperature measurements are approximately equal, the periwound temperature difference may be considered local. A local temperature increase with intact skin is most likely inflammatory (eg, deep inflammation or Charcot joint), and if an ulcer is present, strongly consider infection. Cellulitis (erythema and edema) with warmth may represent an infection, but there is often an identifiable source of entry (eg, local puncture wound, insect bite, abscess, or a distal toe web maceration/chronic fungal infection). Occasionally, osteomyelitis or local infection of the bone is concomitant with an active Charcot joint in the foot. Wound care practitioners should be equipped with an infrared skin thermometer that has a Fahrenheit scale and records the maximum temperature over any continuously scanned region in order to detect signs of deep inflammation or infection. It is easier to detect clinically important differences with the Fahrenheit scale compared with centigrade.

THERMOMETRY VALIDATION STUDY—EASE OF ACCESS

Infrared thermometers have numerous functions and clinical uses in healthcare. One of the major barriers to using infrared thermometers in clinical practice is per unit cost. Clinically tested noncontact infrared thermometers are expensive and can cost up to $700.

The authors' group (A.M., R.G.S.)[4] recently compared 4 different noncontact infrared thermometers—Mastercool MSC52224-A, ATD Tools 70001 Infrared Thermometer, Mastercraft Digital Temperature Reader, and Pro Point Infrared Thermometer —with the clinically accepted reference thermometer Exergen DermaTemp 1001.[4] Central Ethics Board approval was obtained before the start of the study.

The participants consisted of 108 (n = 108) patients. There were 61 men (n = 61) and 47 women (n = 47) enrolled in the study. Furthermore, the population of patients consisted of those with and without wound infection.

Methods

Under consistent ambient conditions, skin temperature readings were obtained from the wound and corresponding contralateral limb with each of the thermometers used for comparison. Accordingly, patients in the study underwent 5 individual temperature recordings. In order to avoid evaporation artifacts of the wound, temperatures were allowed to equilibrate for approximately 10 minutes after dressing removal. The location and etiology of the wounds were also recorded. The target temperature was then subtracted from the contralateral temperature, in order to obtain the parameter of interest: "ΔT." To assess the interrater reliability of the thermometers between different users, the principal investigator and an experienced wound care nurse duplicated temperature readings independently on 20 participants.

There was no statistical difference between the "ΔT" values for the 5 different thermometers (F4,514 = 0.339, P = .852). Furthermore, post hoc analysis yielded the following results when the 4 less expensive thermometers (Mastercool MSC52224-A [P = .987], ATD Tools 70001 Infrared Thermometer [P = .985], Mastercraft Digital Temperature Reader [P = 0.972], and Pro Point Infrared Thermometer [P = 0.774]) were compared with the clinically tested reference thermometer. Interrater reliability was calculated utilizing an intraclass correlation formula. The authors' results demonstrated a high reliability and agreement between different raters, as the intraclass correlation coefficient values for all thermometers were greater than 0.95.

This study validated the clinical and practical reliability of less expensive noncontact infrared thermometers with the reference noncontact infrared thermometer. In addition, the noncontact infrared thermometers selected in this study may also prevent iatrogenic spread of infection. The less expensive thermometers had a greater "distance-to-spot" ratio, compared with the reference thermometer. This increased distance from the wound to obtain temperature readings avoided accidental contamination. In the authors' experience, the reference thermometer often touches portions of the wound, thus creating a potential source of cross contamination or infection when the device is used on another wound. Although further validation studies need to be completed, the authors believe that less expensive infrared thermometers can provide reliable measurements of skin and wound surface temperatures at the bedside.

PATIENT WITH DIABETES: SELF-ASSESSMENT TOOL TO DETECT REPEATATIVE TRAUMA AND RISK OF FOOT ULCERATION

Background and Literature Review

Diabetes mellitus is a metabolic disorder characterized by elevated serum glucose due to a defect in insulin release by the pancreas (type 1 childhood diabetes) and/or an inability of insulin to act appropriately (insulin-resistant metabolic syndrome or type 2 diabetes mellitus).

Chronic and uncontrolled hyperglycemia in diabetes is associated with numerous microvascular complications, including neuropathy, nephropathy, retinopathy, and macrovascular complications such as stroke, coronary artery disease, and peripheral vascular disease. Peripheral neuropathy has 3 components that can be remembered with the mnemonic "SAM": sensory, autonomic, and motor.[5] The sensory component is measured with the monofilament; the autonomic component is identified as dry skin on the plantar surface, and the motor component is determined with a loss of reflexes. Detectable sensorimotor neuropathy develops in 40% to 50% of persons with diabetes within 10 years of diagnosis.[6]

Although clinical neuropathy is uncommon in persons with type 1 diabetes within the first 5 years after diagnosis, individuals with type 2 diabetes may present with peripheral neuropathy at the time of diagnosis, probably due to the blood glucose defect predating the clinical diagnosis of diabetes.[7] With loss of protective sensation, persons with diabetes still suffer from spontaneous neuropathic pain (burning, stinging, shooting, and stabbing) that can limit physical activity, decrease quality of life, and impair work productivity. Risk factors for early onset of neuropathy include the ABCDES of type 2 diabetes: **A**—poor glucose control as measured by an elevated HbA1c, **B**—high blood pressure, **C**—elevated cholesterol and triglycerides, **D**—poor diet with obesity or increased body mass index over 25, and **E**—lack of exercise, and **S**—smoking.[8]

Foot ulceration most commonly occurs from undetected repetitive trauma, and the foot ulcer precedes lower-limb amputation in 85% of persons with diabetes.[9–11] The repetitive trauma causes an increase in local temperature (inflammation and enzymatic autolysis of tissue) that can be monitored with infrared thermometry.[12,13] Indirect signs of the high-risk foot also include previous amputation of a digit or part of the foot, previous foot ulcer, the presence of a callus (increased local pressure), or a hemorrhagic blister (friction and shear). Measuring skin temperature using a noncontact infrared thermometer has been evaluated as an effective diagnostic tool for impending ulceration in persons with neuropathy, including associated diabetes.[11,12,14–17]

There is a growing body of literature supporting the use of patient home monitoring with infrared thermometers. Two randomized controlled trial (RCT) studies by Lavery et al[15,16] and another RCT by Armstrong et al[17] evaluated the effectiveness of daily home foot monitoring of 7 sites (Figure 1) on the neuropathic foot. These patients were compared with regular diabetes education and foot care along with an enhanced foot care program as outlined in Table 1.

These studies and previous publications were assessed in 2 separate technical reviews and meta-analyses. Arad et al[18] evaluated the preventive techniques in patients at high risk for a diabetic foot ulcer and concluded that personal or patient use of thermometry was the most robust preventive intervention. More specifically, Houghton et al[19] utilized a systematic review and meta-analysis that specifically identified strong evidence supporting the use of infrared thermometry for patient self-monitoring.

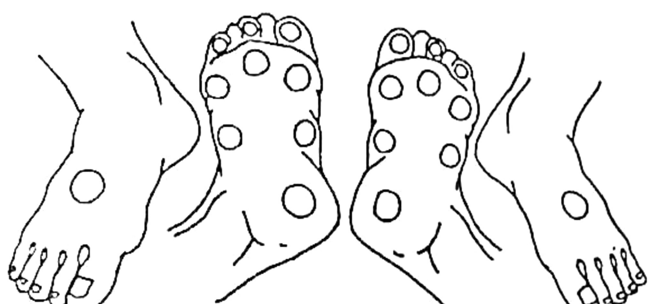
ELEVATED PERIWOUND SKIN TEMPERATURE AND INFECTION

Delayed healing of wounds not only prolongs patient distress and discomfort, but can also increase the risk of complications and add to healthcare costs.[20,21] Previous studies have demonstrated that chronic wounds infected with bacteria have reduced tensile strength and contribute to prolonged healing time. Failure to achieve wound healing in a timely fashion is multifactorial, and periwound deep and surrounding infection is one of the most significant contributors to delayed healing.[22–24]

Sibbald et al[25] developed a clinical guide to standardize the assessment of superficial critical colonization and deep/surrounding chronic wound infection. The assessment categorizes bacterial wound damage into superficial critical colonization and deep and surrounding infection that can be treated topically, and the latter requiring systemic treatment. Each category has a unique set of clinical signs. Three or more of the 5 NERDS signs are required to diagnose superficial critical colonization: **N**onhealing wound status—not 30% smaller in 4 weeks, increased **E**xudate, **R**ed and friable granulation tissue, necrotic **D**ebris, and/or **S**mell (**NERDS**). If 3 or more of these signs are present, topical antiseptics (silver, iodine, polyhexamethylene biguanide, honey, and a combination of methylene blue-crystal violet) are indicated for treatment. Signs and symptoms of deep and surrounding infection include increased wound **S**ize, increased periwound **T**emperature, **O**s (probing to bone), **N**ew areas of breakdown, **E**rythema and/or edema (cellulitis), increased **E**xudate, and **S**mell (**STONEES**). If 3 or more of these signs are present, the wound likely has a deep and surrounding infection requiring systemic antimicrobials (oral or intravenous) for treatment.

It is important to note that quantitative bacterial count on skin biopsy is still considered the criterion standard for deep and surrounding infection. This specialized skin biopsy is predominantly a research tool and not routinely performed in clinical practice.[26] Instead, semiquantitative wound swabs are more commonly ordered because of their relative accuracy (Levine technique), accessibility, and lower cost.[20,27–29] Recently, a validation study of the NERDS and STONEES criteria by Woo and Sibbald[30] illustrated that elevated temperature gradient was 8 times more likely to represent a deep and surrounding infection compared with the mirror-image temperature.[30] This is the highest association, with all the other STONEES criteria individually being 2 to 5 times more likely to be associated with a deep and surrounding infection. The validation of STONEES had a high specificity and sensitivity for the entire population studied (92), as well as for the subpopulation of 44 individuals with diabetes.[30]

Figure 1.
SITES FOR MAPPING SKIN TEMPERATURE[36]



The sites include mid-dorsum of the foot; sole of the foot; first, third, and fifth metatarsal heads; first metatarsal-cuneiform joint; talonavicular joint; and heel. Patient monitoring with the infrared thermometer does not include the 3 points on the plantar aspect of the toes (only the 7 remaining points). Healthcare professionals' 10-point monofilament exam for neuropathy can include all 10 points illustrated with 4 or more negative sites (unable to feel the monofilament) diagnostic for neuropathy.

Table 1.

SUMMARY OF PATIENT SELF-MONITORING RCTS: INFRARED THERMOMETERS VERSUS NORMAL FOOT CARE OR STRUCTURED FOOT EXAMINATIONS

Study	Duration Followed	No. of Patients in Study	% Foot Ulcers—Infrared Thermometer	% Foot Ulcers—Standard Care	% Foot Ulcers—Foot Exam Education
Lavery et al[15] (2004)	6 months	85	2%	20% $P = .01$	
Lavery et al[16] (2007)	15 months	173	8.5%	29.3% $P = .046$	30.4% $P = .029$
Armstrong et al[17] (2007)	18 months	225	4.7%	12.2% $P = .038$	

Because repeated trauma can also result in an elevated local temperature, 2 other STONEES signs are required to make a diagnosis of infection. Elevated temperatures alone, as the authors have previously discussed, may be due to repetitive trauma in the neuropathic foot. The diagnostic accuracy of palpation for an elevated skin temperature is quite limited because it is often more subjective than objective.[31]

Conventional mercury or electronic thermometers are difficult to attach to the wound or periwound area, require time to be calibrated, and are prone to lower or inaccurate readings because of the limited surface for direct contact.[32]

A handheld noncontact infrared thermometer has the potential to provide an accurate, objective, and quantitative measurement of skin surface temperature.[32] Recently, Fierheller and Sibbald[33] illustrated the relationship between increased periwound skin temperature and local wound infection. In this study, the use of the handheld infrared thermometer for 22 patients with leg ulcers was validated. Statistical analysis of the participant's wound temperature data identified a significant relationship between deep and surrounding infection and quantitative increase in periwound temperature. In the absence of deep and superficial infection, the authors reported a mean temperature difference between periwound skin and an equivalent contralateral control site to be equal to or less than 2° F (0.38° F [SD, 0.89° F]). When deep and surrounding infection was present, the mean periwound skin temperature was elevated by more than 2° F (4.43° F [SD, 2.44° F]). It is well known that skin temperature varies depending on the body location, blood flow, and external environment. The results of this study demonstrated that skin temperatures were not significantly different between nonwounded, wounded control, or wounded, noninfected periwound sites.[33] In the authors' clinical experience and based on the STONEES evaluation study,[30] benchmarked temperature elevation of 3° F or greater indicated a potential deep or surrounding infection and a case for further investigation. Using the STONEES mnemonic introduced in this study, any 3 clinical signs can indicate deep and surrounding skin infection. An increased temperature is not an absolute requirement to diagnose infection; however, the individual factor analysis indicated that temperature was the most important single indicator, but this still needs to be combined with 2 other clinical signs.

Handheld noncontact infrared thermometers are effective tools for identifying and quantifying the temperature associated with chronic wound infections. Incorporating infrared thermometers as part of the routine wound assessment provides an objective measurement of periwound skin temperature. The infrared thermometer can assist the healthcare practitioner with early detection of deep or surrounding and spreading infection, facilitating timely management. In addition to repetitive trauma and infection, infrared thermometry can also measure deep inflammatory processes including the Charcot joint.

SKIN TEMPERATURE AND ACUTE CHARCOT

Charcot joint is a progressive musculoskeletal condition that specifically affects neurotrophic feet. As previously mentioned, neuropathy consists of the 3 ''SAM'' components. In addition to diabetes mellitus, Charcot joints may also be associated complications of other causes of neuropathy including trauma, syphilis, chronic alcoholism, leprosy, meningomyelocele, spinal cord injury, syringomyelia, renal dialysis, and congenital neuropathies.

An acute Charcot joint is the result of an acute inflammatory process associated with an increased localized surface temperature of 4° F to 15° F or even higher. An X-ray examination of the foot can usually rule out other causes of trauma (fracture, foreign body), as well as deep infection. The acute inflammatory process in a neuropathic joint is probably initiated by repetitive trauma and results in multiple fractures of the bone, leading to resorption of the bone matrix. When the inflammatory process is controlled, the skin surface temperature normalizes, and the bone solidifies often with a permanent deformity. To resolve the acute process with minimal bone destruction, weight bearing should be restricted (by offloading the joint) with the use of a wheelchair or gradually introducing plantar pressure redistribution devices, including a contact cast or removable cast walker.

Patients with Charcot joint deformity can present with a wide variety of clinical features that are primarily dependent on the stage of the disease. The acute stage is usually characterized by ill-defined unilateral pain (but acute Charcot joints can be painless), edema, erythema, and associated warmth to the affected area. As the Charcot process evolves into the postacute stage, inflammation and the skin temperature tend to decrease.

Determining the complete resolution of Charcot joint is often very difficult. As Charcot joint resolves, the residual signs of inflammation are subtle and difficult to quantify and monitor. Numerous studies have reported the utility of skin temperature monitoring in Charcot joint, especially to monitor healing, and the ability to gradually resume weight bearing is often monitored in specialty diabetic foot clinics.[12,34–36]

In 1997, Armstrong et al[36] conducted a study to monitor the healing of acute Charcot joint with infrared dermal thermometry. Thirty-nine individuals diagnosed with acute Charcot joint were selected to participate in the study. The diagnosis was made primarily based on clinical, radiographic, and dermal thermometric features. Participants with comorbidities such as osteomyelitis, chronic Charcot joint, bilateral involvement, or open reduction of the fracture were excluded from the analysis.

The researchers also described the location of Charcot joint using the Sanders pattern classification. The classification is based on anatomical locations in the foot and ankle (metatarsal heads, midfoot, heel, and ankle). The 39 participants were treated with a standard protocol involving serial total contact casting. As the disease improved, participants were issued removable cast walkers and eventually prescription therapeutic shoe gear. All casts were checked at regular time intervals by study staff to ensure proper fit and appropriate plantar pressure redistribution. Furthermore, the casts were discontinued, and therapeutic footwear introduced if clinical and radiographic signs improved, as well as a return to the same temperature as the contralateral limb.

Skin temperatures were monitored using a portable infrared thermometer, and readings were recorded from 7 sites (Figure 1). These included the soles of both feet, specifically over the first, third, and fifth metatarsal heads; first metatarsal-cuneiform joint; talonavicular joint; cuboid; and heel. The researchers compared the results to the mirror image on the contralateral limb. The temperature difference between the pathological limb and contralateral side was calculated and recorded. A positive value suggested that the temperature of the affected Charcot foot was higher than the contralateral side. The authors reported that the mean skin temperature difference for all participants at initial presentation was 8.8° F+/-2.3° F (range, 5.1° F–14.7° F). In 92% of the participants, the region on the foot with the maximum skin temperature difference correlated to the site of maximum radiographically evident Charcot joint deformity. The skin temperature difference gradually decreased during total contact cast therapy. As the participants transitioned to the prescription shoe gear, the skin temperature difference normalized to a near-zero value.

The results of this study suggest that elevated skin temperatures are directly correlated with location of acute Charcot joint. The temperature differences decrease as acute Charcot joint resolves and transitions into a postacute state. Infrared thermometry can be used to detect subtle temperature differences that can persist for weeks to months, even when no palpable differences can be perceived. During the follow-up period of the study, no recurrences of Charcot joint were reported. The low incidence of recurrences was a result of immobilization of the foot in a removable cast walker or total contact cast if a difference of 4° F or more was observed.

More recently, clinicians and scientists have suggested that a "stress test" might be a promising way forward to identify early Charcot arthropathy. Najafi et al[37] measured preambulation and postambulation skin temperatures following a course of 50 and 150 steps. Patients with Charcot arthropathy had high temperatures that remained high in the postambulation period. However, those with peripheral neuropathy and no Charcot arthropathy displayed a reduction in plantar midfoot skin temperature. The results imply that reduced activity in a susceptible area not involved with an active Charcot reduces the reaction to repetitive stress.

Temperature differences as small as 4° F are difficult for healthcare professionals and patients to perceive simply by palpation.[31] Temperature monitoring utilizing infrared thermometers is quantitative and can be recorded quickly. Because the prevalence of reinjury in individuals with Charcot joint is high, a quantitative method to identify "at risk" patients can significantly reduce the chance of recurrence.

CONCLUSIONS

Infrared thermometry is a safe and effective method to measure the skin surface temperature. Patients at high risk for diabetic foot ulcers can use daily infrared thermometer monitoring for an increased temperature greater than 4° F over the mirror image on the other foot. The increased temperature is a warning of potential foot ulceration and the need to restrict activities. Because the industrial infrared devices are less than $100, patients may pay for them (and several have in the authors' experience). There is RCT, systematic review, and meta-analysis evidence for patient-directed preventive foot care utilizing noncontact infrared thermometry. The ease of use and the relative low cost have the potential to make them readily available to patients along with the current use of glucose monitors.

Noncontact low-cost thermometers are suitable for everyday clinical practice and with a high distance-to-spot ratio can decrease the risk of iatrogenic cross-contamination and potential infections. Differences in mirror-image readings using the Fahrenheit scale are easier to detect a 3° F–4° F temperature difference related to deep and surrounding infection, deep inflammation, or unequal vascular supply. If a foot is closed (intact skin) and hot, think of an acute Charcot joint, and if it is open (open wound) and hot, think of a deep and surrounding infection or repetitive trauma.

An area of increased localized skin surface temperature around a wound compared with a mirror-image temperature usually indicates deep and surrounding infection, but unequal vascular supply must also be considered as an additional diagnostic possibility. For deep and surrounding infection, check for 2 or more additional STONEES criteria. Another diagnostic aid is the presence of increased local pain without another reason that can be a symptom supporting the potential for deep and surrounding infection.

If a neuropathic foot is nonwounded, warm, and swollen without ulceration, an acute Charcot foot should be considered in the differential diagnosis. The clinical suspicion can be confirmed with an x-ray or magnetic resonance imaging. Monitoring of the skin surface temperature to achieve normalization compared with the mirror image can be a sentinel clue for remobilization and resolution of the acute and unstable Charcot change.

Skin assessment with an infrared thermometer is adaptable to routine wound care practice and home health. Furthermore, patients should be educated about the use of these infrared thermometers, especially because inexpensive commercially available infrared thermometers yield similar results as the criterion-standard device.

PRACTICE PEARLS

- Inexpensive commercially available infrared thermometers are a useful instrument for wound care practice.
- Noncontact infrared thermometers can detect localized increases in skin surface temperature comparable to scientific grade instruments.
- Persons with diabetes and a high-risk foot can utilize daily infrared monitoring of the plantar aspect of the foot to detect localized temperature increases, restrict ambulation, and decrease the incidence of repetitive trauma–initiated neurotropic foot ulcers.
- A high temperature elevation (4° F–15° F) over the mirror image on the opposite foot in a person with diabetes without a foot ulcer may indicate an acute Charcot foot.

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