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Comparative effectiveness of videothermography, contact thermography, and infrared beam thermography for scanning relative skin temperature

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Abstract—Videothermography (Video TRM), infrared beam thermography (IRTHRM), and contact thermography (Contact TRM) are utilized to detect asymmetries in temperatures between paired limbs. This information is controversially used in many diagnostic procedures in rehabilitation medicine. In this study, the effectiveness of the above techniques for scanning skin heat patterns and detecting asymmetries is compared. The skin over both lower limbs was imaged with each technique sequentially on 139 male and 15 female patients reporting lower limb pain. Images were also made of an electronic heat producer in order to determine relative accuracy. Contact TRM was unable to accurately image many areas with curved surfaces and was unable to produce accurate recordings when several sensors with differing temperature ranges had to be used on the same subject. It was also relatively inaccurate when imaging the heat producer. Video TRM was easy to use and produced excellent recordings but was difficult to transport. IRTHRM used in conjunction with a grid map of the body was the simplest and least expensive system to use for scanning and was as accurate as Video TRM.

Key words: *measurement, scanning effectiveness, skin temperature, thermography.*

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INTRODUCTION

The use of heat emanating from the surface of the body to detect disease processes is of ancient origin. The recent application of modern thermographic methodology to detect near surface blood flow patterns is simply a refinement of older techniques of assessing surface temperature. Medical thermography is becoming a controversial adjunct in the diagnosis of a variety of medical conditions seen in rehabilitation medicine (1–6). Thermographic techniques are also frequently used in research studies to track changes in blood flow over periods of months to years (7–9). Uematsu is the leading investigator and reviewer in this field and has published papers in which the stability of temperature differences in paired limbs are compared (6,10,11).

The four major ways currently used to measure heat from large areas of body surface are electrical thermistors, contact thermography (Contact TRM), videothermography (Video TRM), and infrared "beam" thermography (IRTHRM). Any method used must be sensitive to differences in paired areas of the body (e.g., the fronts of the left and right knees) and produce consistent recordings over time, as these are the measurements reported as useful in the literature.

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Thermistors

Thermistors are sensors that change their electrical resistance with changes in temperature. They are attached to the skin with tape, either singly or in arrays. They are simple to use and very accurate but cannot be easily used for scanning because they take too long to stabilize to be useful in scanning; their need to be physically attached makes their application time consuming; even the largest arrays available cannot cover all of the required areas in a reasonable amount of time; and both the sensor and required shielding touch the area to be scanned. For these reasons, they are not useful for scanning and are not considered further in this study.

Videothermography

Video TRM systems look very much like television cameras and work in a parallel way: they record the heat emanating from the body rather than the light reflecting from it (**Figure 1**). Thus, the system is safe and noninvasive, as nothing radiates to or touches the subject. Most Video TRMs can differentiate between temperatures as little as 0.15 °C apart and can image areas ranging from one square centimeter to the entire body. As an absolute temperature reference always appears on the screen, the actual temperature of an object being viewed is always known, and day-to-day comparisons can be made. The image produced on the screen is composed of a series of colors or gray tones, each representing a temperature range. Thus, if the device is set so that the entire color spectrum displays a range of 10 °C with 20 colors, each color will cover half a degree. Within that color's resolution, there is no way to tell the actual temperature of the object being observed other than that it falls somewhere within that half-degree range. The alternative is to use options such as electronically generated crosshair sights that can be precisely superimposed on any pixel of the image. The temperature of the targeted pixel is displayed to the nearest 10th of a degree. Video TRMs of the type used in this study are accurate at ranges from virtually against the skin up to 3 m. However, resolution declines with distance.

Contact Thermography

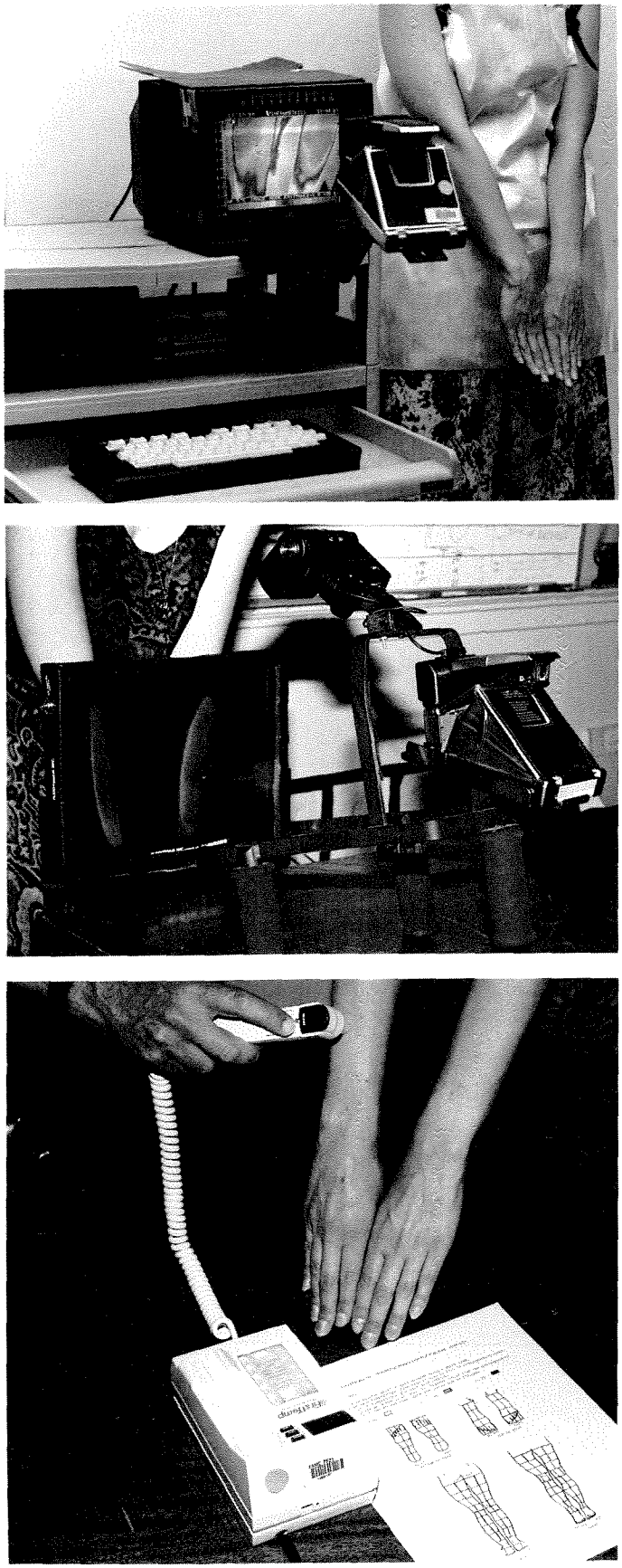
Most Contact TRM systems consist of a series of flexible pillow detectors, generally about 18 in (46 cm) on a side, containing arrays of crystals that change color to correspond to a specific temperature. Crystals sensitive to different temperatures are closely spaced to form "pixels" similar to those that produce color images on a television screen. As shown in **Figure 1,** the pillow is pressed against the part of the body to be visualized, and a color image representing body heat is produced by the colors of the various pixels. The pillow has a transparent window, allowing this thermographic image to be observed and photographed. Typical systems have eight or more detector pillows so that the images of a wide range of temperatures can be recorded. Like the Video TRM, the Contact TRM has a color scale on each window stating the temperature to which each color corresponds, as determined by calibration by the manufacturer. Temperature differences required to produce the various colors do not occur in standard set increments. Rather, the differences between each color can vary from 0.3 to 1.1 °C. This device is theoretically accurate to within 0.2 °C, but each pillow is very limited in temperature range. Several pillows normally have overlapping temperature ranges. Individual pillows cannot record a continuous range of temperatures. Rather, each only indicates a few specific temperatures. For example, pillow 29 can only indicate temperatures of 27.8, 28.5, 28.8, 29.1, 30.1, and 31.1 °C. There is no accurate way to extrapolate readings between these numbers. Thus, the readings are ordinal but not continuous, so the data cannot be analyzed using parametric statistics and comparisons between devices are limited to non-parametric methods.

Contact TRMs cannot be used for long-term recordings, because the pressure of the plastic screen against the body changes the surface heat patterns.

Infrared Beam Thermography

IRTHRMs are now commonly used instead of standard thermometers on wards and in emergency rooms for taking body temperatures (**Figure 1**). They work the same way as Video TRMs, but only indicate the temperature of one spot of skin at a time. They are similar to thermistors in that they do not directly produce a heat "picture" of the surface of the skin, and they are similar to Video TRMs in that they do not need to touch the surface to record temperature. Since Video TRM and IRTHRM involve no physical contact with the patient, neither can influence the results nor spread infectious diseases.

Video TRM, IRTHRM, and Contact TRM are utilized to scan heat patterns on large areas of the surface of the skin. Asymmetries in these patterns between paired limbs or sides of the body are used to determine if a problem is present. Thus, any method



incapable of detecting asymmetries with sufficient accuracy to permit determining abnormalities is not useful for scanning. Conversely, the method that is sufficiently accurate and simplest to use is likely to be optimal for this purpose. Previous studies comparing the ability of these methods to scan sufficiently large areas for them to be useful in making diagnoses were not found. Togawa provides an excellent review of the methodology for static measurements of skin temperature, while Hobbins reviews relationships between skin temperature, thermal measurement, and blood flow (12,13).

We performed two related studies in order to determine the relative effectiveness of the three devices for determining the extent of asymmetries typical of those found on human skin. The first study compared the abilities of the devices to register temperatures on the lower limbs of patients reporting pain in the areas imaged. If a device cannot pick up relative temperatures of the areas to be recorded, it is not useful for scanning. The second study determined whether the three devices registered similar changes in temperature as the heat emanating from a black body heat source increased. This was done to determine whether the amount of difference between readings for each device was the same. For example, if the Video TRM registered a difference of 2°, would the Contact TRM also register about the same difference? This is critical, because the amount of asymmetry determines whether the difference between the paired areas indicates a problem or simply normal variation. If a device does not accurately determine the amount of difference, it is not useful for scanning.

METHODS

Study One

We assessed ability of Video TRM, Contact TRM, and IRTHRM systems to image differences in temperatures on the lower limbs of patients reporting lower limb pain.

Figure 1.
Three types of thermal measurement devices: top = Video TRM; center = Contact TRM; bottom = IRTHRM with grid for recording temperatures. Each is shown as used to record temperatures from the arms. Right edge of the figure: Video TRM's "TV like" camera. Subject's arms imaged on TV monitor. Center: subject presses her arms against the Contact TRM "pillow" sensor to create an image on the side facing the camera.

Subjects

One hundred and fifty-four subjects participated, 110 of whom were otherwise healthy male soldiers without histories of trauma who were in basic training at a large Army post and reporting for sick call with lower limb pain. Their average age was 20.5 years [standard deviation (SD)=3.2; range=17–34 years] and each was recorded an average of 1.52 times (SD=0.95). The participating post did not train females, so none participated at that site. The remaining 44 subjects (29 males and 15 females) were patients reporting a variety of lower limb pain problems at an Army Medical Center's Psychophysiology Laboratory. Their average age was 37.9 (SD=15.5; range=17–76 years) and each was recorded an average of 2.1 times (SD=1.19).

The study was approved by the appropriate Human Use Review Boards and each subject signed a consent to participate after the study was explained.

Thermographic Recordings

Subjects were recorded in a temperature-regulated environment with drafts reduced to a minimum. Smoking and use of caffeine were prohibited for a minimum of 1 hr before the evaluations. A strictly enforced alcohol prohibition was in effect for the basic training program, and therefore should not have been a factor. Subjects were barefoot, wore shorts, and waited for the session while sitting with their feet elevated for a minimum of 15 minutes, to allow body temperature to stabilize.

At the end of the equilibration period, the plantar surfaces of the feet were imaged using an Inframetrics model 600M Video TRM (Inframetrics, Inc., Bedford, MA). The instrument was capable of resolving temperature differences of 0.1 °C and was sensitive to the heat created by blood flow patterns (spectral range of 8–12 μm) up to 1.5 cm deep. Thus, all heat sources in a structure as thin as a foot would be visible, but only a diffuse reflection of heat sources deep in the leg is directly visible. The device produced either gray tone or color images on a television screen, which were recorded on videotape and Polaroid photographs for later analysis. Sensitivity was adjusted so that differences of 0.1 °C levels could be differentiated. The thermograph has an internal temperature reference, so day-to-day changes in temperature could be objectively related. The device is nearly continuously self-calibrating against the temperature of liquid nitrogen stored within it and is calibrated annually by the manufacturer.

After the plantar surfaces of the feet were thermographed, the subject stood up and the dorsal surfaces of the feet and the fronts and sides of the legs were immediately thermographed while the backs of the legs equilibrated for at least 10 min. It should be noted that the temperature of the floor was not taken into account because the dorsal surfaces of the feet were thermographed immediately after the subjects stood up. Thus, minor fluctuations in floor temperature occurring from day to day across the several months of the study should not have influenced the data.

After each Video TRM view was taken, the FirstTemp Model 2000A IRTHRM (Intelligent Medical Systems Inc., Carlsbad, CA) was run along the surface just photographed and measurements taken along the distal-proximal midline of the surface at approximately 2.5 cm intervals. The FirstTemp relates readings to an internal calibration each time the unit is used, and it was calibrated by the manufacturer within a year of the study. After the IRTHRM was run across the surface, the Flexi-Therm Mark II Contact TRM (Flexi-therm Inc., Westbury, NY) was pressed against the surface for about 30 s and a color photograph taken of the image produced. The Contact TRM was used last to eliminate the possibility that holding an inflated plastic pillow against the skin would alter the temperature of the skin and thus distort the data produced by the other devices. The Flexi-Therm was calibrated by the manufacturer just before the study began.

The procedure of taking a thermograph by this method involves holding the detector against the skin for about 30 s. The detector is then pulled away from the patient to flatten its surface so that the image can be photographed. The thermographic image changes as the detector is removed. If there is a camera malfunction or a time delay of more than a few seconds, the picture will change or be completely lost. Since the pillow detector had to be in a flat position to be photographed without glare, the image appears in a slightly distorted shape and the thermographic information may also be distorted.

The Contact TRM system was recalibrated once during the 2 years of the study, because the crystals "drift" and the temperature required to produce a specific color can change over time.

The IRTHRM registers the temperature of the spot at which it is aimed, rather than providing a multi-temperature image of heat patterns in the limb. In order to use the temperatures generated by the thermometer, many measurements must be made of exactly paired

areas of the limbs or accurate assessments of symmetry cannot be made. The temperatures of individual areas of skin were converted into a useful depiction of temperature patterns by jotting each temperature on a gridded diagram of the lower limbs (**Figure 2**). According to the literature reviewed in the introduction, patterns of asymmetries useful for current diagnostic tests are a minimum of 4 cm square, so the grid was designed with segments about that size.

Study Two

We assessed the relationships between readings on the three thermographic systems and a heat-producing reference device.

Differences between the temperatures of paired areas of skin are determined to be either within or beyond normal limits of symmetry, depending on the magnitude of the difference, usually 1 °C. Many researchers consider the problem being diagnosed as being worse as the asymmetry increases. Any method used for measuring heat in order to determine the amount of asymmetry between paired areas is of little use if the readings produced by the instrument are not consistent with differences in actual temperatures. Thus, if two points on the skin's surface are 0.8 °C different from each other, the instrument must accurately reflect this amount of difference at any actual temperature likely to be encountered. In other words, if paired points on the top of the left and right feet are 29.4 and 30.2° respectively, while paired points on the left and right calves are 33.1 and 33.9° respectively, the measuring device must show that both sets of paired points differ by 0.8°. If the device indicated that the feet differed by 1.2° while the calves differed by 0.4°, the feet would be considered abnormal and the calves normal. It is very important that the amount of difference read on a device increase linearly with the actual amount of difference, because it would be too time consuming to refer continuously to tables or curves translating direct readings to degrees of asymmetry during a scanning procedure. None of the literature provided by the manufacturers indicated that their devices were nonlinear within the ranges used for human skin.

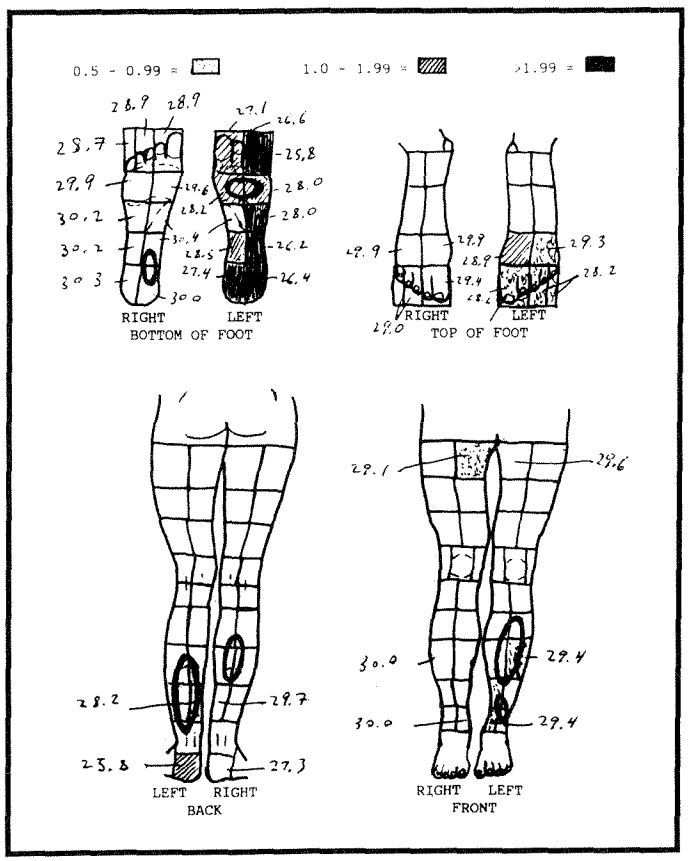


Figure 2.
Grid overlay for depicting pain and temperature patterns: painful areas are drawn in with an oval; temperature of each grid box is written in. When one grid box is at least 0.5 °C cooler than the corresponding box on the paired limb, the cooler box is marked according to the gray scale shown at top.

The linearity of all three systems was evaluated with an AGA Model 23 variable temperature reference unit (AGA Inc., Pine Brook, NJ). This device consists of a flat black disk, about 2 in (5 cm) in diameter, that radiates heat at a level set by a calibrated dial. Because its surface is flat, the problems inherent in measuring heat from curved surfaces are reduced significantly. The use of the artificial, flat surface rather than readings from the skin was necessary because, even if the sensing units were apparently pointed at exactly the same point on the skin, they might give different readings due to differences in the angles from which the views were taken. This is because even the smallest curvature in the skin significantly affects the amount of radiation reaching the infrared sensor for the same reasons that solar energy at the earth's high latitudes is less than at the equator: the essentially parallel rays from the sun are spread further near the poles.

The Video TRM was set 4 feet (1.22 m) from the reference disk and pointed directly at it with no measurable angle: this is the distance at which normal recordings are made. The cross hair sight was set to show the center of the disk, and its temperature was recorded. The thermometer was then applied at a right angle to the center of the disk and its reading was recorded. Then the Contact TRM pillows covering that

temperature range were pressed against the reference and their readings recorded. The reference was then reset to the next higher temperature. This process was repeated at 1° intervals between 28 and 35 °C. This procedure permitted both the evaluation of linearity for each instrument and the calculation of consistent differences in temperatures measured by the systems.

The Video TRM and the IRTHRM made 10 readings each per temperature setting. The devices required <2 s to stabilize before each reading was taken. Several thermograph pillows were used at each setting because the pillows have overlapping ranges. Each was held against the heat source until the colors stabilized for at least 5 s.

RESULTS

Study One

General

For areas such as the dorsum of the foot, the shape of which prohibits perpendicular imaging, the temperatures observed with the Video TRM may be different than those taken with an IRTHRM. This is because the IRTHRM is always held the same distance from the skin with no angle. The Video TRM shows a very detailed picture of exactly where temperatures are observed. This makes it very easy for the thermographer to concentrate on the specific areas that are affected. The exact point at which the temperature difference is the greatest can easily be detected and recorded. With the IRTHRM, temperatures were taken at set areas and may not have always reflected the point where the greatest temperature could be observed. This may have diminished the temperature differences observed with the surface temperatures.

Problems Applying Contact TRM to the Lower Limbs

Numerous patients were seen with conditions (especially reflex sympathetic dystrophy) that caused hyperalgesia of the skin. Many found the pain from even the light pressure of the detector too much to withstand. This prevented use of the Contact TRM among these patients. The Contact TRM could not be used with patients having open wounds, rashes, or fresh surgery scars. During the early stages of the study, attempts were made to use the Contact TRM to make images of the entire leg and foot area. The size and shape of these areas prohibited making a single image using one 12 × 9 in (30.5×23 cm) pillow. The edges of the detectors would cool the skin, producing a cold line across it. These factors precluded production of clear images of the entire area of interest.

A specific pillow is chosen so that, ideally, the majority of the thermographic image should appear in the center of its temperature range. This was often difficult if not impossible. Often a leg or foot would be too cold to be observed in the range of even the pillow with the lowest temperature detecting ability. The leg and foot areas often have temperature differences that are greater than a few degrees, and with some subjects, the left and the right side could not be observed with the same pillow. This indicated that there was a temperature difference but did not permit determination of what that difference was, because the same body area would often produce a different temperature reading with the use of a different pillow. This may not be a critical factor, since relative differences from right to left are what we are trying to determine. However, since the study showed that temperature differences may occur that are too great to fit in the range of a single detector, this is not an effective or accurate diagnostic method.

Certain areas of the lower limbs could fit within the field measured by the detectors, such as the bottom of the feet. If both the right and left feet are relatively symmetrical in temperature and there was not much variability in the temperature of the foot from heel to toe, then a relatively clear picture could be obtained. When an adequate thermographic image was obtained, the thermographic trends observed followed those seen with the other forms of thermography.

Figure 3 illustrates inter-pillow calibration problems which prevent use of Contact TRMs for determining absolute differences between limbs where the difference is too great to be visualized by the same pillow. **Figure 4** illustrates the effect of the Contact TRM frame on the ability to properly visualize areas. **Figure 5** shows the effect of the Contact TRM's inability to visualize highly curved surfaces on its ability to detect critical asymmetries.

Results of Comparisons of the Three Techniques when Used with Patients Reporting Lower Limb Pain

The Video TRM was consistently simple to use and could visualize all required areas. For those regions upon which the pillow could be pressed, the Contact TRM always showed a difference when the Video TRM showed one. However, the actual amount of difference

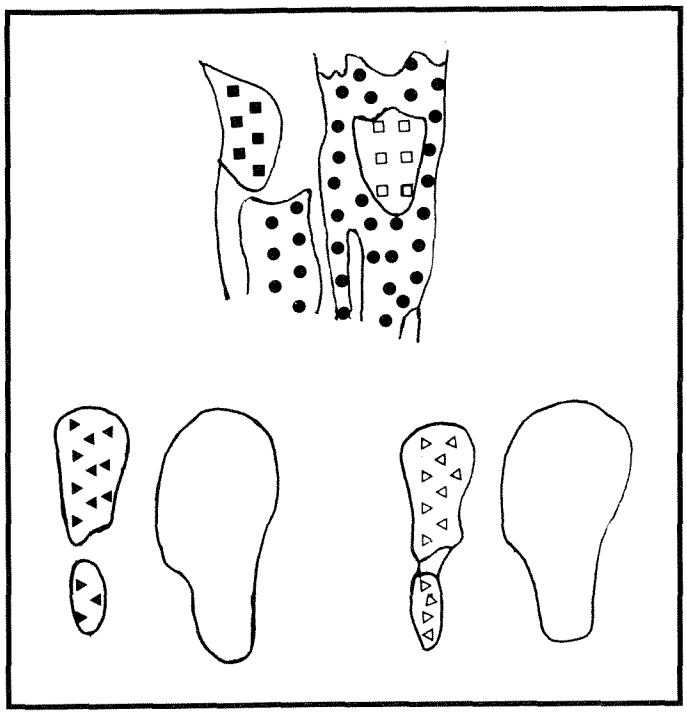


Figure 3.
Lack of correspondence between pillows in the Contact TRM system presents a diagnostic problem. Top: significant assymetries shown on Video TRM have been redrawn for reproduction here. The open and closed squares differ by a clinically significant 5.4 °C. Bottom: Contact TRM images of the same limbs moments later. Two pillows (both of which could read the left leg) were used to span that 5.4 °C range. Filled triangles show 29.1 °C for the left leg measured by the left pillow; open triangles show 29.7 °C for the same leg measured by the right pillow. The actual difference between two limbs cannot be determined when they must be measured using different pillows.

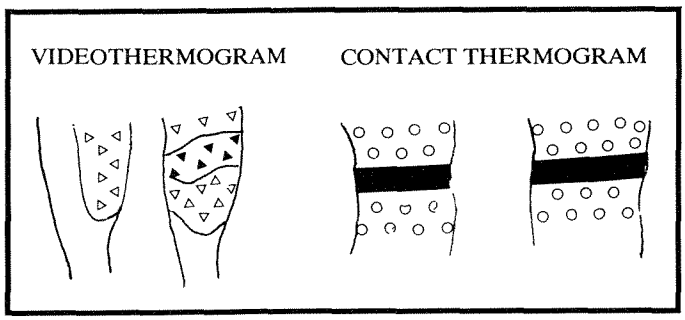


Figure 4.
Effect of Contact TRM frame on ability to properly visualize areas. Left: redrawn Video TRM contains a crucial area (filled triangles) about the same size as marks left on the skin by the Contact TRM frame (filled bars at right). These frame marks prevent proper visualization of an entire limb without waiting for the marks to fade (about 10 min), making the evaluation take too long to be practical.

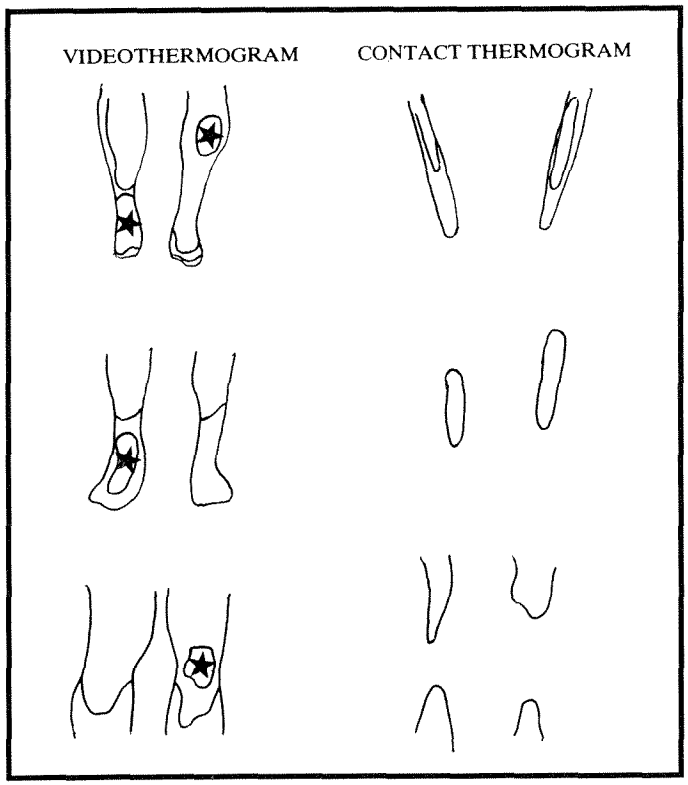


Figure 5.
The Contact TRM is unable to detect critical asymmetries on highly curved surfaces. Left: redrawn Video TRMs show critical areas of asymmetry. Right: the Contact TRMs failed to make images of the critical areas—the curve was too great for the pillows to wrap around or get into. Top and middle images: front of the legs with the front of the ankles and sides of the legs missing in the Contact TRMs. Bottom: back of the legs with the backs of the knees missing in the Contact TRM views.

was usually not calculable due to the problems discussed above. Thus, the pillow could be used to pick up problems but not to track their progress across sessions.

The IRTHRM could measure the temperature virtually instantly anywhere on the limbs with equal ease. It had none of the problems that make the Contact TRM cumbersome and ineffective. The grid pattern shown in **Figure 2** was prospectively tested with 122 lower limb pain subjects (62 of whom were patterned twice) and missed only 1 small asymmetry on 1 subject. Other asymmetries on the subject were picked up, so the interpretation of the overall body pattern was not changed. This grid has the advantages of permitting an overlay of the location of the pain diagram as well as showing the amount of asymmetry. **Figure 2** is a copy of an actual transcription made while using the IRTHRM with the grid. It is provided in its "hand

written'' state, so the data presentation actually achieved can be evaluated for adequacy of meeting the needs of readers. Use of the grid took longer than taking a Video TRM but about the same amount of time as it takes to use the Contact TRM, because the thermographic pillows have to be changed and adjusted frequently.

Table 1 lists the relative sensitivities, specificities, predictive values, and efficiencies for the contact system and the thermometer used without the grid. Using the thermometer without the grid meant that the technician was simply moving the thermometer from one side to the other on a patient without any guidance as to how far to go between readings or where to read.

As can be seen from inspection of the table, the results produced by thermometer when used without the grid are not much better than those of the Contact TRM. The large number of false negatives at the ''one degree of difference'' level is largely an artifact of the criteria. As detailed above, the thermometer tends to read somewhat lower than the Video TRM at the lower temperature ranges. Thus, the difference between two relatively cool points will be slightly less for the thermometer than the Video TRM. If a criteria of 0.8° difference is used, the number of false negatives decreases by 49 to 130, and the number of true positives would then be 144. This would change the sensitivity to 53 percent. However, when the thermometer was used with the grid, the Video TRM and the thermometer produced virtually the same results.

Table 1.
Relative effectiveness of the 3 methods: all readings were taken from as close to the same places on the body as could be determined.

	Video TRM	Contact TRM	Video TRM	IR THRM
# TN	47	74	22	107
# TP	116	76	275	95
# FN	93	49	84	176
# FP	21	55	6	11
Sensitivity	56%	61%	77%	35%
Specificity	69%	57%	79%	91%
Predictive Value	85%	58%	98%	90%
Overall Efficiency	59%	59%	72%	51%

For significance, limbs must differ by >0.5° under Video TRM, and by >1° under Contact TRM and IRTHRM; calculations are shown for both levels of difference. TN = true negative; TP = true positive; FN = false negative; FP = false positive; Sensitivity = TP/(TP + FN); Specificity = TN/(TN + FP); Specificty = TN/(TN + FP); Predictive Value = TP/(TP + FP); Efficiency = (TP + TN)/all readings. When it was impossible to place the Contact TRM to produce an adequate image of a spot, the reading was counted as a FP if the Video TRM detected a significant difference. The IRTHRM was used without a grid for this test, hence, its readings were relatively random in location relative to those of the Video TRM.

Study Two

Linearity

The digital temperature shown by the Video TRM was read three times at 10 s intervals for each reference setting. The reference was changed from 28 to 40° in 1 °C intervals and permitted to stabilize at each temperature before readings were made. The Video TRM registered virtually a 1° increase with each change with the result that there was a 0.994 Spearman's correlation ($p<0.0001$) between the actual and detected temperatures. The IRTHRM was tested similarly. Its readings also went up reliably as the temperature of the reference increased. The Spearman's correlation was 0.990 ($p<0.0001$). The Contact TRM was tested similarly but the different pillows did not register similar increases in temperature and several pillows reacted identically to different temperatures produced by the reference. Thus, the Spearman's correlation was lower (0.856) but still significant. Even this relatively high correlation is quite misleading as it only shows that the Contact TRM usually indicated an increase in temperature with increased temperature of the reference.

Relationships between the Three Devices

The readings are summarized in **Table 2.** One hundred and ninety-seven comparisons were made between readings on the contact and video systems (the colors could not be interpreted on three of the contact readings). The Pearson's correlation coefficient was 0.35. When the same comparison was made between the thermometer and the video system, the correlation was 0.97. All statistics were performed using the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL).

DISCUSSION

Contact TRM was a surprising disappointment. It was cumbersome or impossible to use as required. It could not visualize important areas that have greatly curved surfaces, such as the front of the ankle and the back of the knee. Although it is initially enticing to see an image of the heat produced on a screen, the limitations of that image reduce its value. Due to the

Table 2.
Temperatures recorded by the devices from a reference heat source.

Reference	Video TRM*	IR THRM*	Contact TRM No. : Temp
28	30.18 (0.08)	28.07 (0.05)	28 : 26.0
			29 : 29.9
			31 : 28.7
29	31.56 (0.05)	28.52 (0.08)	28 : 28.0
			29 : 29.1
			31 : 29.7
30	32.77 (0.07)	29.06 (0.10)	28 : 28.5
			29 : 30.1
			30 : 28.6
			31 : 31.0
			32 : 30.0
			33 : 31.0
31	34.03 (0.07)	29.76 (0.16)	28 : 29.5
			29 : 30.1
			30 : 29.3
			31 : 31.8
			32 : 31.0
			33 : 31.7
32	35.02 (0.04)	30.60 (0.12)	28 : 29.5
			29 : 31.1
			30 : 30.3
			31 : 32.5
			32 : 32.0
			33 : 33.0
33	35.90 (0.05)	31.09 (0.17)	29 : 31.1
			30 : 31.9
			32 : 32.0
			33 : 33.6
34	36.78 (0.04)	32.11 (0.10)	30 : 32.4
			32 : 34.0
35	37.44 (0.07)	32.48 (0.18)	
36	38.22 (0.04)	33.42 (0.19)	
37	38.94 (0.05)	33.83 (0.25)	
38	39.78 (0.04)	34.74 (0.36)	
39	40.42 (0.04)	35.01 (0.22)	

*mean of 10 readings (SD); all temperatures in °C.

very limited range of temperature to which each pillow is sensitive, most of the image does not appear. Neither of our sets of Contact TRM pillows were properly calibrated, so the readings from one pillow could not be related to the readings on the one above or below it along the temperature range. This meant that no absolute difference between two limbs could be generated in the frequent case where the temperatures of the limbs are so different that each has to be visualized using a different pillow.

The Video TRM consistently and easily produced superb images of all required areas. However, a Video TRM configured for medical evaluations would cost approximately $45,000, and the device is difficult to move from place to place because it is mounted on one or two carts. Most units require liquid nitrogen and 110 volts of electricity to function.

An IRTHRM system costs a few hundred dollars, and at least one is probably available at most medical facilities. It seems to be the most valuable of the three devices as: 1) it can take body temperatures virtually instantly without risking contamination of the instrument by touching the patient, 2) it does not require a source of line voltage or liquid nitrogen, and 3) it can accurately take all required views.

An "image" of temperature asymmetries was produced using this device as quickly as could be done using Contact TRM. As discussed above, differences between limbs must be noted on an image of the limb rather than just referring to a photograph of an image. However, the notations produce an accurate assessment of the asymmetries, while the Contact TRM images give a vague notion of problems at best. The grid system can be used by nonprofessional personnel to produce an accurate picture of both temperature and pain patterns in the lower limbs within 5 min.

Video TRMs are superb for research applications involving visualization of rapid changes in temperature of large skin areas, such as those required for evaluating changes in near surface blood flow with changes in muscle tension due to contractions (14). However, no clinical requirements for scanning rapid changes in temperature are in wide use. Problems in the use of thermographic scanning for detection of disease were reviewed by Paul (15). When thermography is used to confirm the presence of a problem partially diagnosed through other methods (as in confirmation of stress fractures) the clinician already knows exactly where to look for temperature asymmetries based on location of pain and other symptoms. In these cases, an IRTHRM could be used to identify asymmetries and hot spots: there is no real need to produce an actual image of the area.

CONCLUSION

Video TRMs are accurate but expensive and bulky. Contact TRMs simply do not work well enough for scanning. Thus, it is recommended that any group intending to try thermography for evaluating and/or tracking a medical problem begin with an inexpensive

IRTHRM used in conjunction with a grid such as the one illustrated in **Figure 2.** If it produces valuable clinical information, the Video TRM may be of more value.

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