Diagnostic Thermography
A technology update for professionals

Thermogram of Trees on a Winter Night

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During rest or sleep, the average human generates seventy-five watts of heat.

- This heat is radiated from our skin in the 10µm infrared wavelength.
- IR Emissivity of human skin is close to 1.0 (very efficient emission of IR).
- We control our internal temperature by first changing our skin circulation, then by sweating or shivering.
- An unclothed resting human is in temperature balance at 77°F in still air. Warmer feels too hot, cooler feels too cold.
A Brief History of Thermography

- Fever and the heat of infection were well known in prehistoric times as signs of disease.
- In Hippocrates’ time, physicians applied thin mud plasters over the body surface. The mud dried most quickly where the body was warmest - indicating the location of the disease.
The Very First Instruments

In the 1600’s Galileo invented the Thermoscope---a glass tube device that measured temperatures. This was the grandfather of thermometers. It was too large to detect the body temperature.

Later, the mercury-bulb thermometer allowed temperature measurements of the internal body temperature. Clinical thermometers appeared in 1868.

Photo: Armagh Observatory, Northern Ireland
1960s - Infrared Imagers Were Complicated
But they showed the body surface temperature well enough to be diagnostic.

- The patient was scanned with an optical-mechanical device that focused a spot on a single cooled infrared detector.

- Scans were slow (2-15 minutes). Patient movement - including breathing - would distort the image.

- Scans were low-resolution due to the limitations of these electromechanical systems.
Liquid Crystal Thermography Was Developed in 1960s

• **Principle:** Thermochromatic liquid crystals in films or paint change color with temperature.

• Subjects were painted with thermochromatic paint, or films were pressed against their skin. Then visual photographs were taken to record the results.

• **Problems:** The tests were complicated and time-consuming. And the film or painting process could alter the surface temperature and create artifacts.

Here a modern thermochromatic film is being used to detect “cellulite.”

Photo: International Products & Services srl - Milano (Italy)
The military developed thermal imaging Integrated Circuits so that soldiers could find combatant troops in the dark.

From the 1950s to the 1970s, advancements were made in goggles, cameras, and hand-held devices to allow military and law enforcement to find people hidden in buildings or brush – even through smoke.

But these devices were military secrets until the end of the “Cold War” in 1991.
21st Century Infrared Imagers

Detector: 320 x 240 Focal Plane Array, Vanadium Oxide (VOX) uncooled microbolometer.

Refresh Rate: 60 frames/sec

Spectral Band: 8 μm to 14 μm

Thermal Sensitivity: 
≤ 0.050 °C at 30 °C
Accuracy ±2 °C or ±2 %

Germanium Lens, Manual Focus

Spatial Resolution: 1.3 mrad

Focus Distance: 0.15 m – Infinity.

IR Imagers: The Old Versus the New

Significant advances have been made in spatial and temperature resolution capabilities of clinical imagers in the past ten years.

Which image would you rather interpret?

IR Image from Ville Marie Study, 2000

IR Image taken with the Fluke Ti55, 2010
IR Images are Grayscale but giving the image false color is useful for various tasks.
Ambient Temperature Affects the Clinical Thermogram Greatly.

This man is clothed and warm. His ears and nose are warm as shown by IR thermography. Note that eyeglasses appear cool to IR.

This unclothed man has been cooled in a 70°F room for 15 minutes. His ears and nose are cool. The warmest spots are between the eyelids and nose.
Thermograms of Cold Subjects Are More Diagnostic

The thermographic image of the body when cold shows localized blood flow changes, as long as shivering is not produced.

Hands of a subject when cool. Arteriolar constriction causes fingers to be cold. The returning veins are the warmest sites.

Same subject after a warm bath. Now the fingers are warm to the tips. The palms are now the warmest areas.
Feet React to Cold as Hands Do.

After equilibration in a 70°F room for 15 minutes, the toes and heels are the coolest areas. The arches are warmer.

The subject must cool off lying down for good foot thermograms. Then the subject stands up for the views of the top side of the feet.
Design of a Thermography Room

• 8 x 10 ft minimum floor space.
• No windows or incandescent lights (fluorescent lights OK).
• 68-70°F with no air drafts (the screen blocks drafts from AC).

• Clothes hooks and a shelf for jewelry, glasses, etc. for the subject to disrobe.
• Mirror for dressing after the session.
• No reflective surfaces or warm spots in the background of the thermograms.
Cooling the Thermography Room

Where does the heat go?

• A small in-room air conditioner pumps the heat out of the room.
• The heat is exhausted out into the space above the dropped ceiling.
• Replacement air is drawn into the room through the vent behind the AC Unit.
The Thermography Read Station

The “raw” grayscale images from the camera must be made visually diagnostic and surface temperatures documented for the final interpretation and report.
Thermography in Breast Cancer Detection

Thermography was approved by the FDA for breast cancer detection in 1982.
Early Breast Thermography

Dr. Benjamin Rush, around 1800, detected breast cancer as being a warm, painless mass of the breast.

The first thermogram was performed in 1956 by a Canadian surgeon Dr. Ray Lawson, who noted that the skin temperature of his breast cancer patients was higher compared to normal patients.
Why is Breast Cancer Warm?

Increased Venous Flow creates the Vascular Pattern

Tumor

Arteriolar Dilation due to Nitric Oxide from tumor

Line Drawing from Gray's Anatomy
Breast Arteries and Veins

It is the VEINS that show up best on thermograms.
Breast Veins Thermographically
Routine Images for Breast Thermography

Shown in time sequence

Supine (Lying down)  Frontal  R Oblique  L Oblique

R Close-up  L Close-up  Face Frontal  Temp. Standard
Breast Thermography Conditions:

• Infrared imaging takes place in a draft-free, thermally controlled room maintained between 20 and 21 C (68 – 70 F) after a 15-minute equilibration period during which the client is disrobed above the waist with hands and arms held away from her trunk.

• Clients are asked to refrain from alcohol, coffee, smoking, exercise, deodorant, and lotions prior to imaging.

Villa Marie Breast Thermography Grading Scale I

*Abnormal Signs*:


2. Vascular anarchy (unusual tortuous or serpentiginous vessels that form clusters, loops, abnormal arborization, or aberrant patterns).

3. A $1^\circ$C ($1.8^\circ$F) focal increase in temperature ($\Delta T$) when compared to the contralateral site and when associated with the area of clinical abnormality.

4. A $2^\circ$C ($3.6^\circ$F) focal $\Delta T$ versus the contralateral site.

5. A $3^\circ$C ($5.4^\circ$F) focal $\Delta T$ versus the rest of the ipsilateral breast when not present on the contralateral site.

6. Global breast $\Delta T$ of $1.5^\circ$C ($2.7^\circ$F) versus the contralateral breast.

*Unless stable on serial imaging or due to known non-cancer causes (abscess, recent benign surgery, trauma, eccymosis, etc.).

Villa Marie Breast Thermography Grading Scale II

**TH-1** = Absence of any vascular pattern to mild vascular symmetry. (Normal).

**TH-2** = Significant but symmetrical vascular pattern to moderate vascular asymmetry, particularly if stable. (Normal Vascular).

**TH-3** = One abnormal sign. (Equivocal).

**TH-4** = Two abnormal signs. (Abnormal).

**TH-5** = Three abnormal signs. (Severely Abnormal).

The Normal Breast Thermogram TH-1

The breasts are both uniformly cool without hot spots or vascular markings. This is graded as “TH-1, Normal Exam”
The “Normal Vascular” Thermogram TH-2

The breasts show slight to moderate vascular patterns that are mostly symmetrical. These vascular patterns should remain stable through the years.

The global temperature of the breasts should be almost identical.
In this case there is marked vascularity of both breasts, with a warm area near the left nipple, but the temperature differences are not significant.

Plan: Repeat thermogram in 3 to 6 months to check stability. 
*Ask the subject to stop all estrogenic hormones during this period.*
Equivocal Breast Thermogram TH-3

Early invasive ductal adenocarcinoma of Lateral Left Breast
Hormonal Effects on Breast Thermography

TH-2 After 2 months of Estrogen/Progesterone (“Wiley” Transdermal)

TH-3 After 8 Months of hormones.

TH-1 after stopping hormones for 8 months
Abnormal Breast Thermogram TH-4

Asymmetrical vascular marking over upper part of Left breast. The temperatures along the horizontal line are shown in the graph.

The graph shows a significant temperature difference of over 2°F in the left breast.
Severely Abnormal Thermogram

TH-5

Nipple Retraction and mass also present.
Another TH-5 Severely Abnormal Breast Thermogram

Both the maximum and average temperatures of the Left breast are 2°F warmer than the Right in this case of biopsy-proven carcinoma.
Why Do an Image of the Undersides of the Breasts?

TH-4 Abnormal

This woman’s other images were all normal.
This woman was concerned about a lump here.

Surgery removed a malignant tumor.
Does Thermography Help Breast Cancer Detection?

Relative sensitivity of clinical exam, mammography, and IR imaging in 100 cases of DCIS, Stage 1 and Stage 2 breast cancer – The Ville Marie Study.

Thermography is a Risk Indicator for Breast Carcinoma

• “An abnormal (TH4 or 5) infrared image is the highest risk indicator for the future development of breast cancer, and is ten times as significant as a first-order family history of the disease.”


• “Thermography may warn that a cancer may be forming up to ten years before any other imaging procedure can detect it.”


This causes frustration for both the patient and the physician because *mammography can be normal in the face of abnormal thermography.* But the thermographically abnormal area should be closely followed.
# Mammography vs. Thermography

(1999 Literature Review of IR flying-dot scanner technology)

<table>
<thead>
<tr>
<th>Modality</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive Predictive Value</th>
<th>Negative Predictive Value</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Mammography</td>
<td>86%</td>
<td>79%</td>
<td>28%</td>
<td>92%</td>
<td>Structural Anatomic Image</td>
</tr>
<tr>
<td>Thermography</td>
<td>86%</td>
<td>89%</td>
<td>23%</td>
<td>99.4%</td>
<td>Physiologic Metabolic Image</td>
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Where does Thermography Fit in Breast Cancer Screening 2013?*

• For the best chance of BrCa detection (~98%):
  • Clinical Exam and
  • IR Thermography and
  • X-Ray Mammography.

• For Low-Risk / Stable patients:
  • If clinical and self exams are normal, and
  • IR Thermography TH1 or TH2 and stable over years,
  • offer Screening Mammogram if patient wishes.

*Scientifically-based opinion of the Author, JC,MD.
What Else Can Thermography Detect?

**Warmer than Normal**
- Fever
- Vascular inflammation (Arteritis)
- Infection / Abscess Sites (including sinus & tooth infection)
- Small Joint Inflammation – gout, auto-antibody diseases, etc.
- Thyroid disorders (thyroiditis, neoplasm)
- Tendinitis and bursitis
- Recent soft-tissue injury (blood outside of vessels is inflammatory)
- Bone Fracture, including stress fractures
- Varicose veins and perforating artery sites
- Neuropathy or nerve injury (arteriolar constriction due to cold is nerve-mediated)

**Cooler than Normal**
- Lack of arterial circulation
- Muscular disuse or atrophy
- Complex Regional Pain Syndrome (Reflex Sympathetic Dystrophy)
Fever Detection by Thermography

• For screening of airline passengers in times of epidemics, studies show an “eye region” temperature cutoff of 94.3°F.
• Any IR camera needs frequent temperature calibration on a known blackbody IR source to correct for sensor “drift”.

The Camera Correction Factor is +3.1 °F. for this thermogram.

So the actual surface temperature is

95.6 – 3.1 = 92.5°F

This man can board the plane...

E.Y.K. Ng and E.C. Lee, Fever mass screening tool for infectious disease outbreak, Ch 16 in Medical Infrared Imaging, Diakides and Bronzino, eds. CRC Press, 2008.
Muscular Atrophy of the Right Calf

Post-Polio syndrome in an older man. Leg and foot pulses were normal.
Inflammation of Left Thorax
Due to Harrington Rods. This inflammation cleared on removal of the rods.
Increased local heat and vascularity are seen over time, indicating disease progression.
Sinus Infection
This person was having pain in the Right cheek.
The hot area is over the Right Maxillary Sinus.
Varicose Veins of the Right Upper Leg

These veins were not inflamed or tender.
Vasculitis affecting the hands

Note the “blotchy” thermal pattern,
And finger temperatures are not equal.
Vasculitis – Chest Wall
Fracture of the Second Toe
Left Foot

Image taken six weeks post injury

Fracture is at the proximal M-P joint.

Note the diffuse inflammation involving even the arch of the foot.
Pectoral Tendinitis Seen Incidentally on Breast Thermogram
Lung Tumor in R Lower Lobe

The tumor was reported as 7 cm x 5 cm on CT scan. Note the significantly warm area over the tumor area with “rib masking.” Also, an asymmetric vascular pattern is present over the upper R chest.
Costo-Chondritis
(Rib cartilage inflammation)
This hot area over the Left breast was painful to pressure. Mammography was completely normal.
This woman was having intense pains under her Right Breast.

She wore underwire bras exclusively.

UnderWire Inflammation

Intercostal nerve inflammation due to pressure from wire bra stay.
Post-Radiation Effects

Four months after radiation therapy to Left breast.
Escharotic Treatment Effect

This treatment may cause severe inflammation and even necrosis of the skin.
Nipples After Breast Reduction

Transplanting the nipples during reduction surgery cuts their nerves, thus the nipple area cannot constrict the local arterioles when the body is cooled.
Moles May Appear Cool

This is a good sign, indicating that the mole has a low metabolic rate and is probably non-malignant.
Thermography may show many things...

It is possible to detect your key strokes after you leave the ATM...

This frame of an ATM keypad was captured by a thermal camera during a study to determine whether the camera could enable unauthorized access to security codes. The image was captured immediately after the keyboarder’s hand was removed from view. The regions of interest are shown by the colored boxes, and the temperatures are shown in Fahrenheit on the scale bar. The four digits pressed appear to be 1, 4, 5 and 8, and it seems most likely that 1 and 4 were pressed before 5 and 8. The code entered was indeed 1485. Image courtesy of Keaton Mowery and Sarah Meiklejohn.
Beware of Poor Thermography

- At present, there are few standards and training is hard to find – caveat emptor!
- If you are not cooled down before the image, it will not be diagnostic.
- Be sure to get the actual images, either digitally or in print. These are important for later comparison. Always keep your copies.

These images have poor spatial and thermal resolution.
The Future for Thermography Looks Hot!

Prediction: Clinical thermography will become common within 5-10 years, but studies and standards are needed for mainstream acceptance.
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JC, MD. '09

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