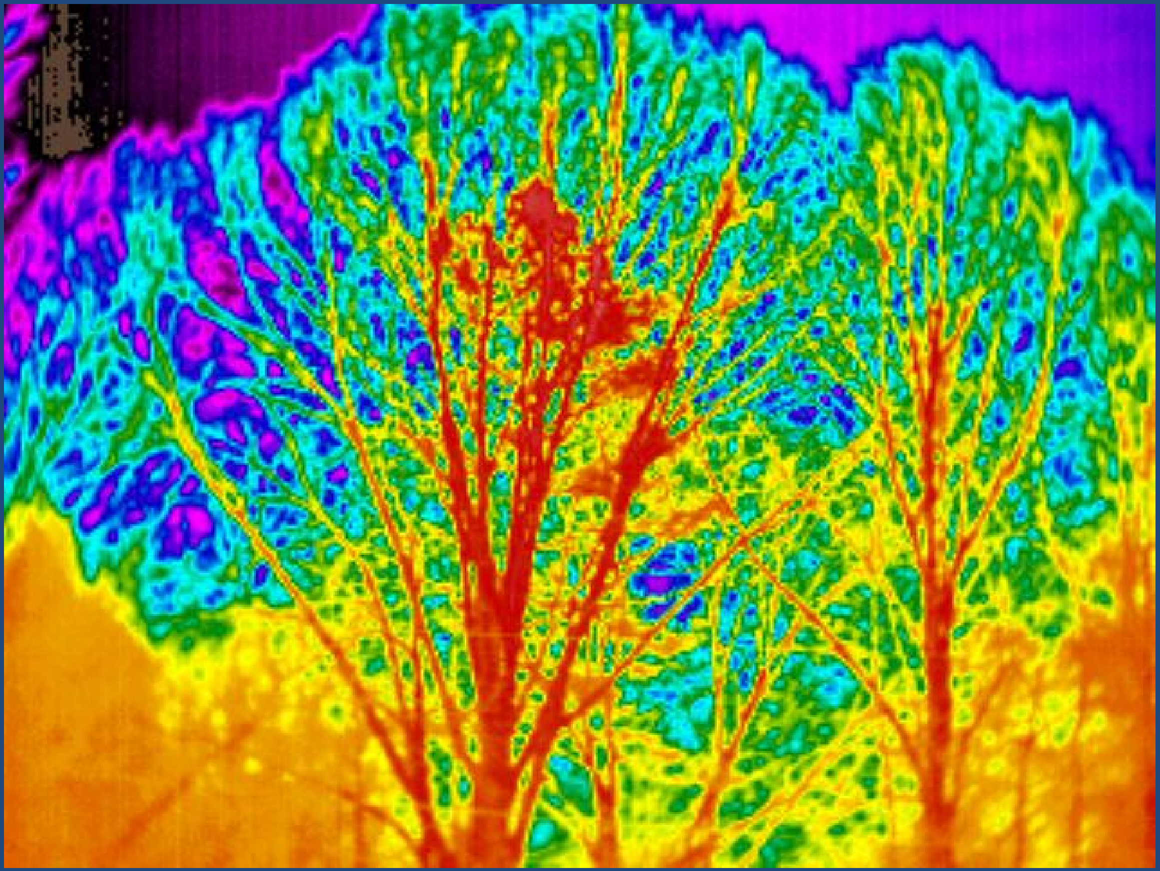
Human Medical Thermography

A technology update for professionals



The Secret Life of Trees (IR Thermogram) **JC,MD. '09**

James S. Campbell, EE, MD, MEDesign LLC, Pfafftown, NC.

All Mammals GLOW – Humans Included

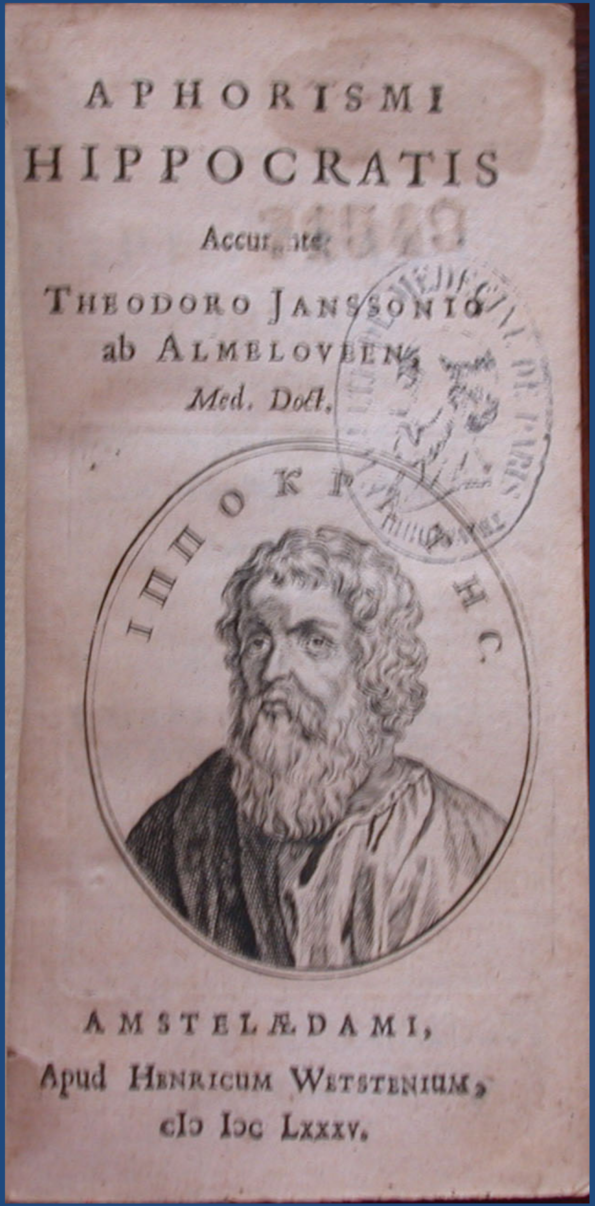
Warm man standing outside on a 40 °F winter night.

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 0.98 (very efficient emitter of IR).
- We control our internal temperature by first changing our skin circulation, then by sweating or shivering.
- A typical unclothed resting human is in temperature balance at 27°C (80.6°F) *in still air*. Warmer feels too hot, cooler feels too cold.

A Brief History of Thermology*

- Fever and the heat of infection were probably 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 science and study of heat; in this case the heat of the human body and its detection.

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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. Doctor Carl Wunderlich pioneered the study of fever and fostered the development of "Fever Hospitals".

A Wunderlich thermometer, 10 inches long, with wooden case. Axillary temperatures took 30 minutes. Photo courtesy of medhxtour.

Modern decorative Thermoscopes

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1960s - Infrared Imagers Were Cumbersome

But they showed the body surface temperature well enough to be diagnostic.

- The patient was scanned with an optical-mechanical device that focused a “flying” 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.

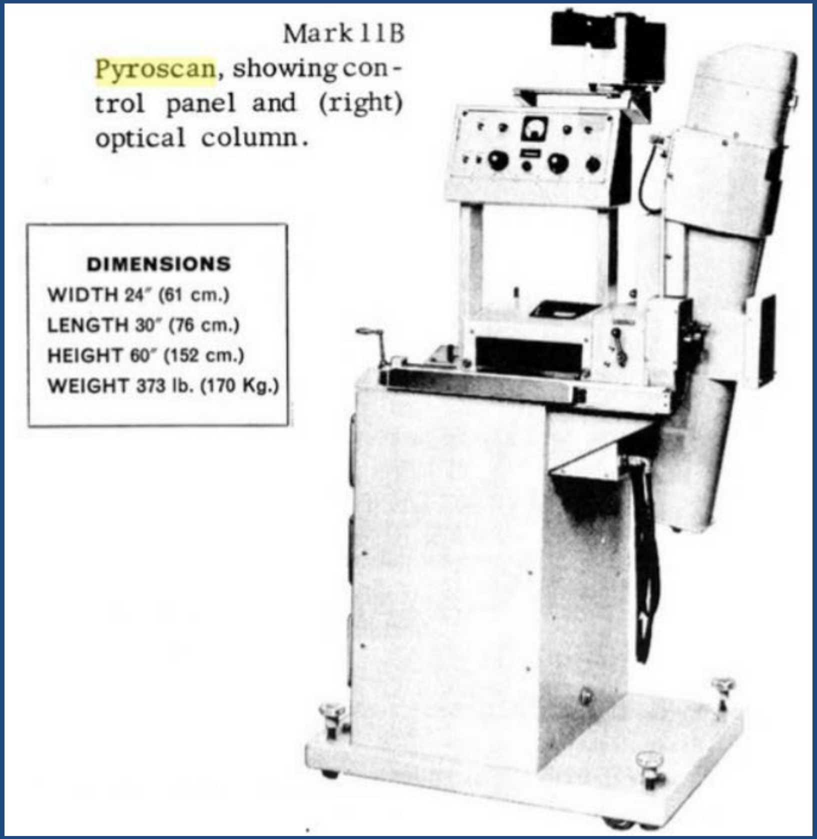


Illustration courtesy of University of Padua, Italy.

The Advent of Integrated-Circuit Imagers

•The **military** developed thermal imaging microbolometer chips 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”. They were declassified in 1994 and entered medical use about 2000.

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

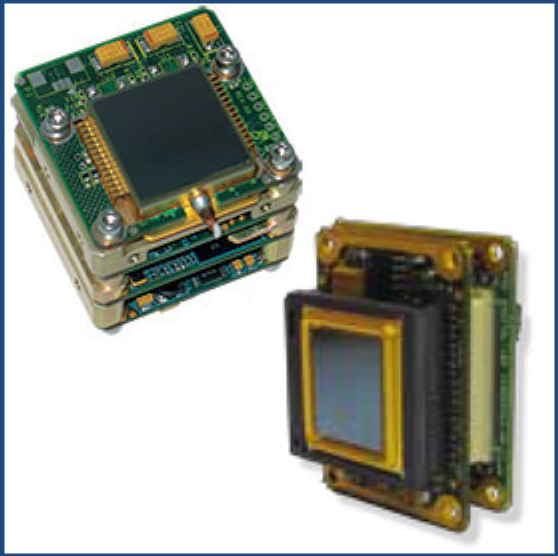
Thermal Sensitivity:
≤ 0.050 °C at 30 °C
Accuracy ±2 °C or ±2 %

Germanium Lens, Manual Focus

Spatial Resolution: 1.3 mrad

Focus Distance: 0.15 m – Infinity.

Actual specifications of the Fluke Ti-55 IR Camera, 2007.



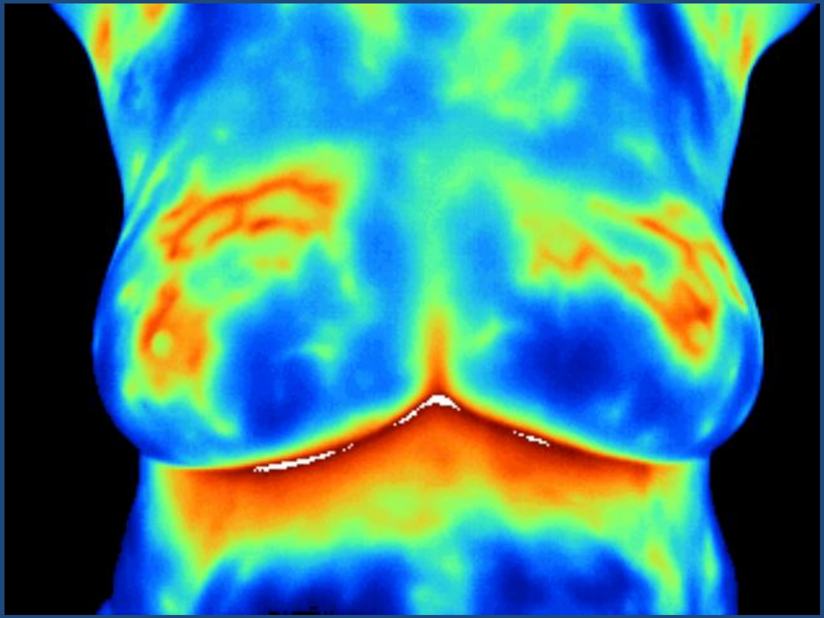
Uncooled IR Imaging Modules by ElectroPhysics, Inc.

IR Imagers: The Old Versus the New

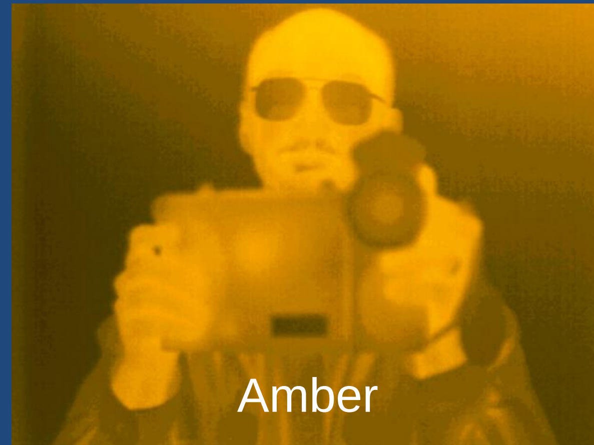
Significant advances have been made in the spatial and temperature resolution of clinical imagers with the advent of the integrated circuit microbolometer.

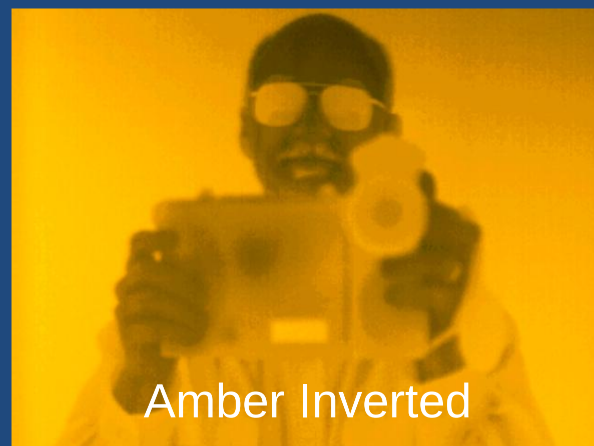
Which image would you rather interpret?

IR Image from 2000 Ville Marie Study taken with a Bales thermal scanner.



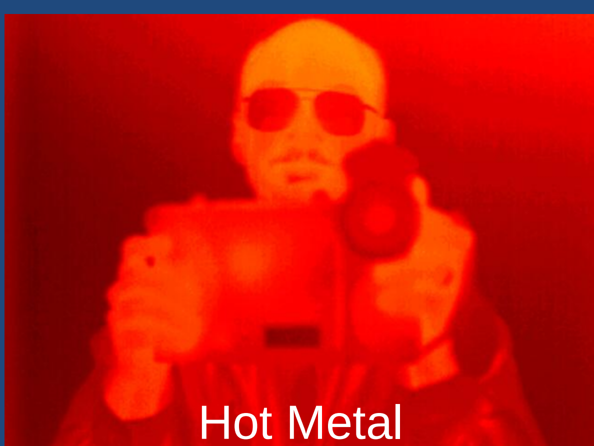
IR Image taken with a Fluke Ti55 microbolometer-based imager, 2010





IR Images are Grayscale

but giving the image false color is useful for various tasks.



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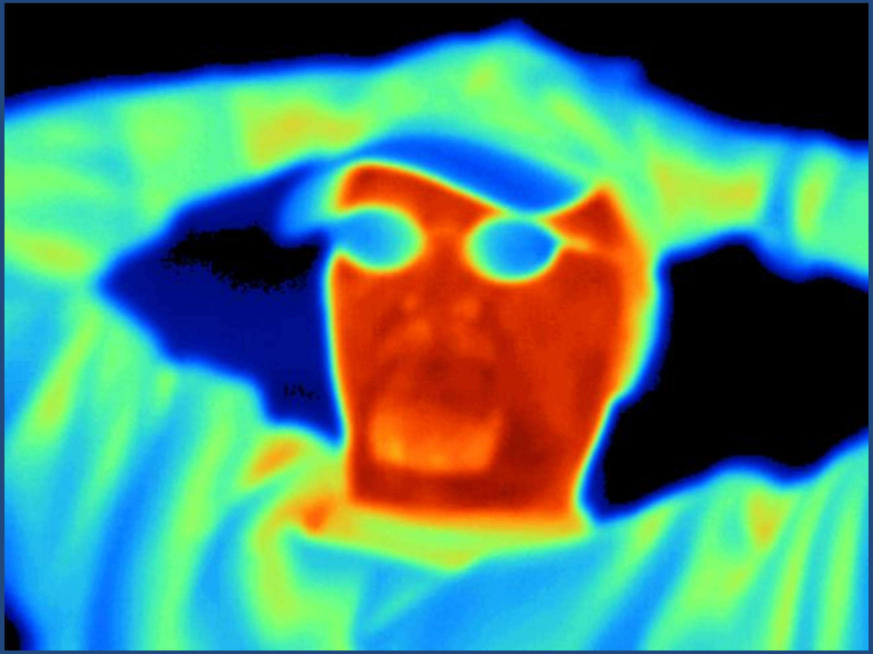
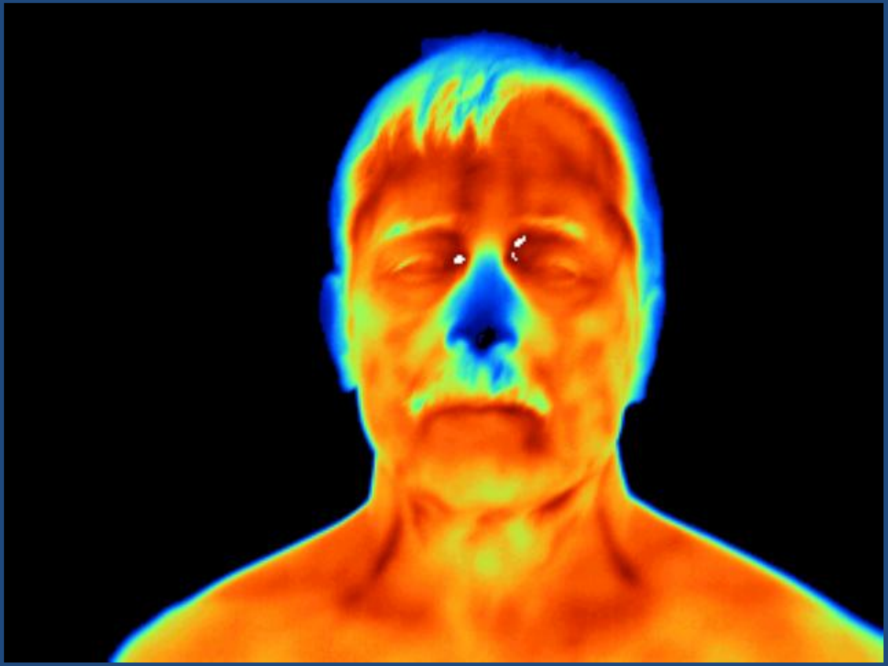
Ambient Temperature Affects the Clinical Thermogram Greatly.

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.

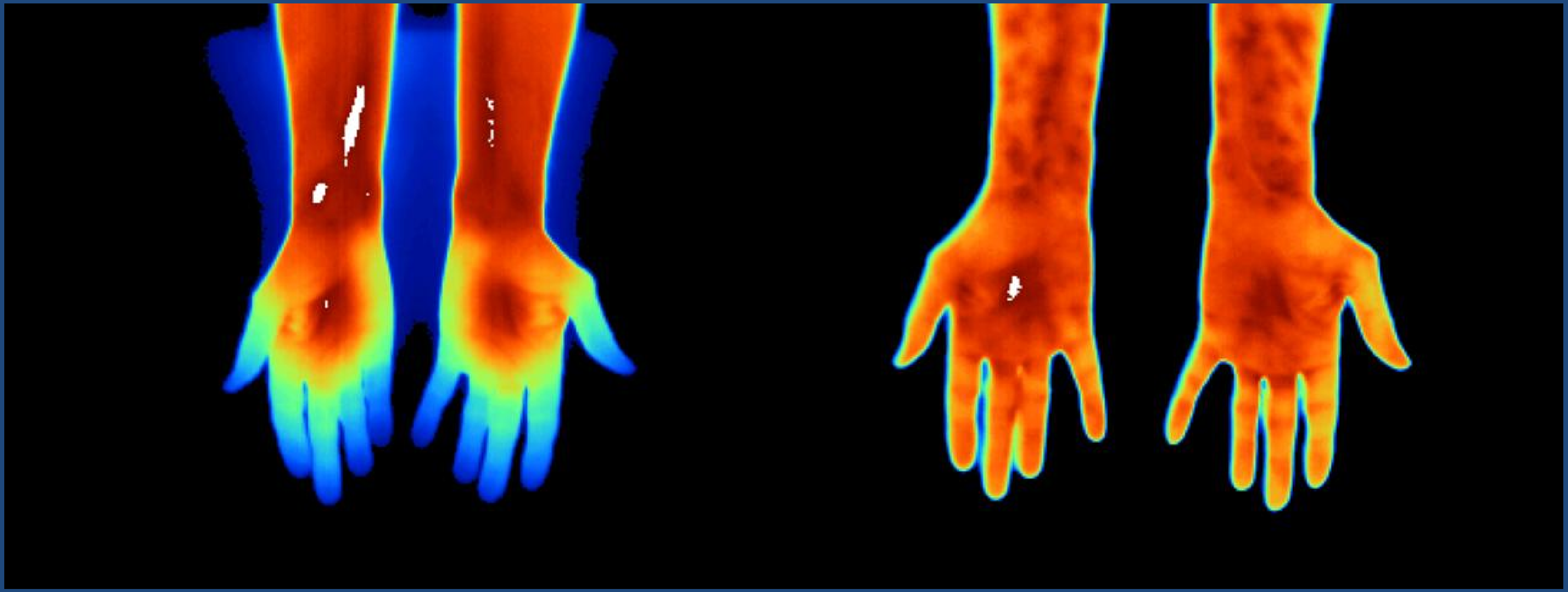


Thermograms of Cold Subjects Are More Diagnostic

The thermographic image of the body when cold shows localized blood flow reduction, *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.



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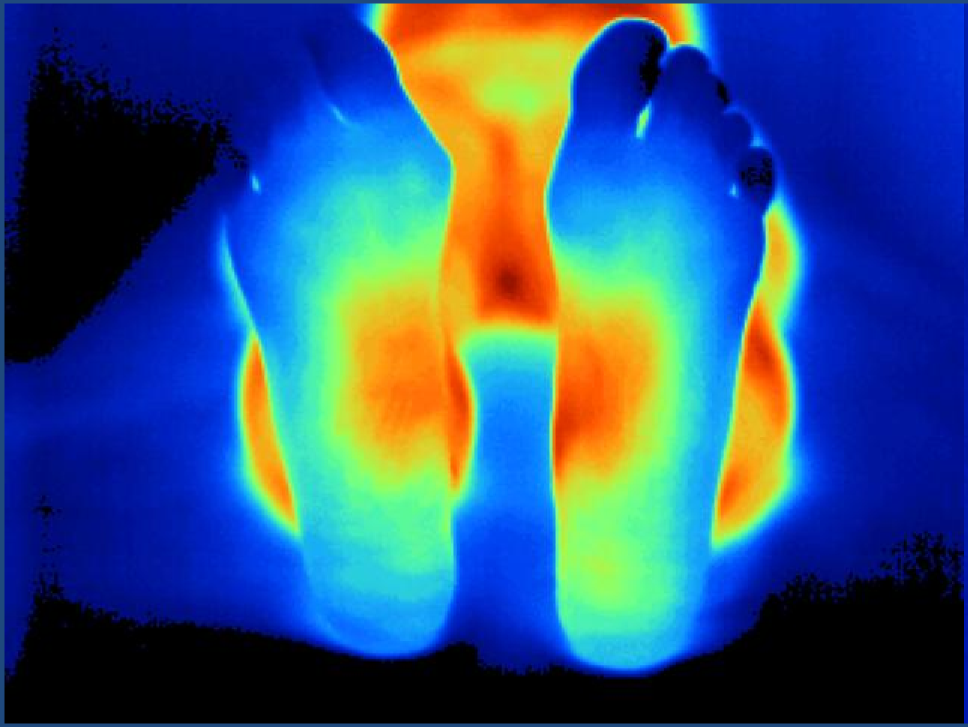
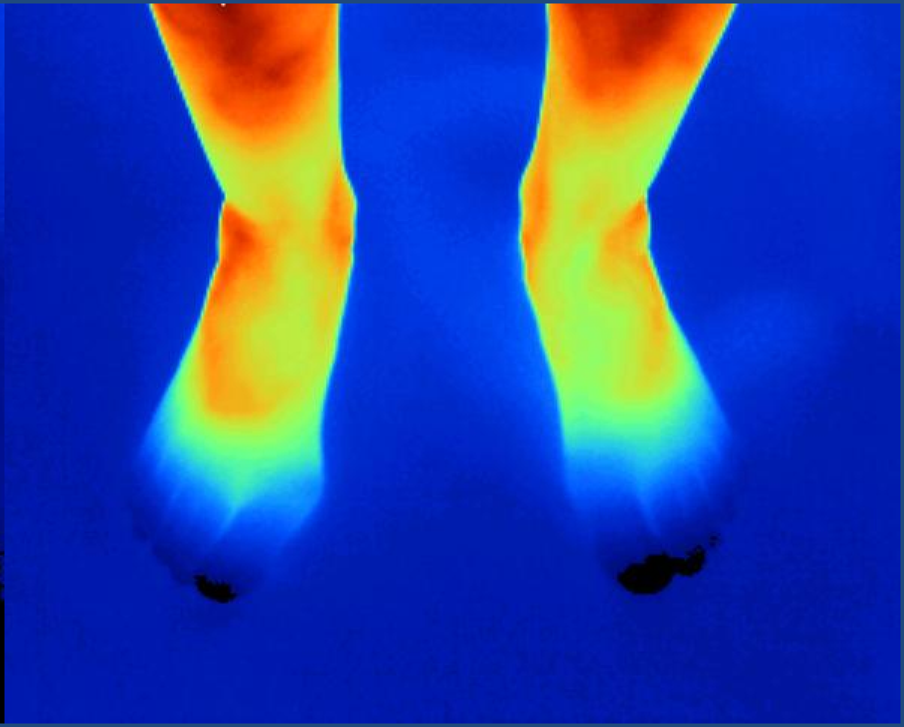
Feet React to Cold as Hands Do.

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 a good foot thermogram.



Then the subject stands up for the views of the top side of the feet.



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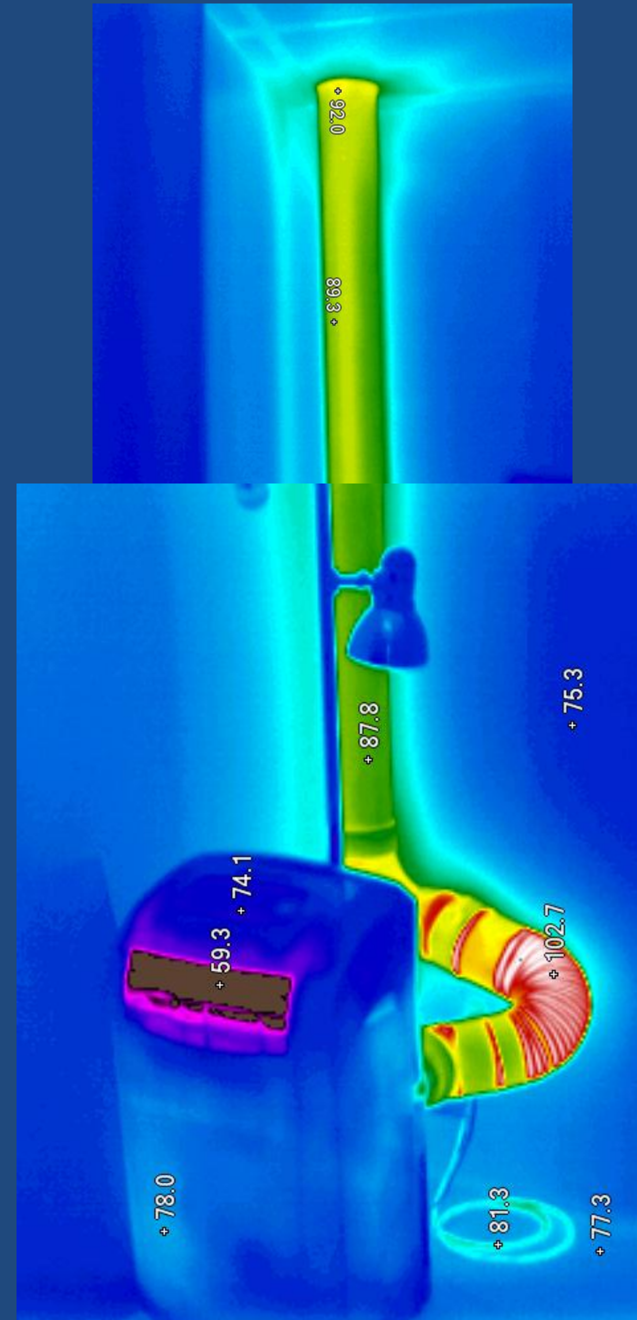
Design of a Thermography Room

- 8 x 10 ft. minimum floor space.
- No windows or incandescent lights (fluorescent and LED 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 in this example.
- 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.

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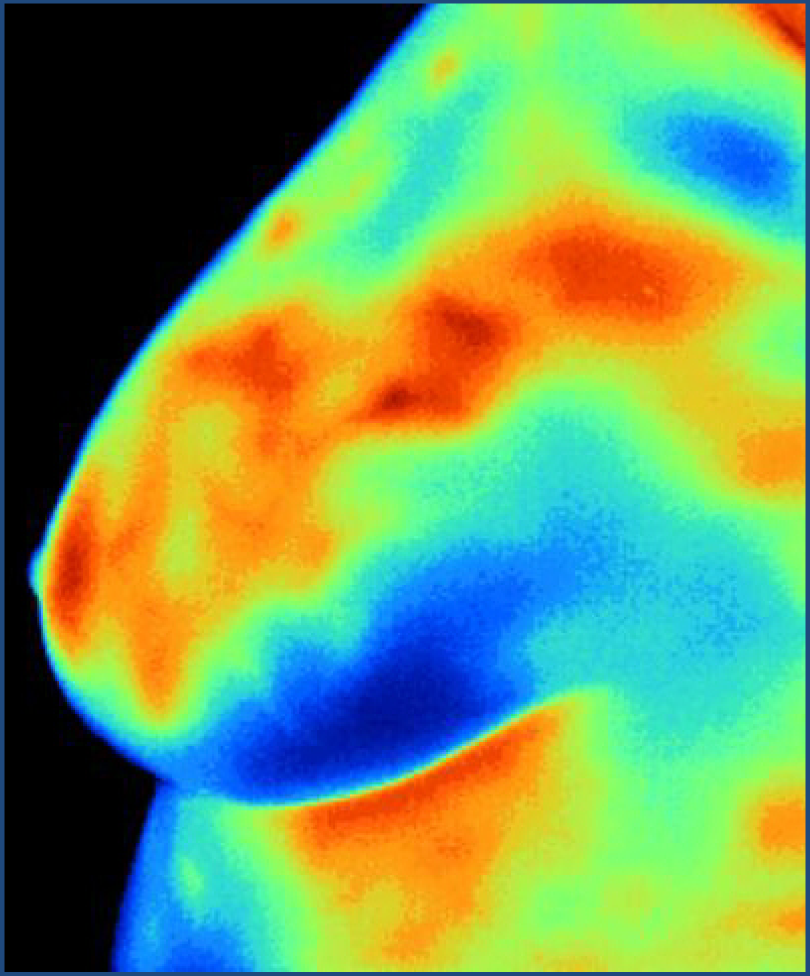
Thermography in Breast Cancer Detection

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



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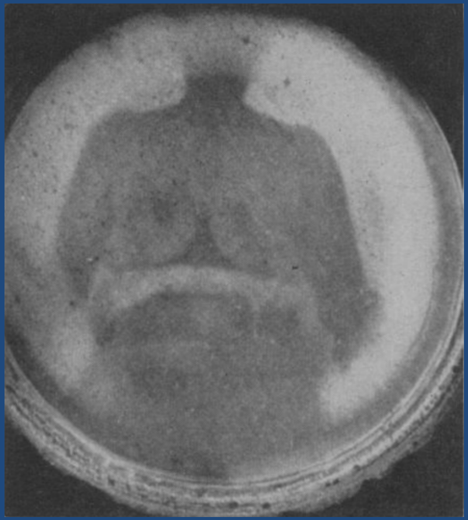
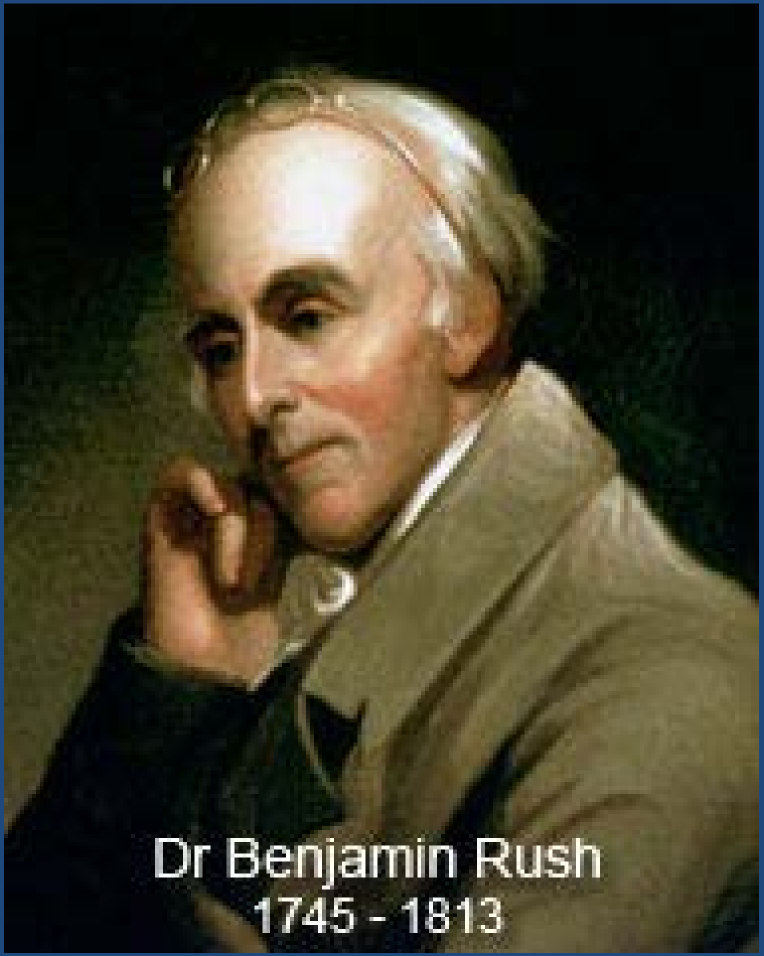
Early Breast Thermography

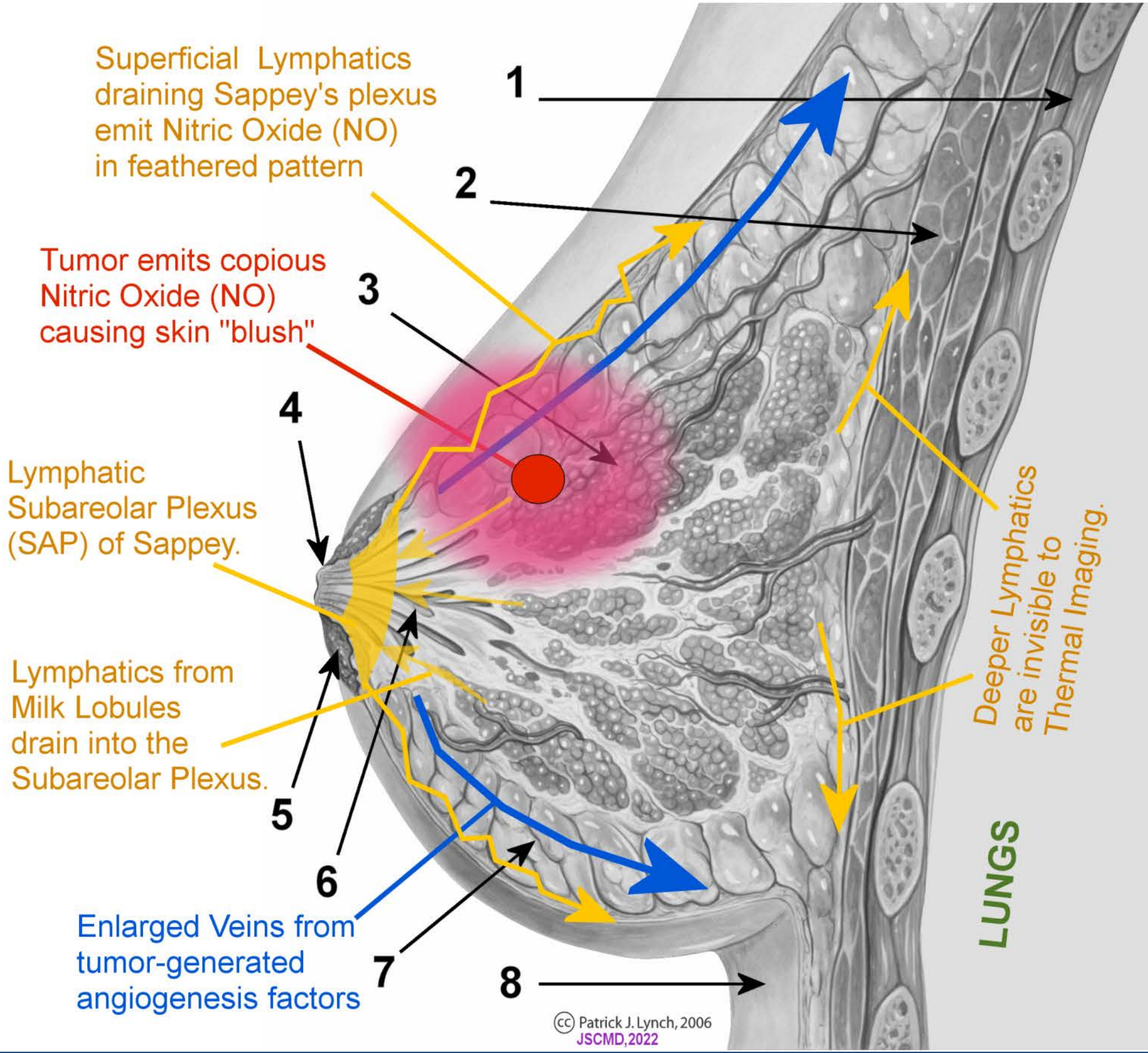
Dr. Benjamin Rush, around 1800, detected breast cancer as being a warm, painless mass of the breast.

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:





The Three Thermological Effects of Breast Cancer



1. Chest wall
2. Pectoralis muscles
3. Lobules
4. Nipple
5. Areola
6. Milk duct
7. Fatty tissue
8. Skin

Breast Lymphatics and Veins

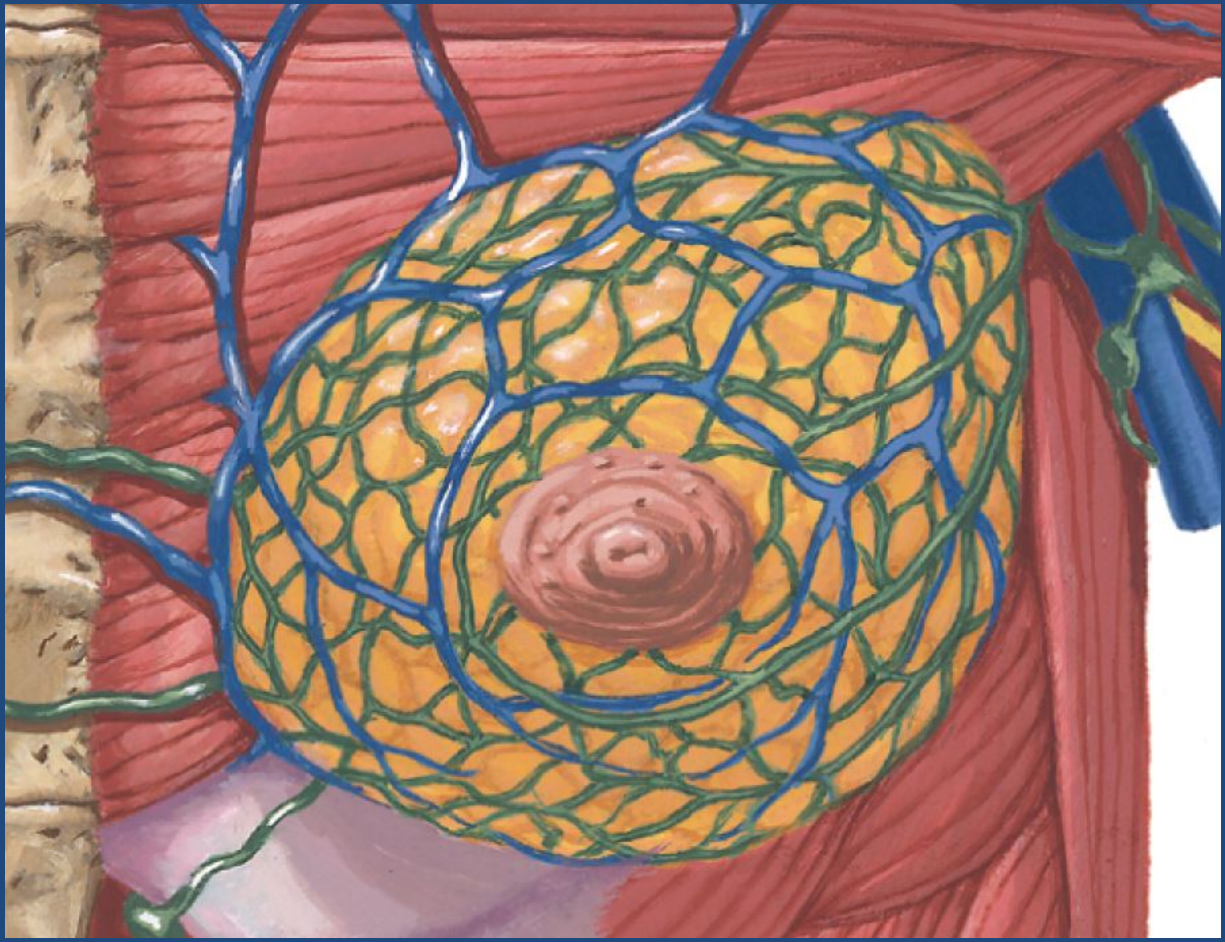
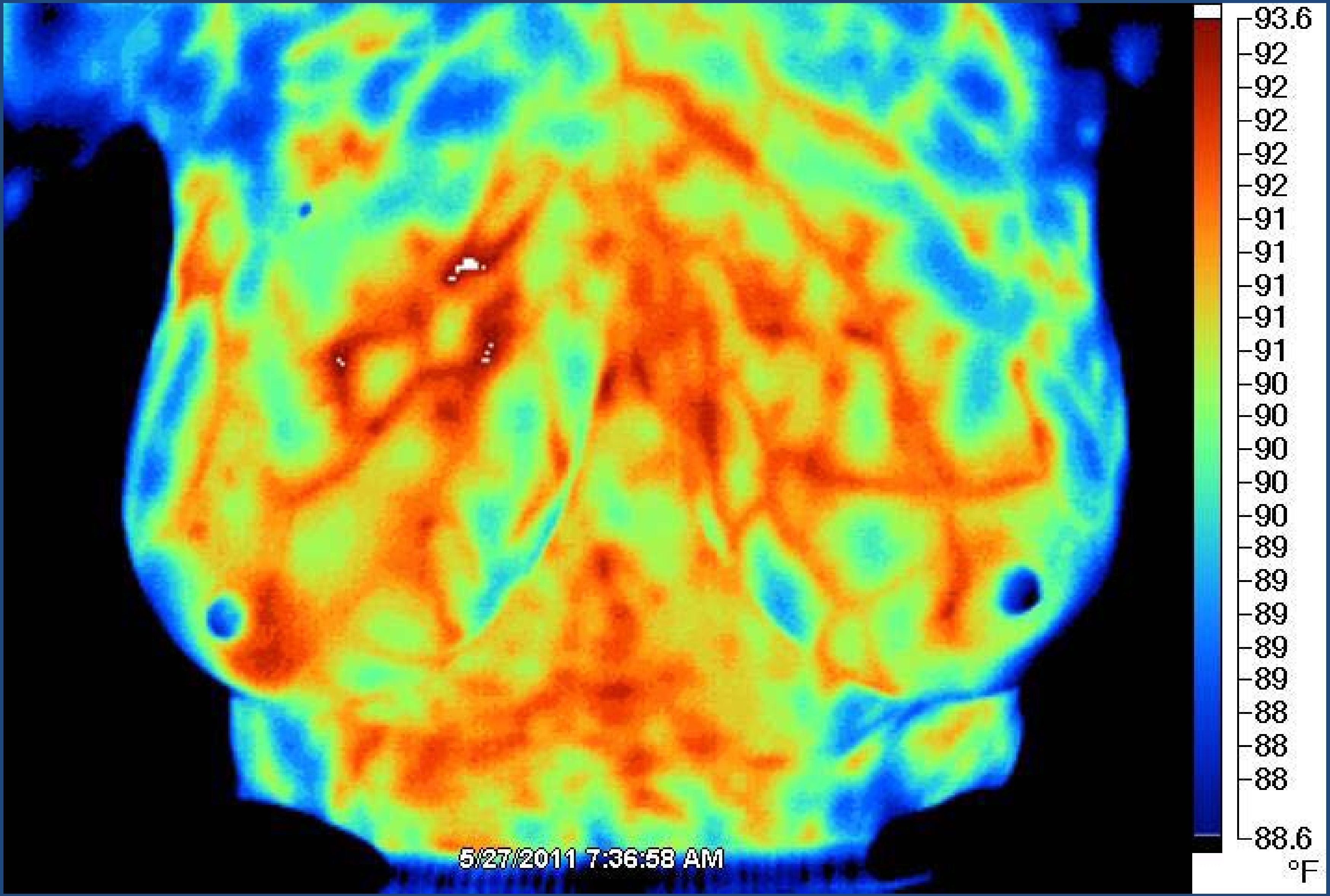


Illustration by John A. Craig, Netter images.
The Left breast is shown.

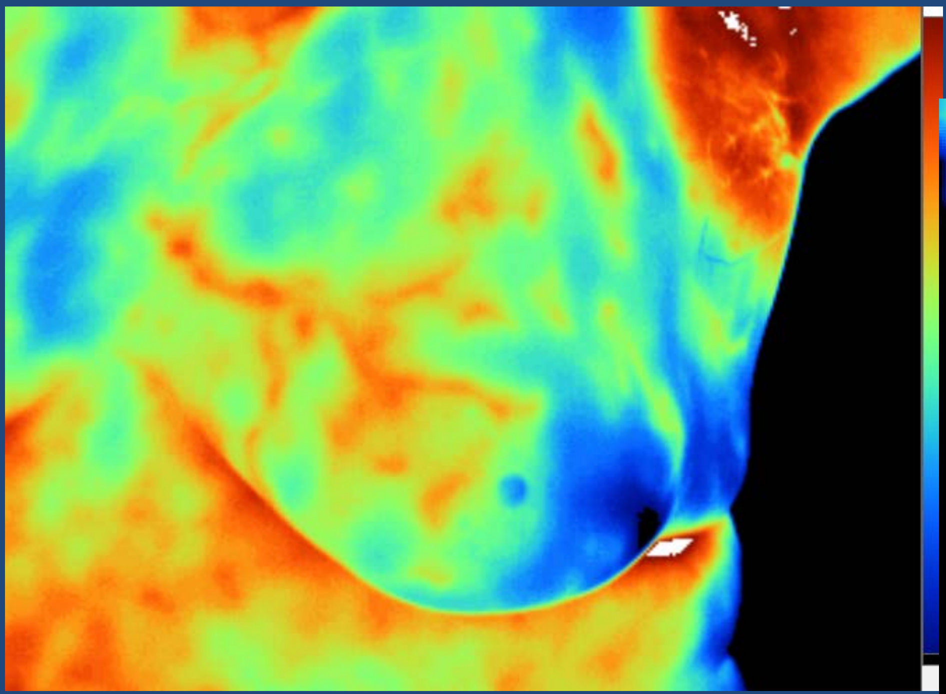
The lymphatic network is shown in green.

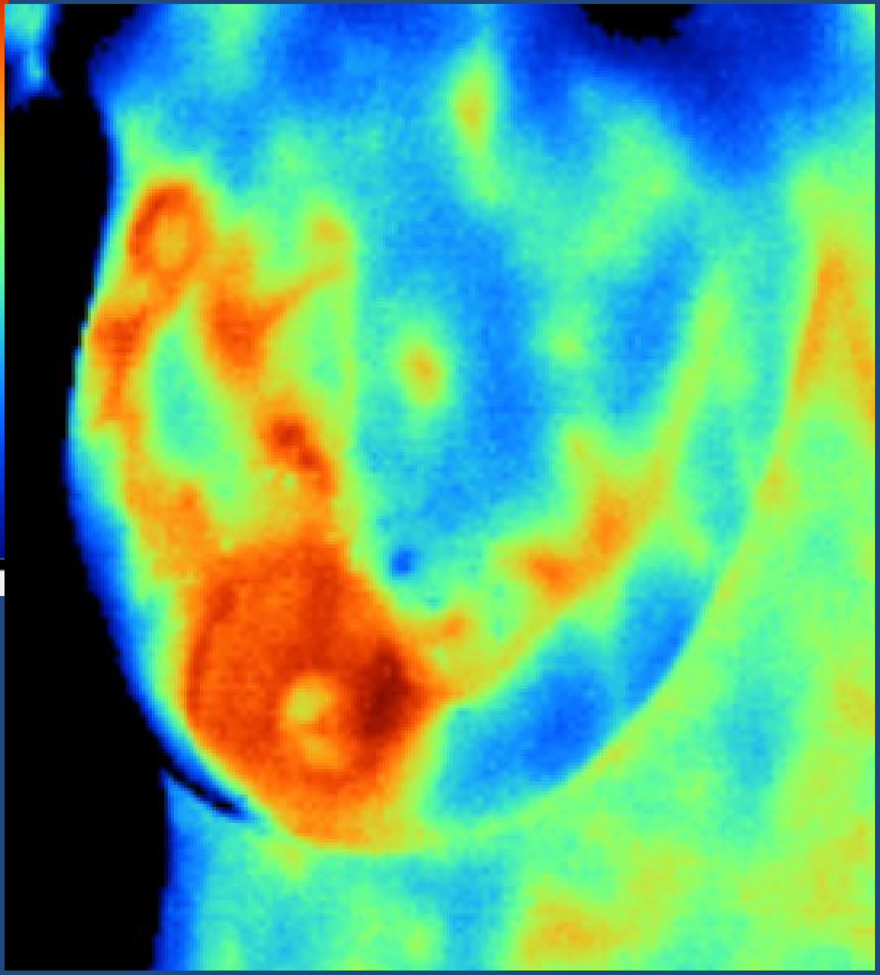
The Veins are in blue.

Breast Veins Thermographically



Breast Lymphatic Thermal Appearance

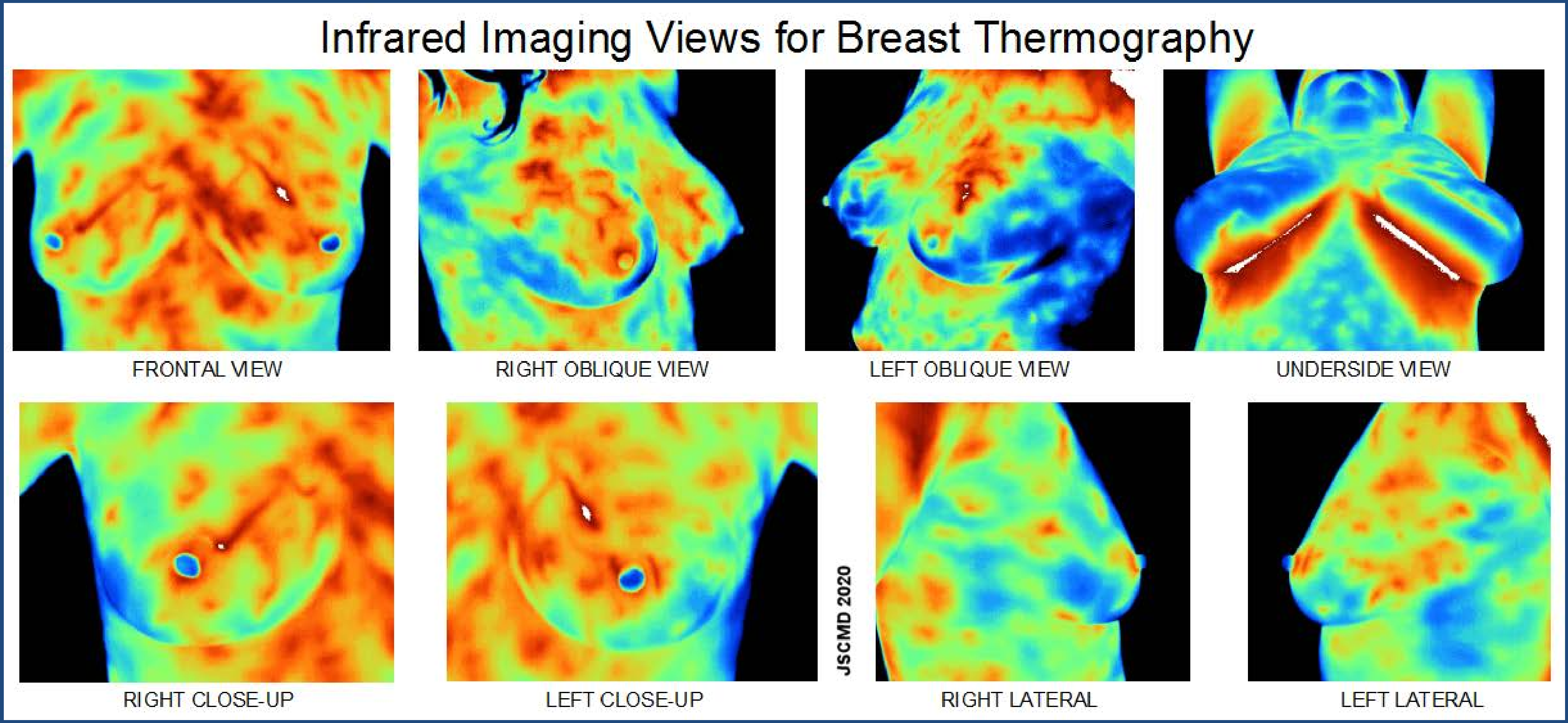




Unlike the more linear veins, inflamed breast lymphatics appear wispy, like cirrus clouds, and may form loops or whorls.

Routine Images for Breast Thermography

Only the four views at the top are required.
The four other views are not necessary for a full breast exam.



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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 subject is disrobed above the waist with hands and arms held away from the trunk.
- Subjects are asked to refrain from alcohol, coffee, smoking, exercise, deodorant, and lotions to the chest prior to imaging.

Adapted From Functional Infrared Imaging of the Breast. *In* The Biomedical Engineering Handbook, Medical Devices and Systems, 3rd edition, Ch26, p.11, JD Bronzino, ed, CRC Press, 2006.

Villa Marie Breast Thermography Grading Scale I

- **Abnormal Signs with the V-M Infrared Grading Scale***
- Significant area of vascular asymmetry or visible intermammary temperature difference in a scaled gradient color image. *Nipples not symmetrically cool.*
- Vascular anarchy, i.e., unusual tortuous or serpiginous vessels that form clusters, loops, abnormal arborization, or other aberrant patterns. This includes unusual venous clusters and lymphatic inflammation patterns.
- A 1°C (1.8°F) focal increase in temperature (ΔT) when compared to the contralateral site *and* when associated with the area of clinical abnormality, such as a palpable mass or retracted (or warm) nipple.
- A 2°C (3.6°F) focal ΔT versus the contralateral site, without a clinical abnormality.
- A 3°C (5.4°F) focal ΔT versus the rest of the ipsilateral breast when not present on the contralateral site.
- Global breast ΔT of 1.5°C (2.7°F) versus the contralateral breast.

*Unless stable over 3 to 6 months' time period (minimum) or due to known non-cancer causes (local infection, recent benign surgery, radiation, trauma, bruising, sympathetic imbalance, etc.).

From: Campbell JS & Mead MN, Human Medical Thermography, CRC Press 2002, Ch. 9.

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**).

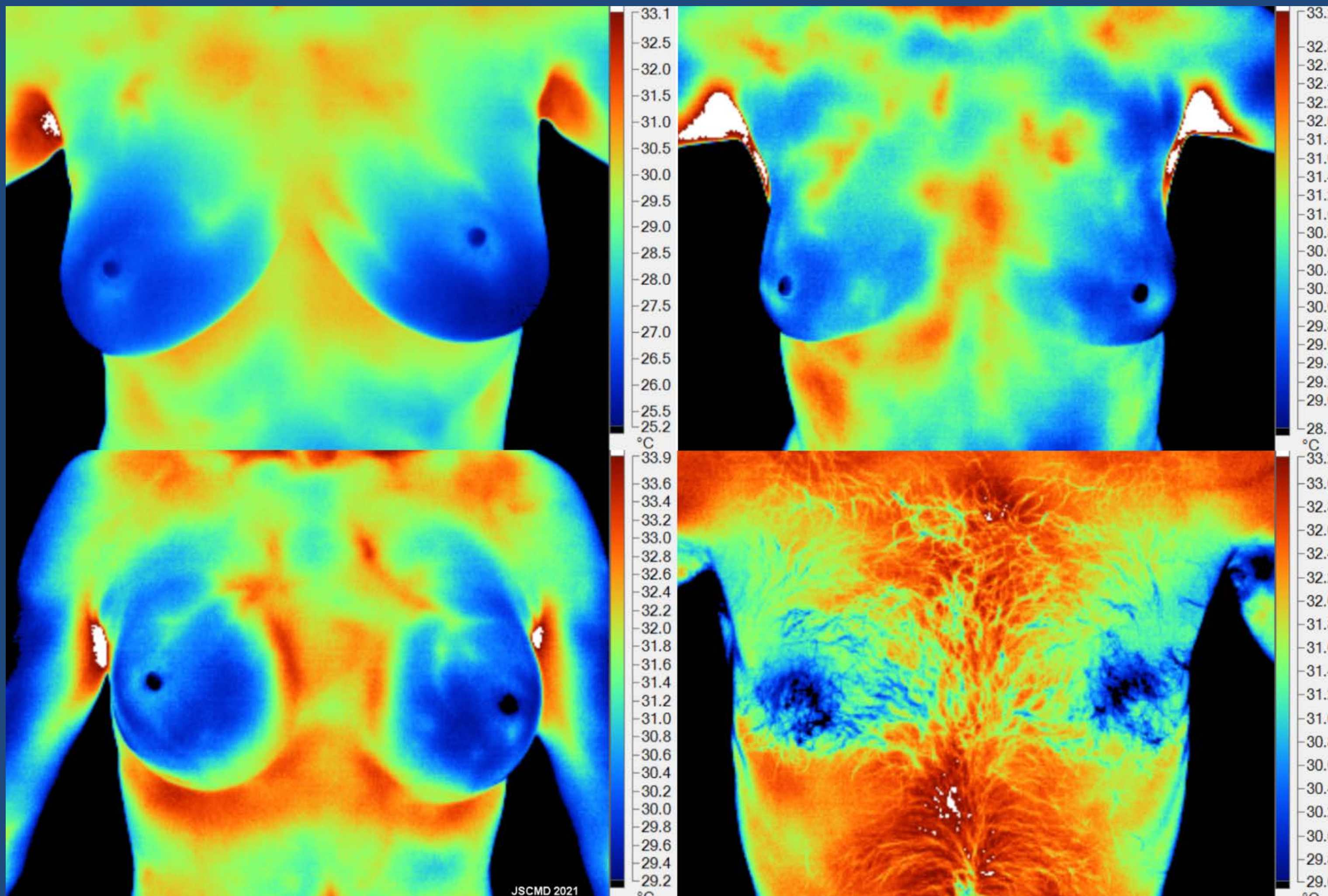
TH-4 = Two abnormal signs. (**Abnormal**).

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

Adapted From Functional Infrared Imaging of the Breast. *In* The Biomedical Engineering Handbook, Medical Devices and Systems, 3rd edition, Ch26, p.11, JD Bronzino, ed, CRC Press, 2006.

The Normal Breast Thermogram TH-1

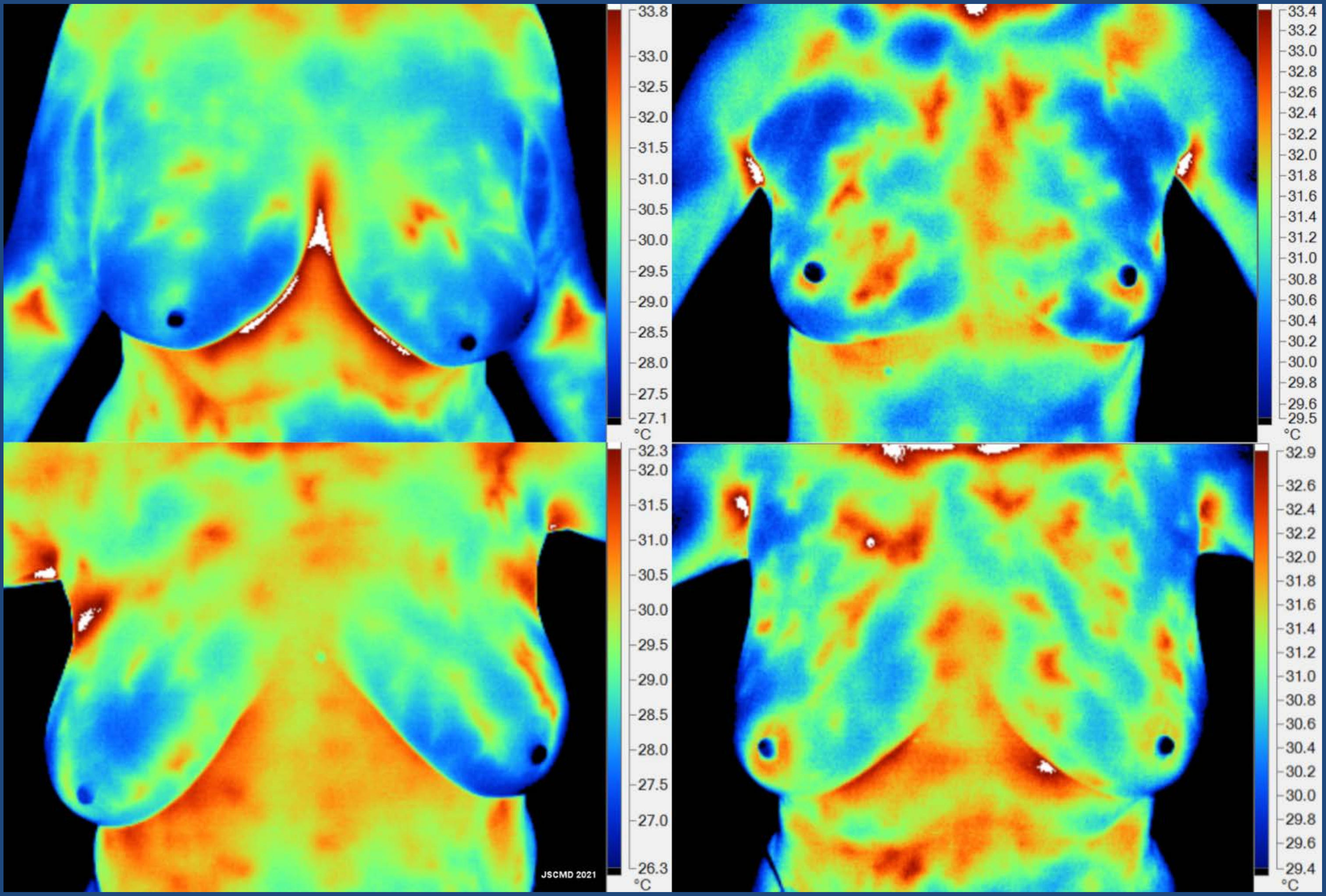
The breasts are both uniformly cool without hot spots or vascular markings. This is graded as “TH-1, Normal Exam”



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.



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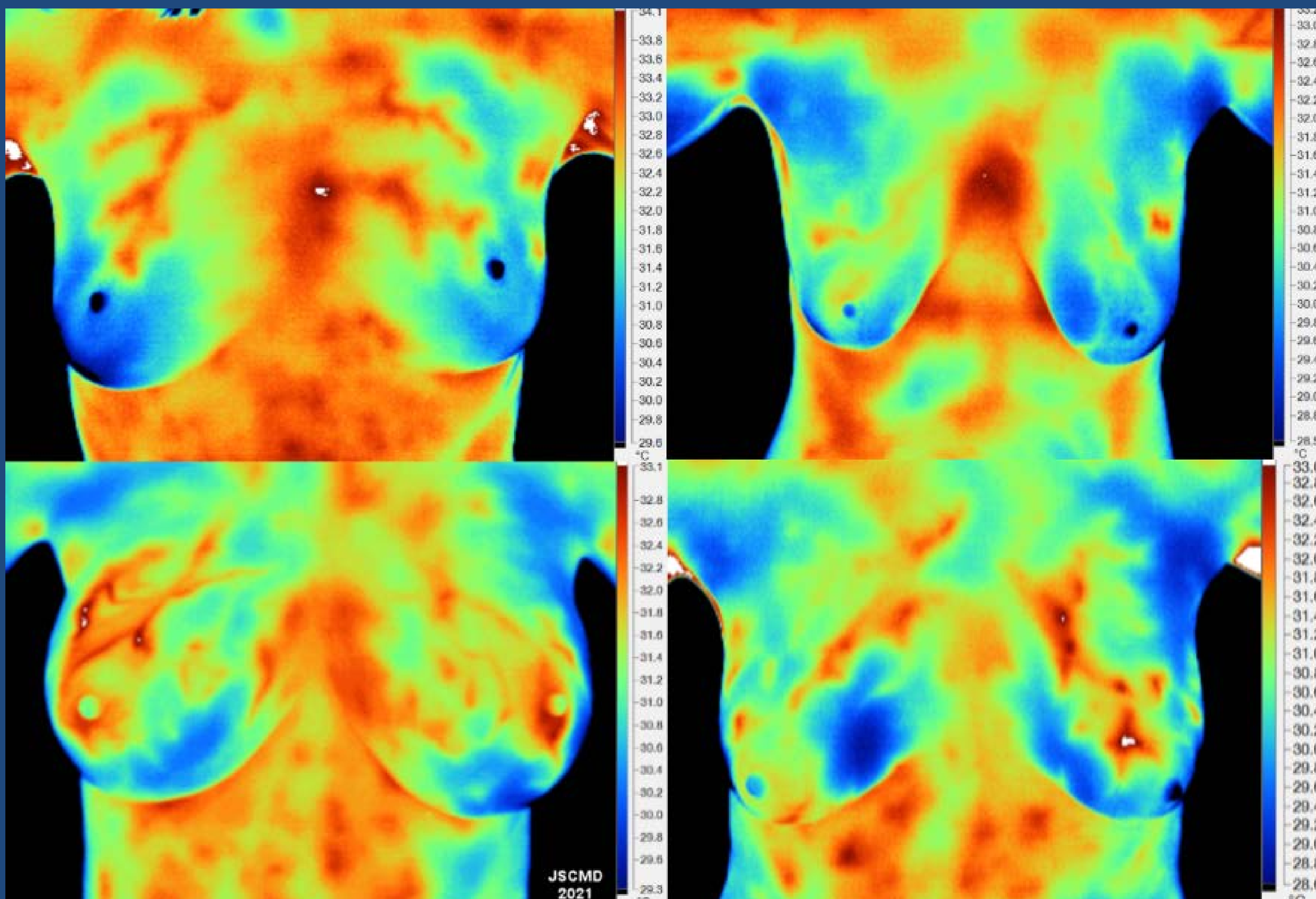
Equivocal Breast Thermogram TH-3

In these cases there is vascular asymmetry, 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.



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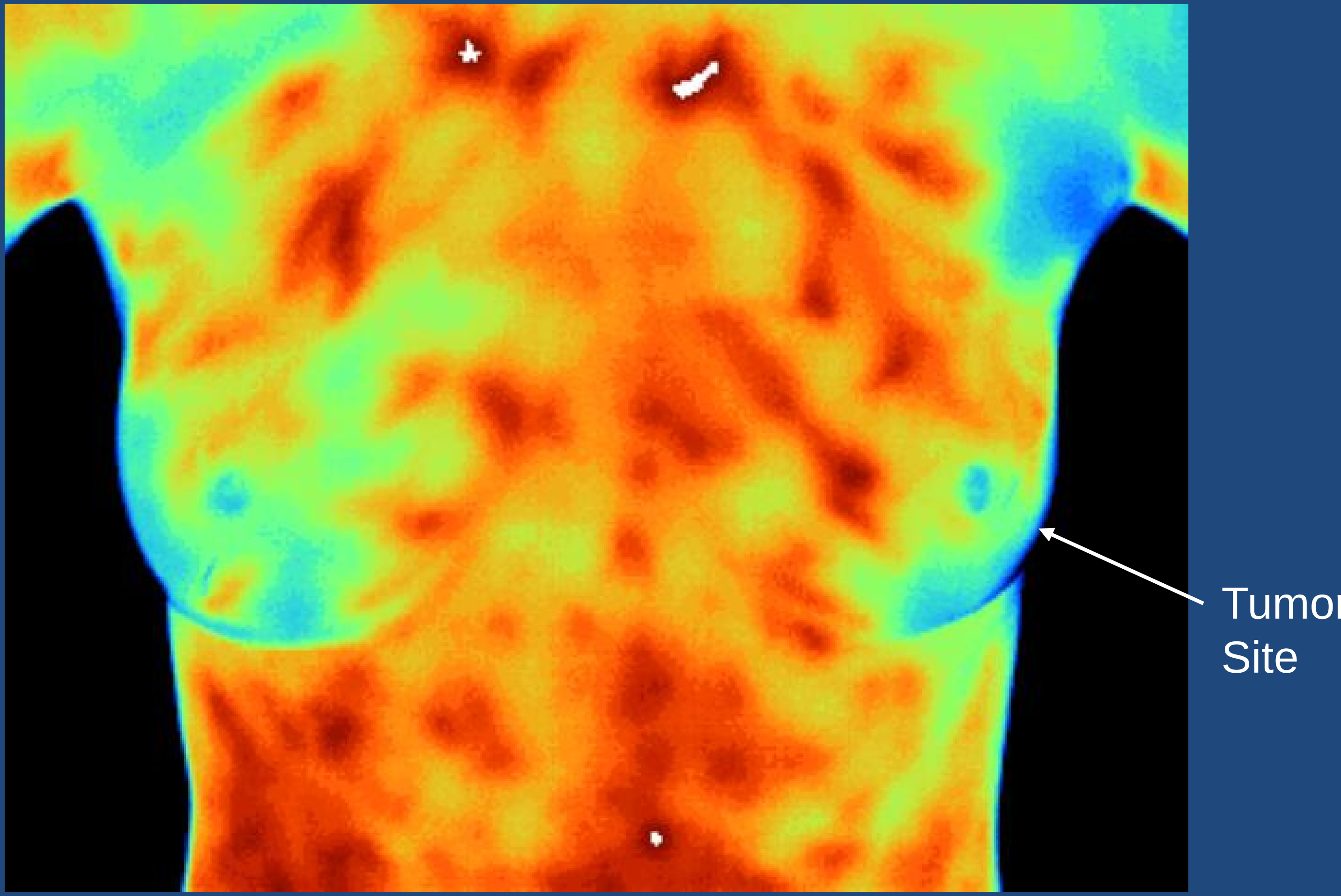
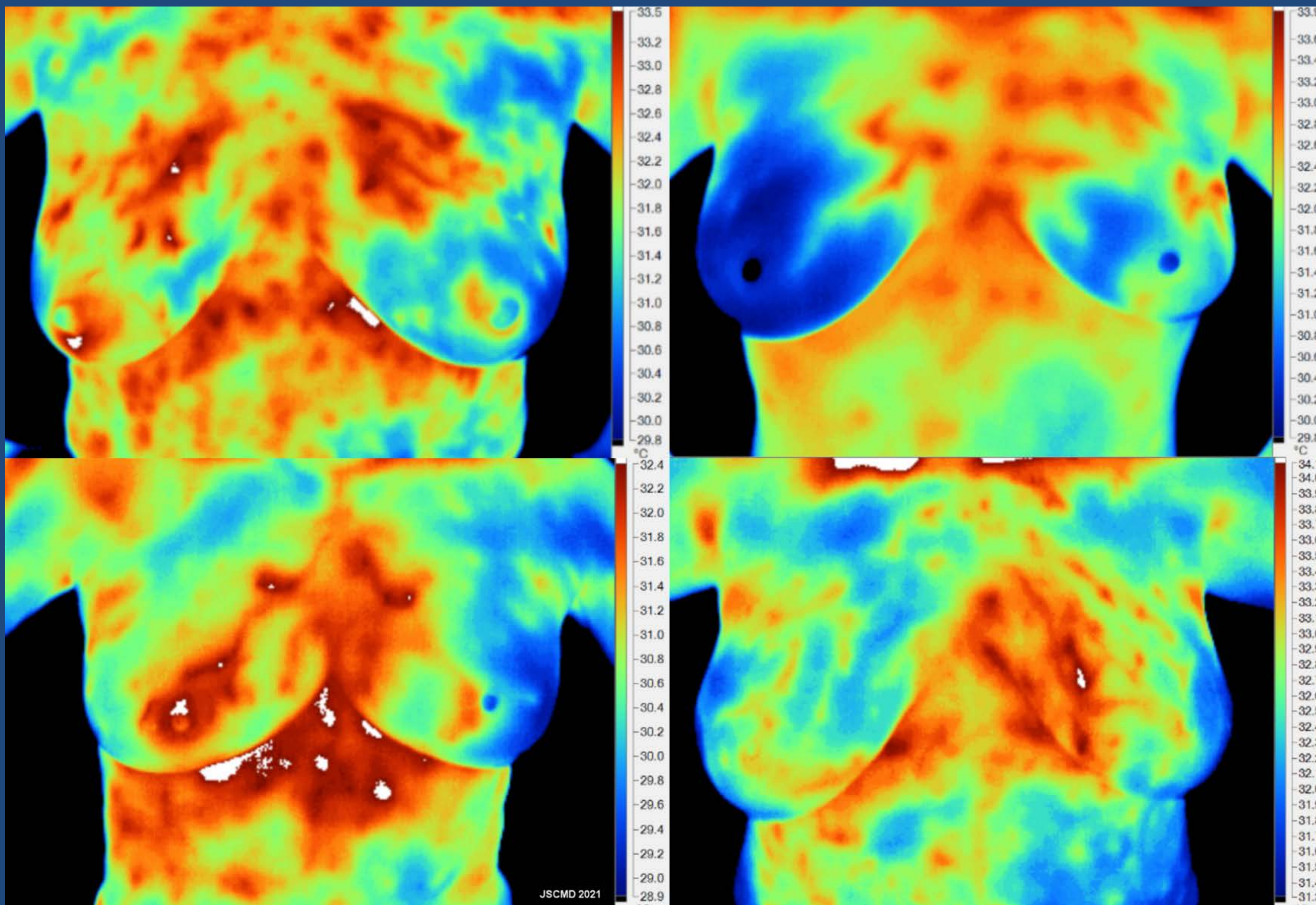
Equivocal Breast Thermogram TH-3



Early invasive ductal adenocarcinoma of Lateral Left Breast

Abnormal Breast Thermogram TH-4

Definite thermal asymmetry is present in all examples. Note the dissimilar nipple temperatures in some cases.



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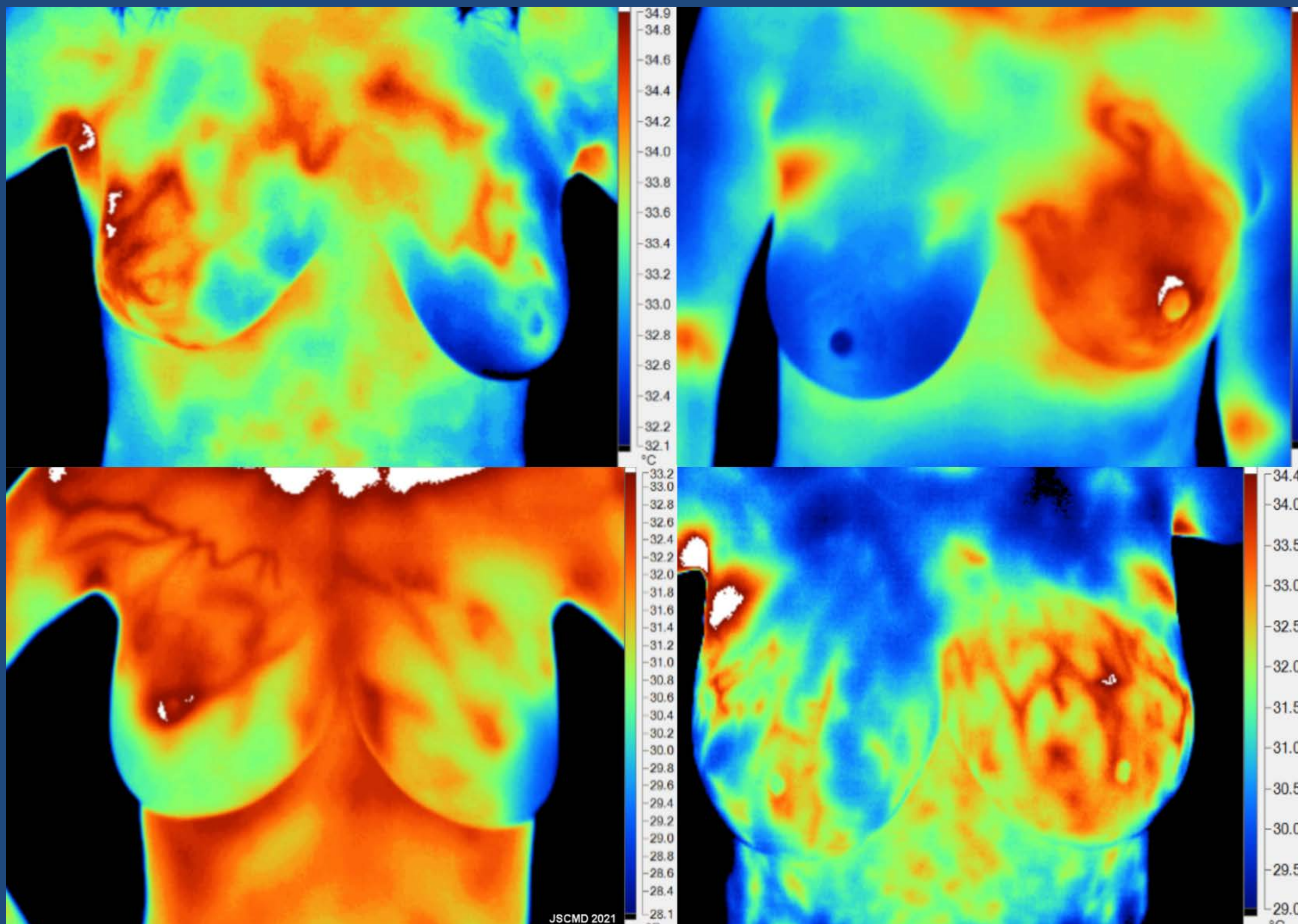
Severely Abnormal Thermogram TH-5

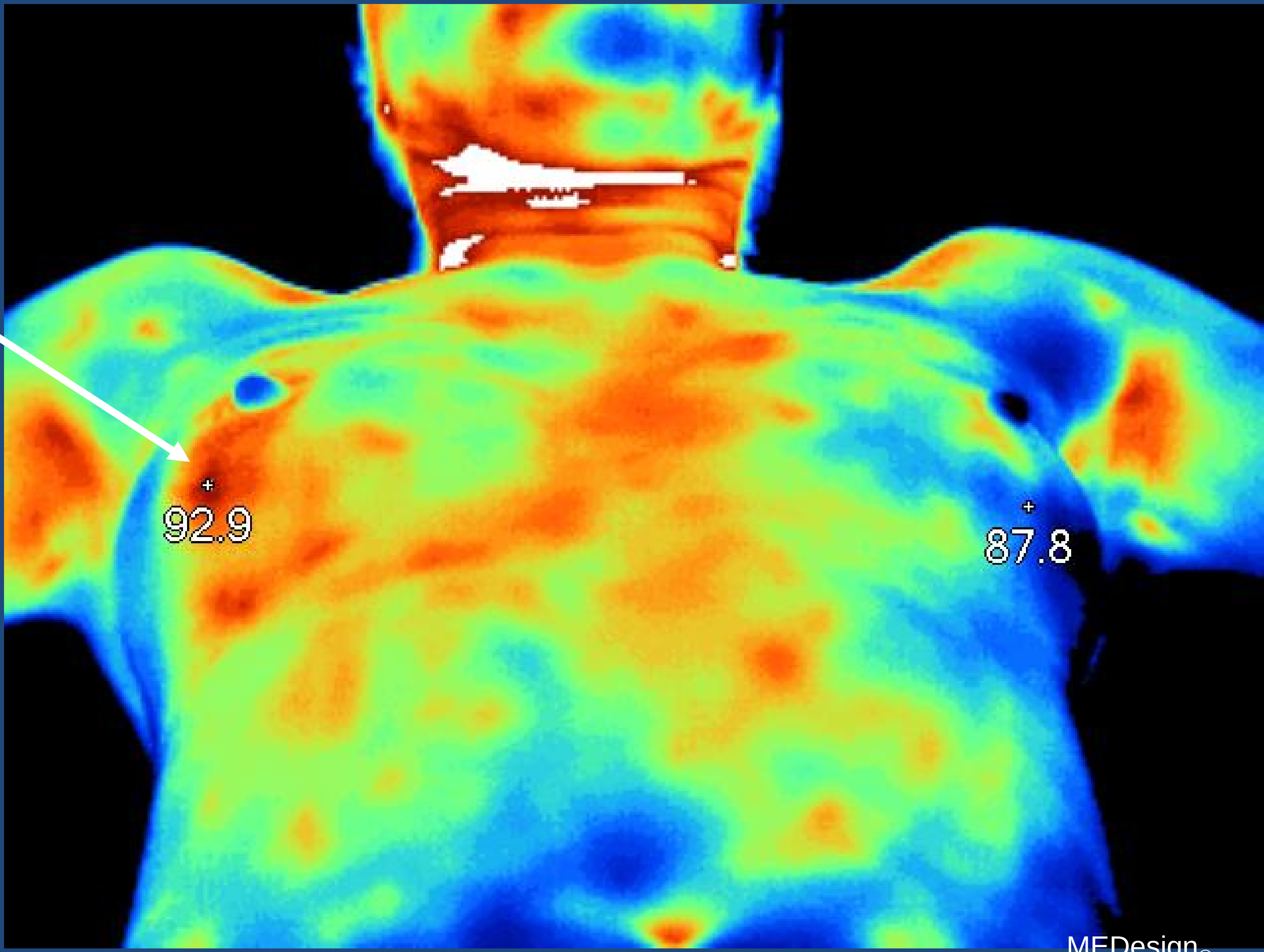
Marked breast asymmetry and dissimilar nipple temperatures are seen in all examples.



Why Do an Image of the Undersides of the Breasts?

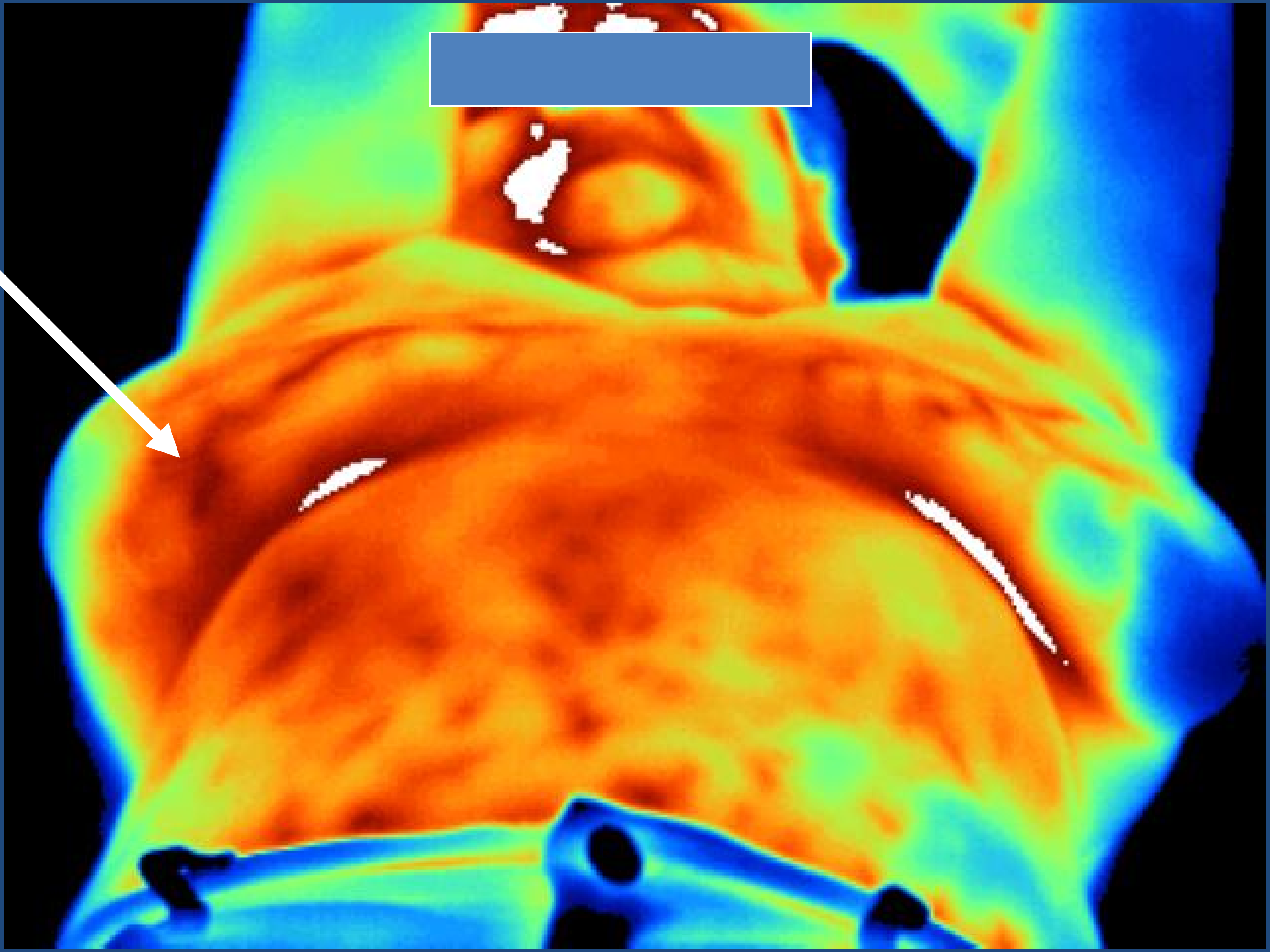
TH-4 Abnormal

This woman's other images were all normal.



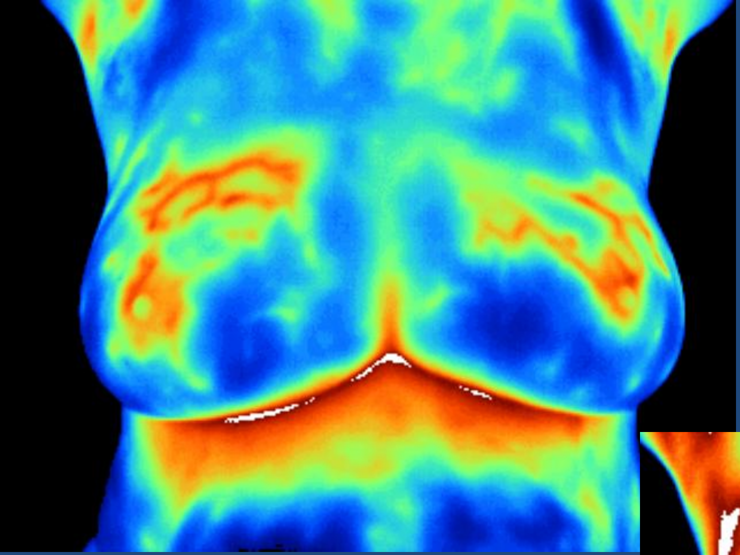
TH-5 Image of Undersides of the Breasts

This woman was concerned about a lump here.

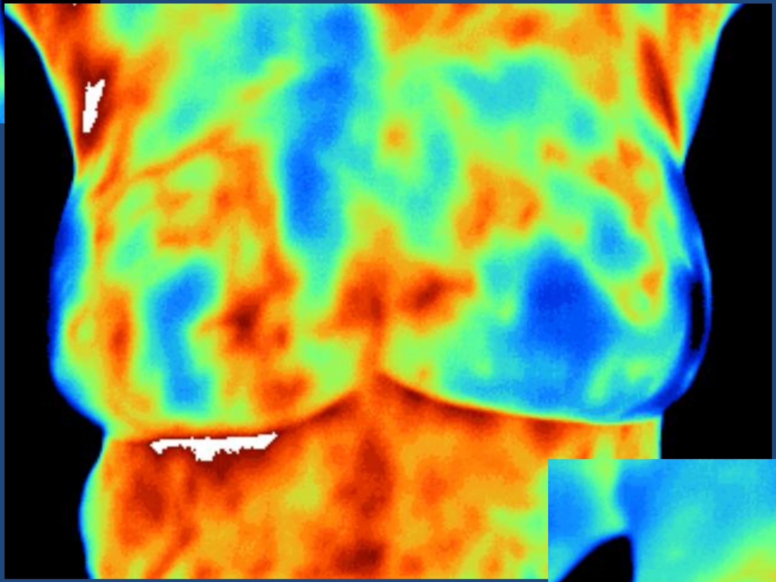


Surgery removed a malignant tumor.

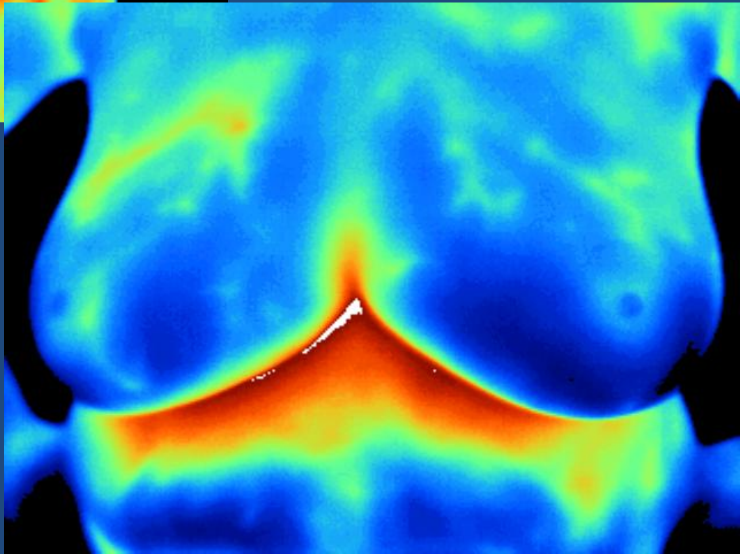
Hormonal Effects on Breast Thermography



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

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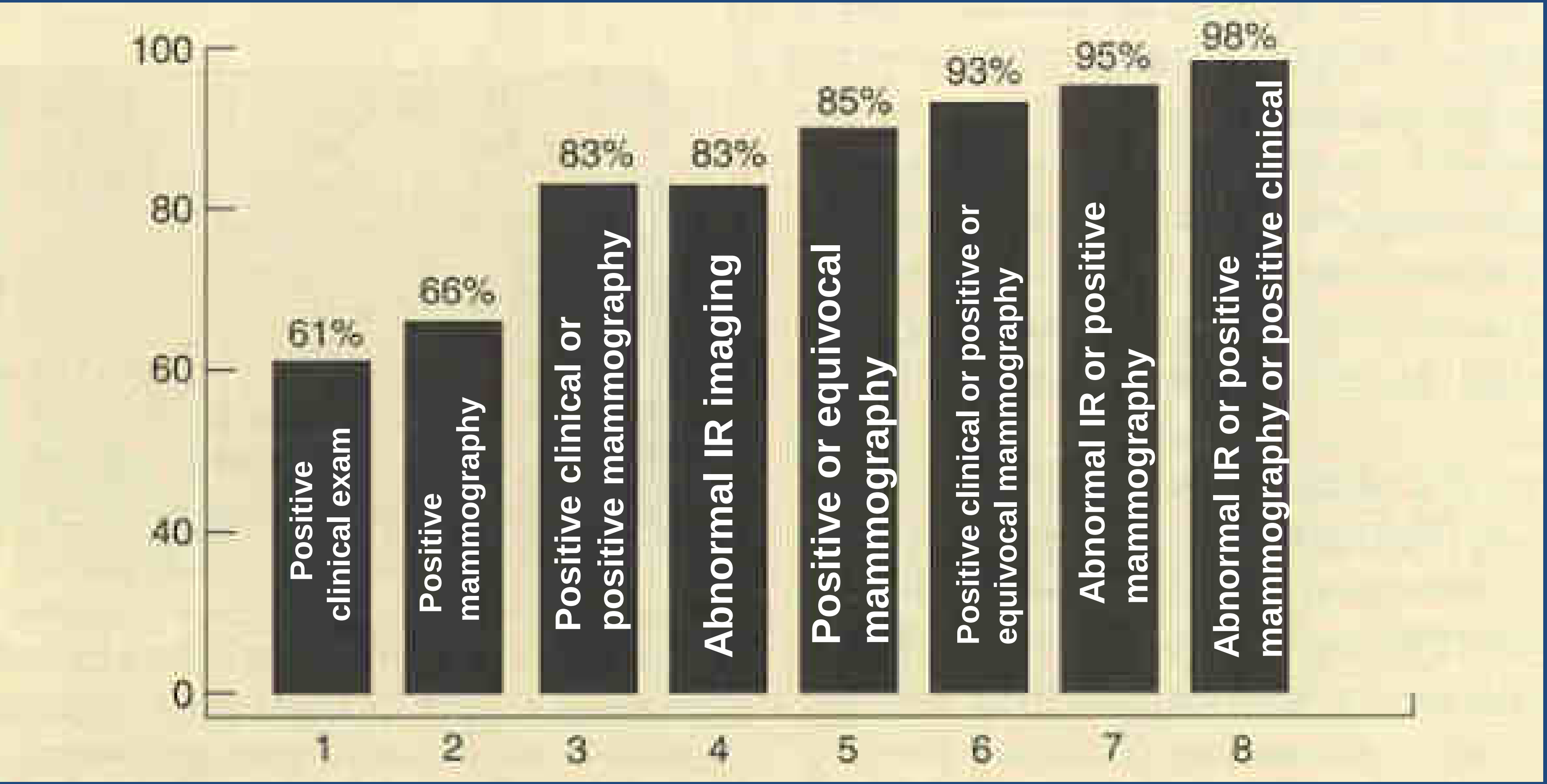
Does Thermography Help Breast Cancer Detection?

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.



Source: Functional Infrared Imaging of the Breast. J, Keyserlingk et al, Journal of IEEE EMB, pp 30-41, May/June 2000

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."

Louis, K., et. al., Long-term assessment of breast cancer risk by thermal imaging. In *Biomedical Thermology*, Alan R. Liss, Inc, 1982, pp. 279-301.

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

Amalu, WC, et. al., Biomedical Engineering Handbook, 3rd Ed, CRC Press 2006, p 25-17.

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 older scanner technology)

Modality	Sensitivity	Specificity	Positive Predictive Value	Negative Predictive Value	Notes
Mammo-graphy	86%	79%	28%	92%	Structural Anatomic Image
Thermo-graphy	86%	89%	23%	99.4%	Physiologic Metabolic Image

Head, JF, Lipari,CA, Elliot, RL, Comparison of mammography and breast infrared imaging: sensitivity, specificity, false negatives, false positives, positive predictive value and negative predictive value. *IEEE*, 1999.

Where does Thermography Fit in Breast Cancer Screening 2022?*

- **For the best chance of BrCa detection (~98%):**
  - Clinical Exam and
  - IR Breast 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 - Inflammation

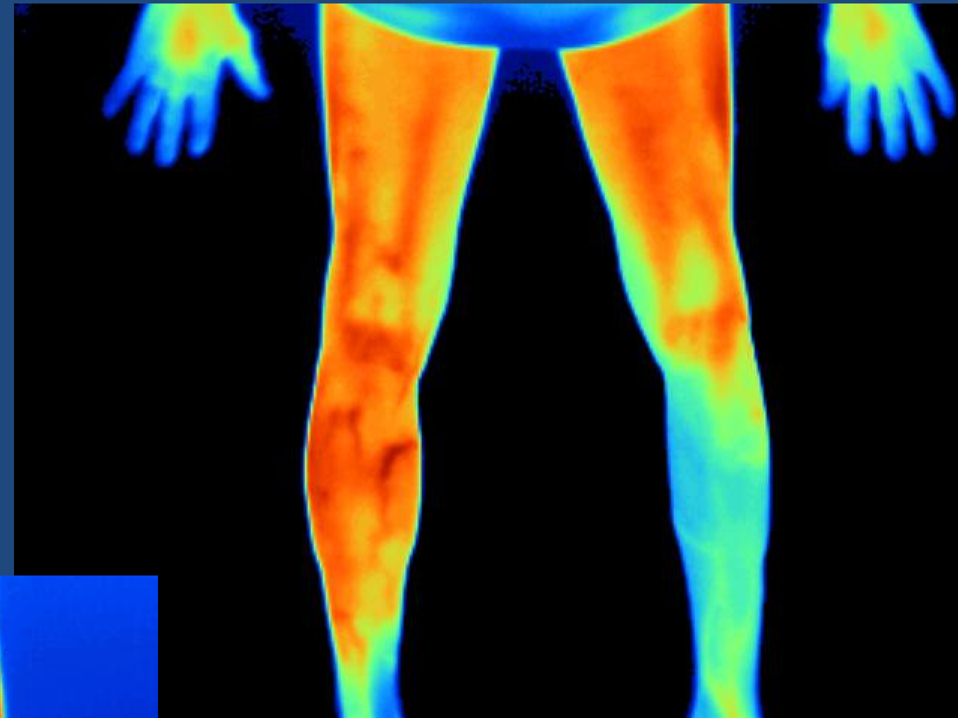
- Fever
- Vascular inflammation (Arteritis)
- Infection / Abscess Sites (including sinus & tooth infection)
- Small Joint Inflammation – gout, auto-antibody diseases, etc.
- Thyroid disorders (thyroiditis, neoplasm)
- Tendinitis and bursitis
- Recent soft-tissue injury (healing involves inflammation)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

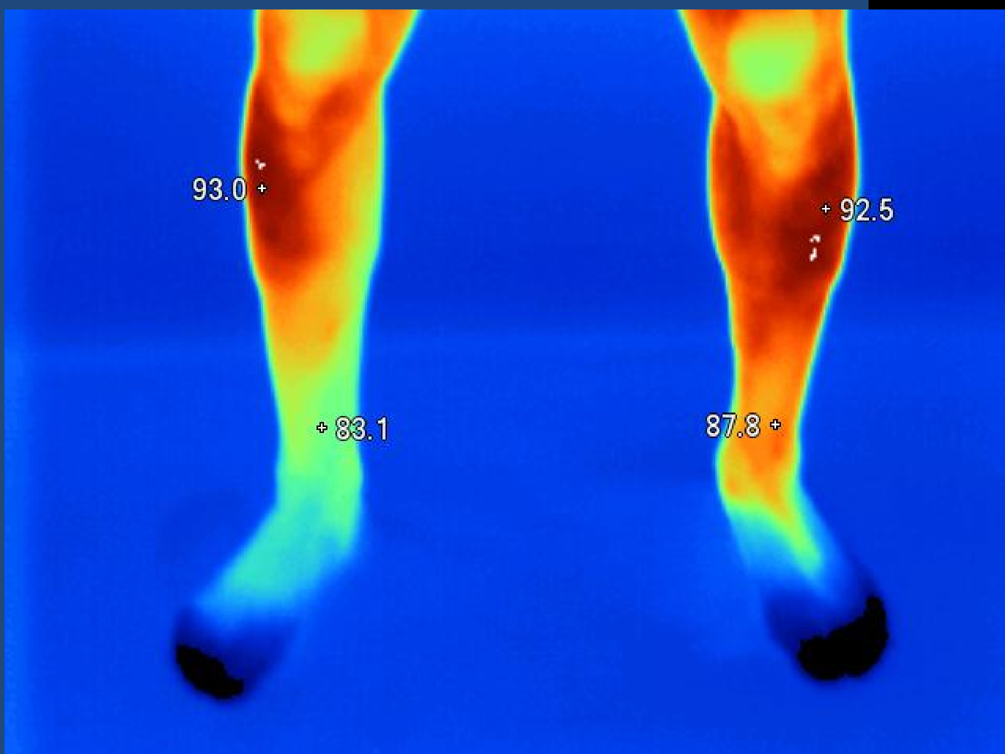
Cooler than Normal

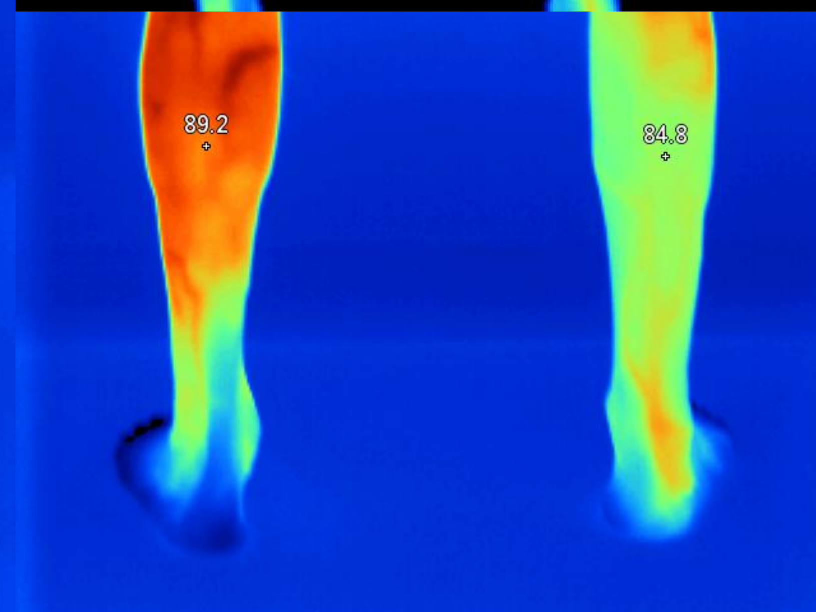
- Lack of arterial circulation
- Muscular disuse or atrophy
- Glaucoma (one or both corneas cooler than normal)
- Complex Regional Pain Syndrome (Reflex Sympathetic Dystrophy)

Muscular Atrophy of the Right Calf

Post-Polio syndrome in an older man.
Leg and foot pulses were normal.

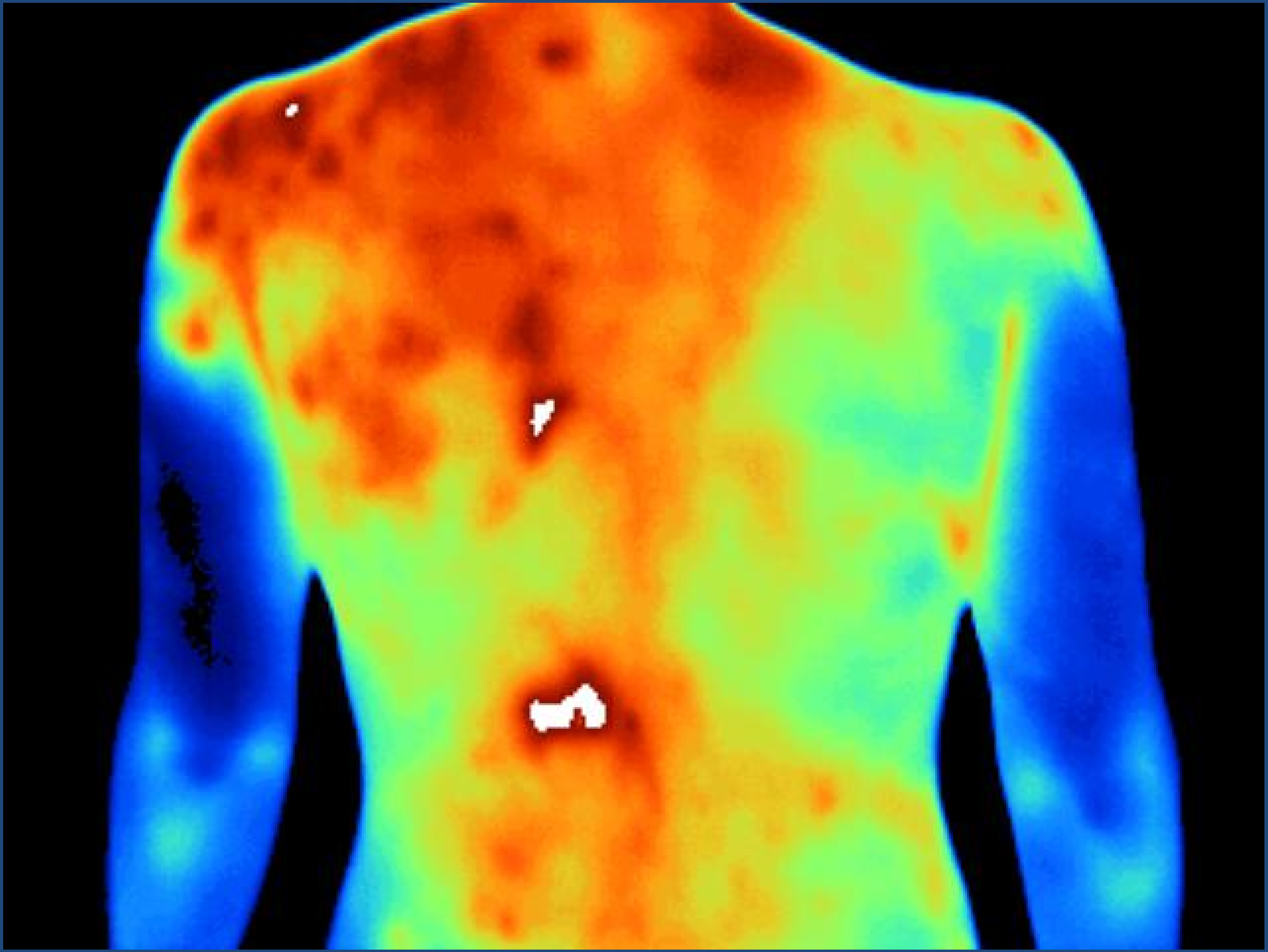






Inflammation of Left Thorax

Due to Harrington Rods. This inflammation cleared on removal of the rods.



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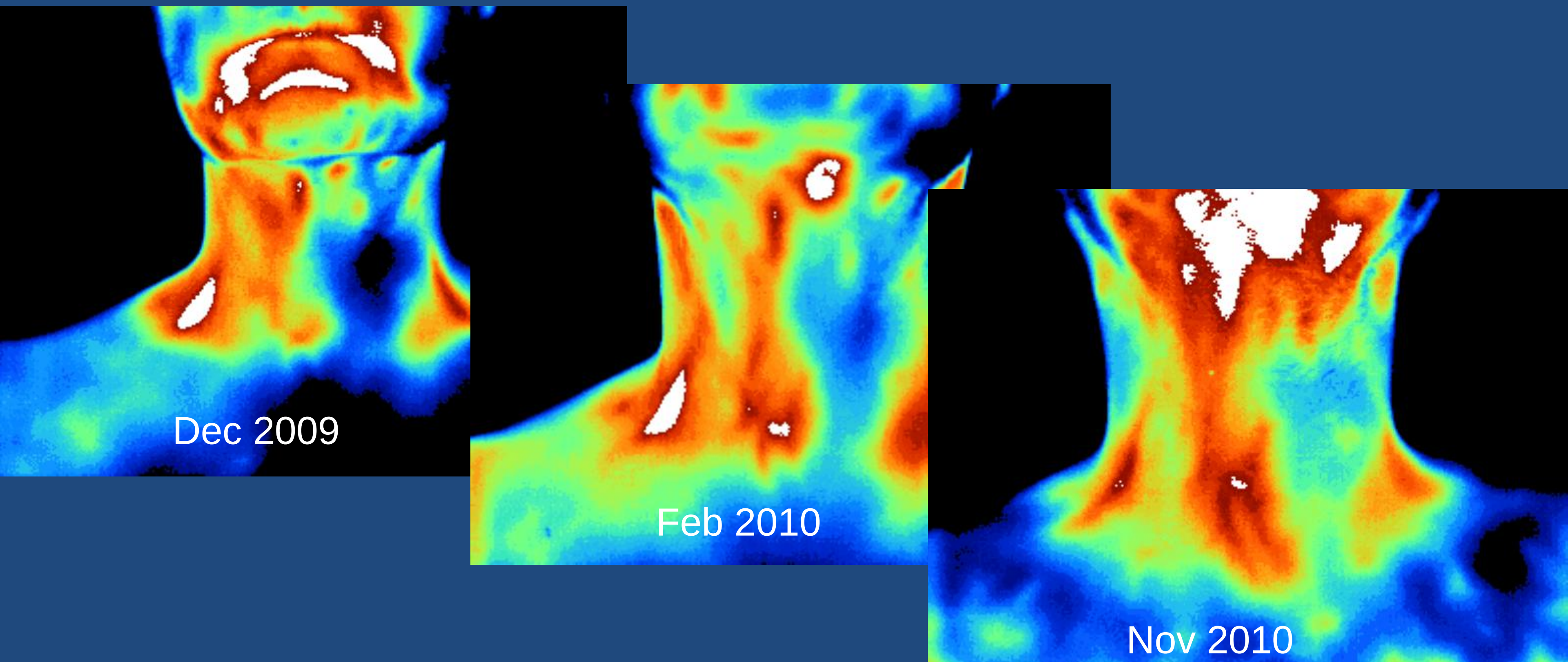
Thyroid Nodule on the Right Side of Neck

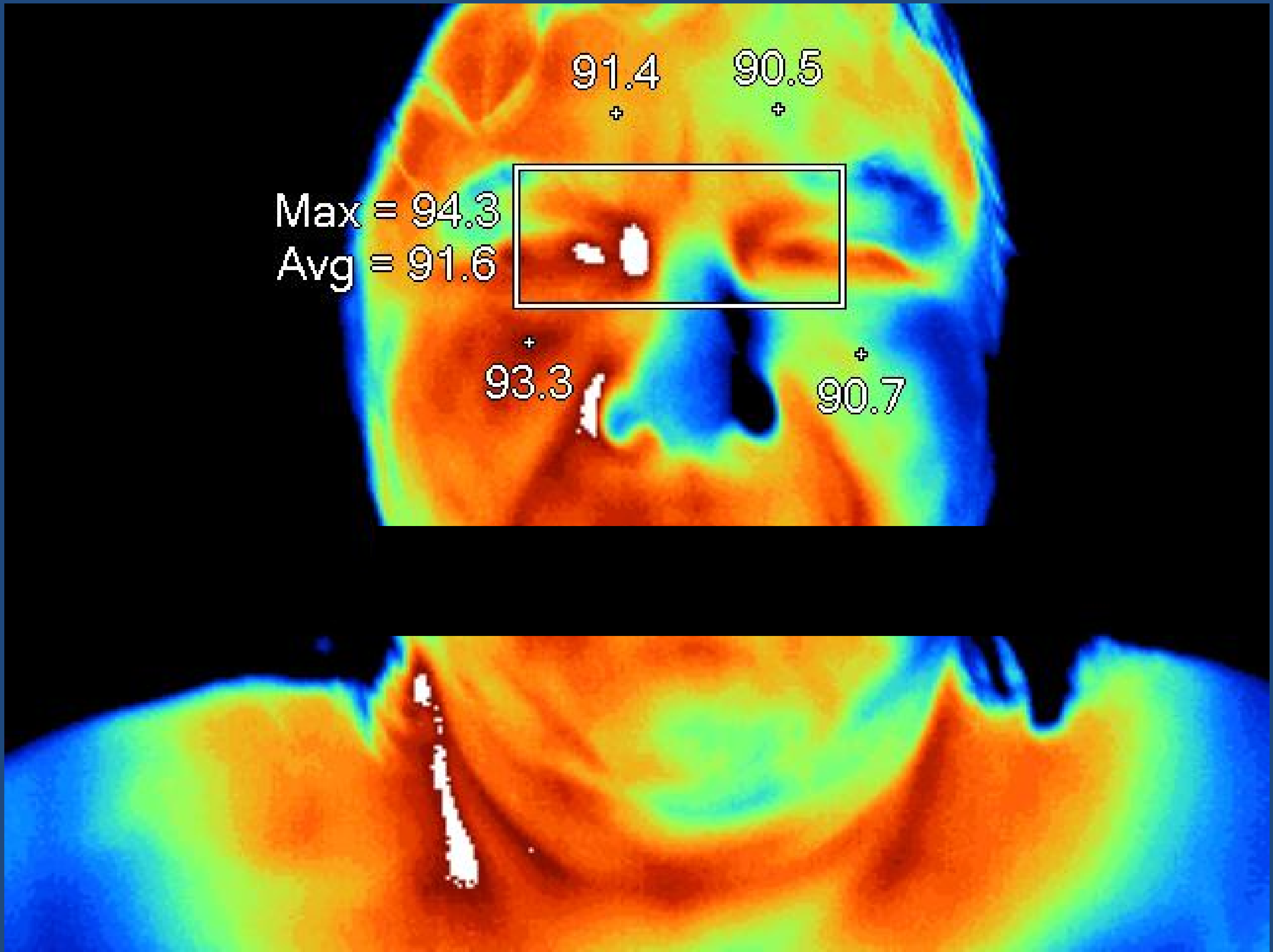


Increased local heat and vascularity are seen over time, indicating disease progression.

Sinus Infection

This person was having pain in the Right cheek.

The hot area is over the Right Maxillary Sinus.



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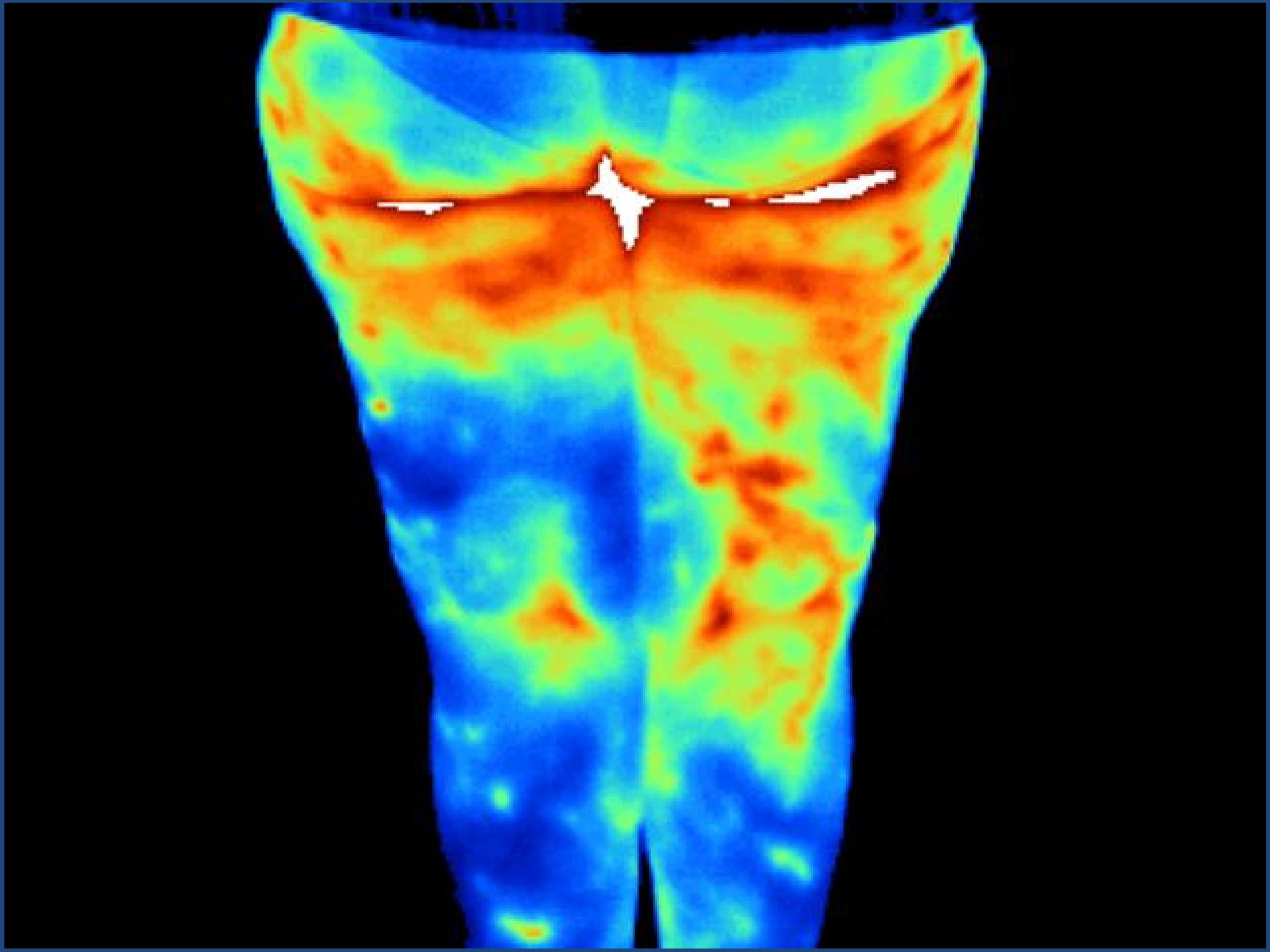
Varicose Veins of the Right Upper Leg

These veins were not inflamed or tender.



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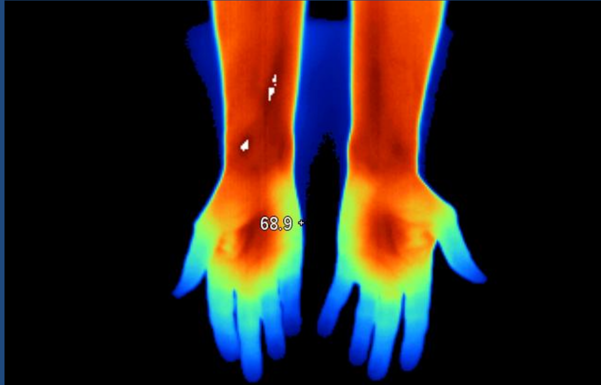
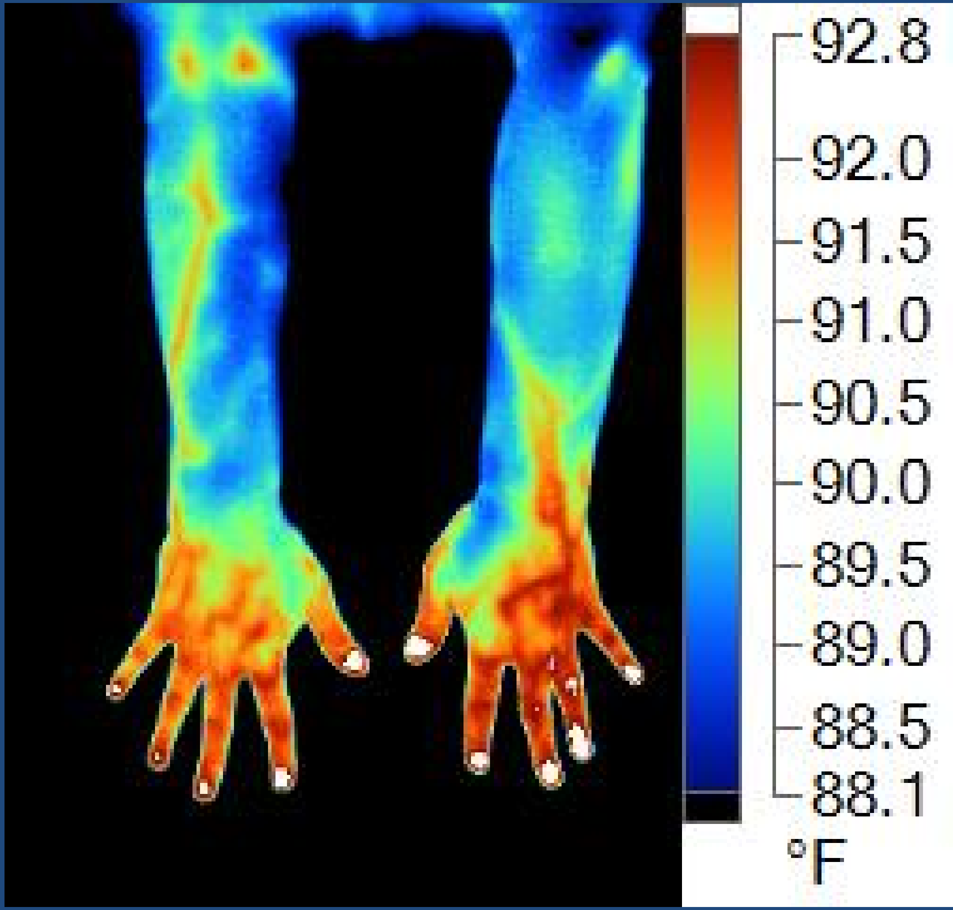
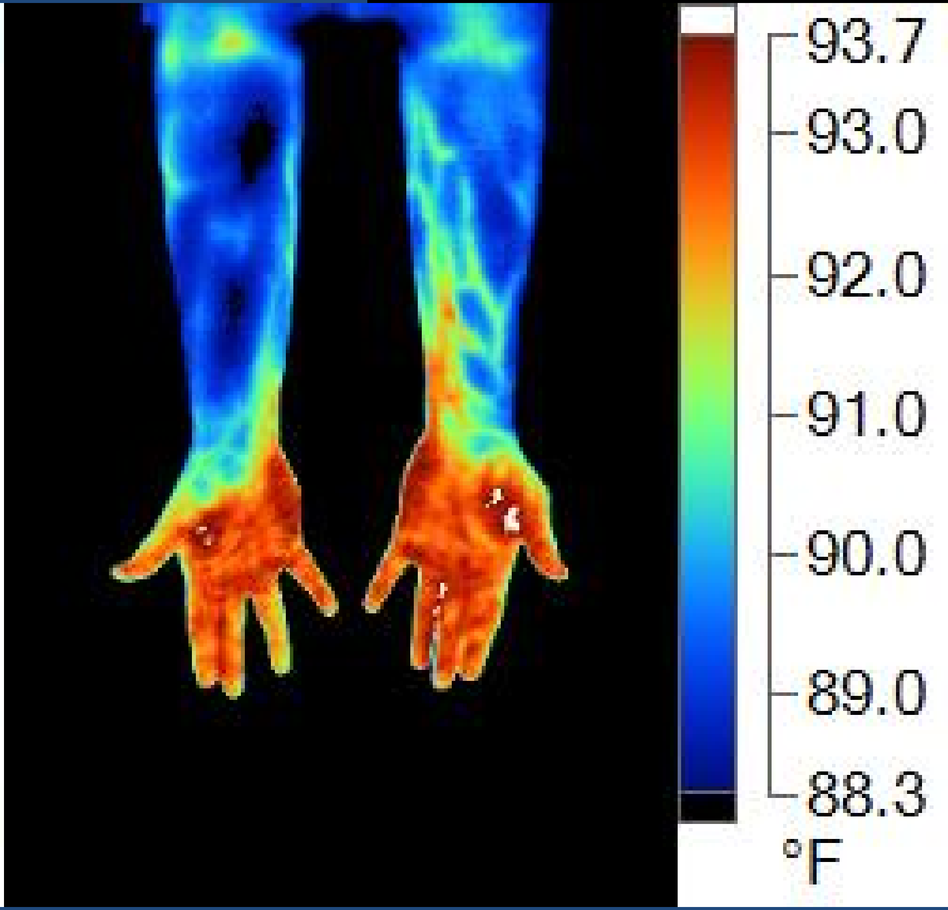
Vasculitis affecting the hands in a cooled individual

Note the “blotchy” warm palm pattern, the hot fingernails, and the warm returning veins.



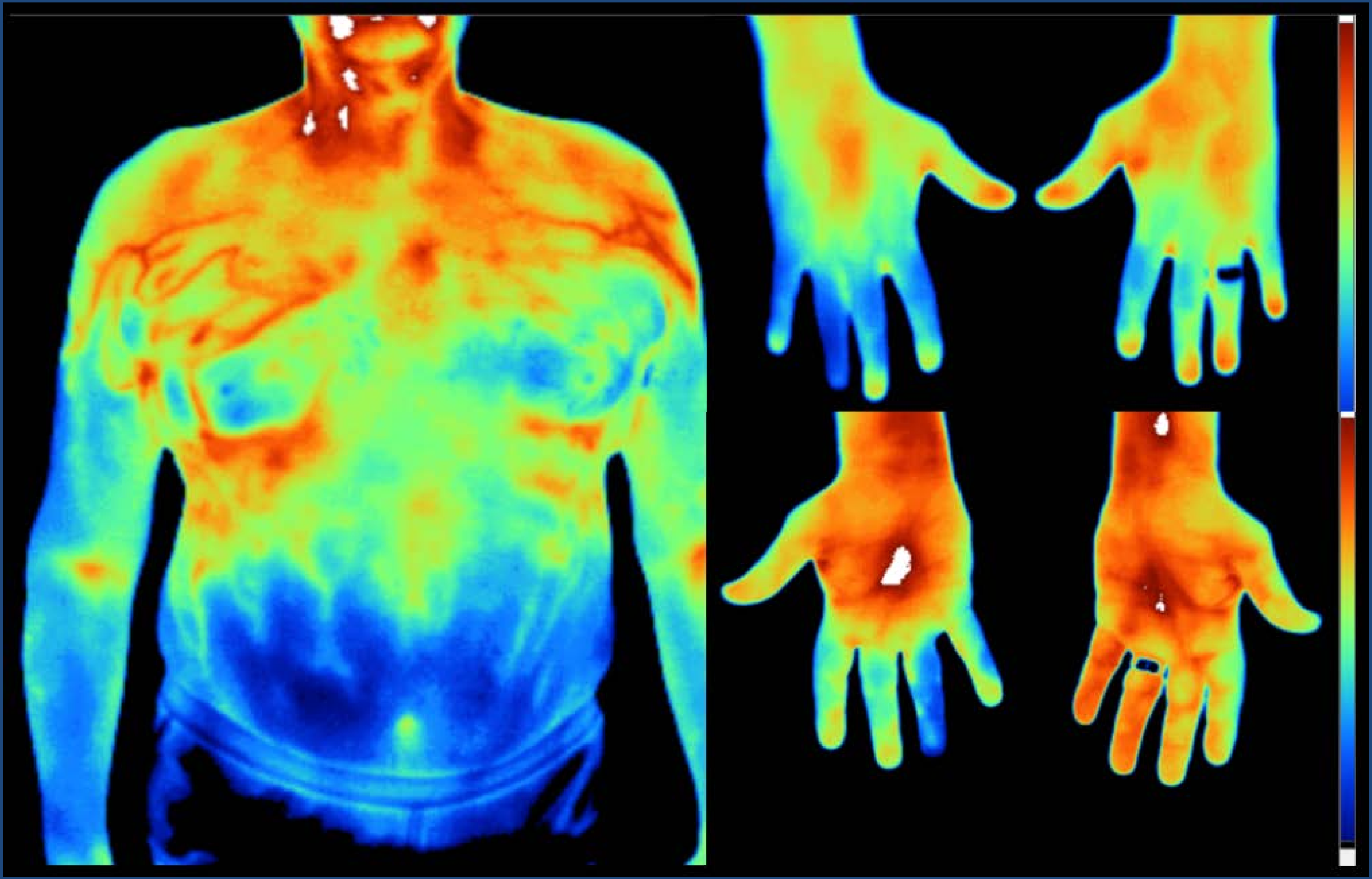
Normal Hands



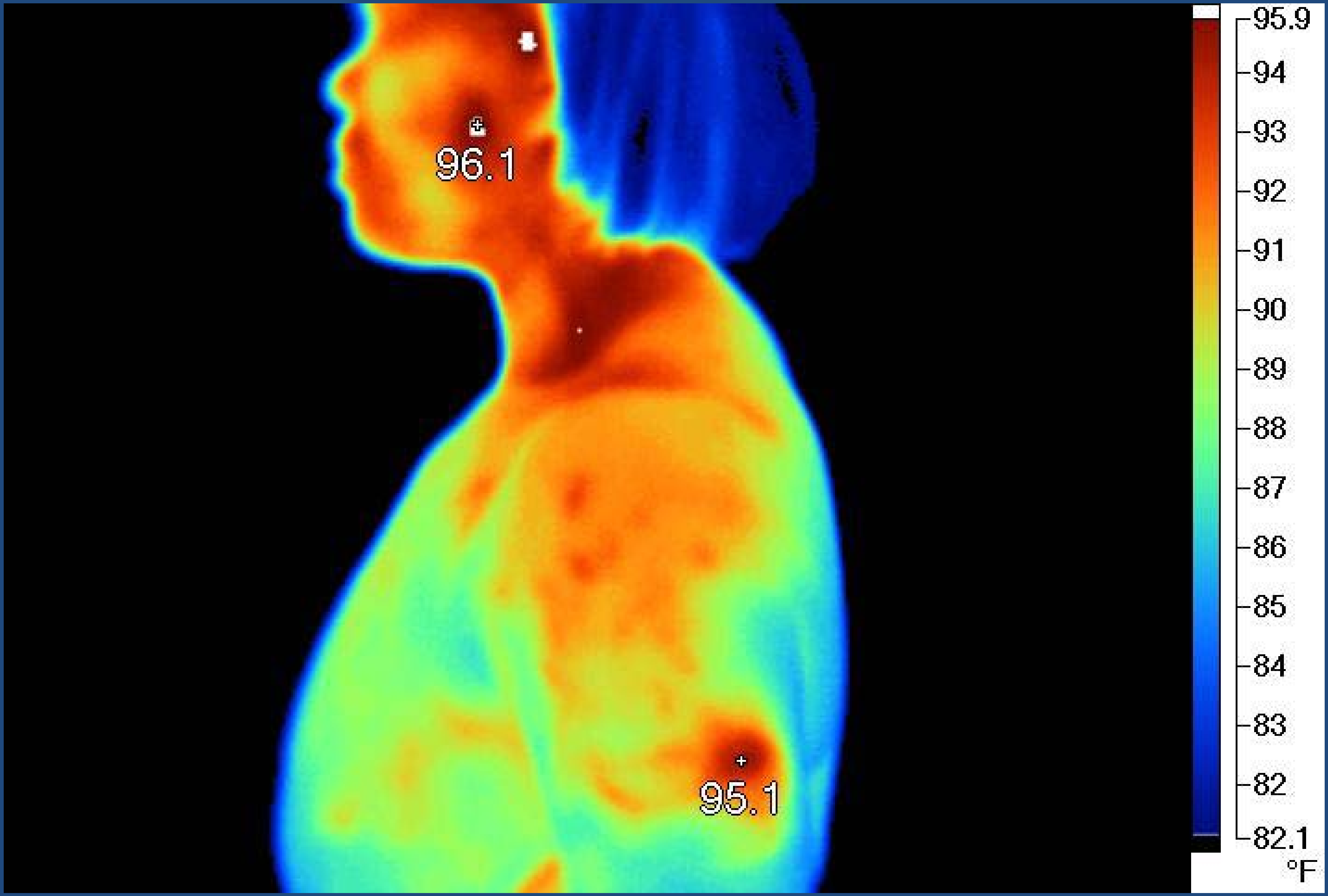


Vasculitis – Chest Wall

Thermal signs of scattered glomus body (AVA) dilation in the hands is also present.



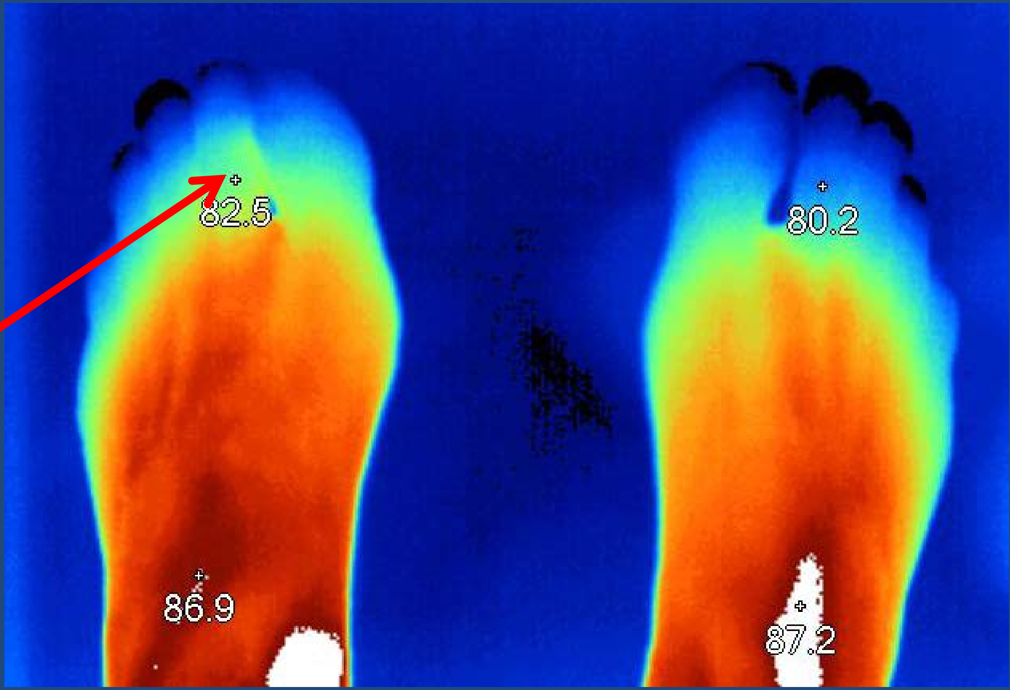
Insect Bites

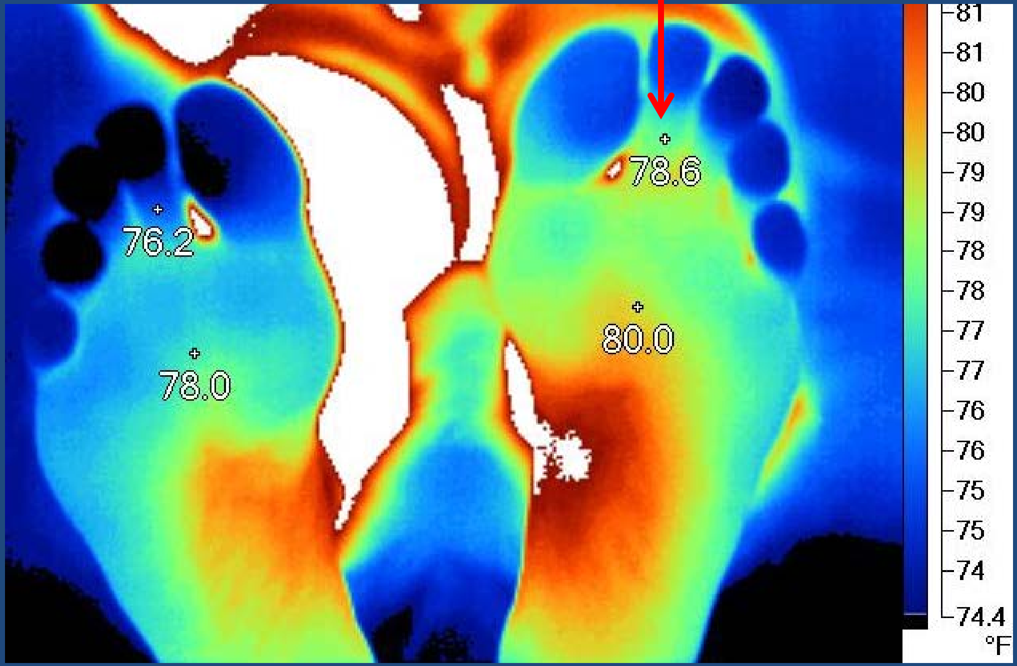


Fracture of the Second Toe
Left Foot

Image taken six weeks post injury

Fracture is at the proximal M-P joint.



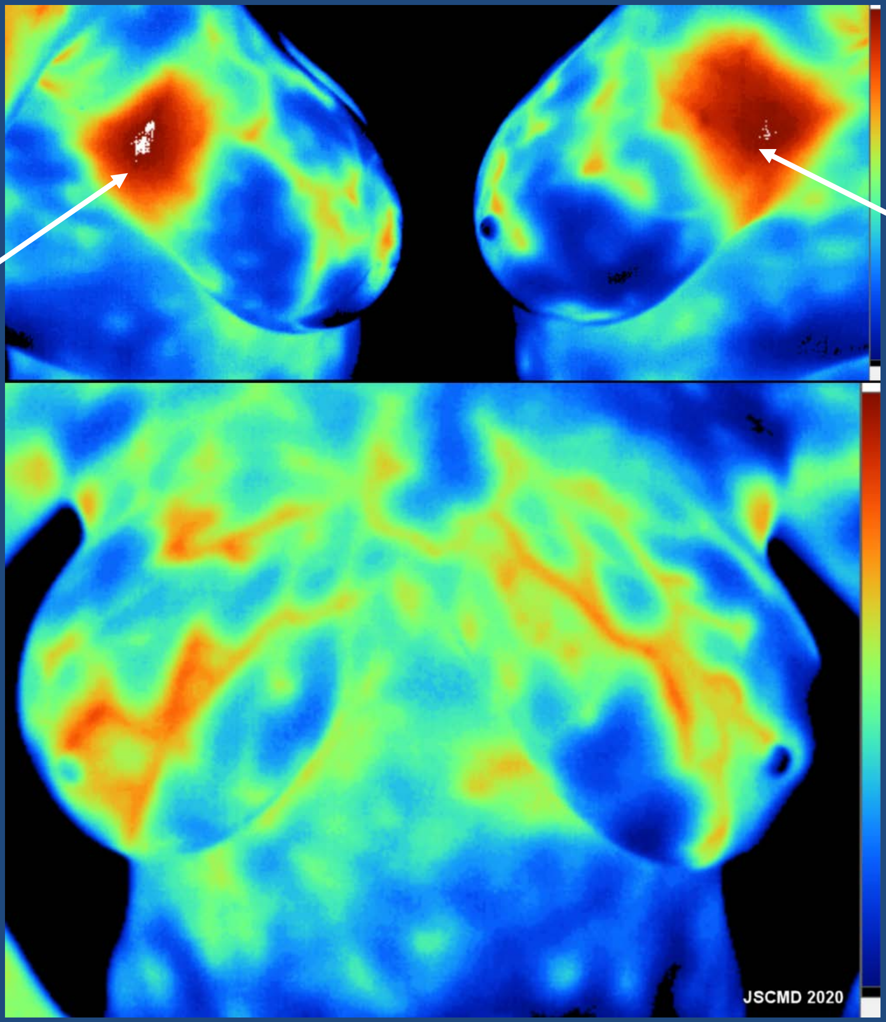


Note the diffuse inflammation involving even the arch of the foot.

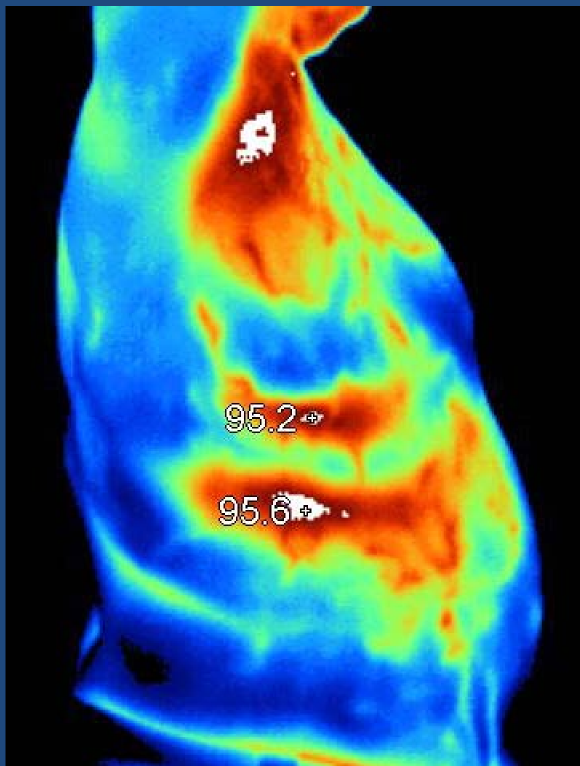
Cooper's Ligament Inflammation Seen on Breast Thermogram

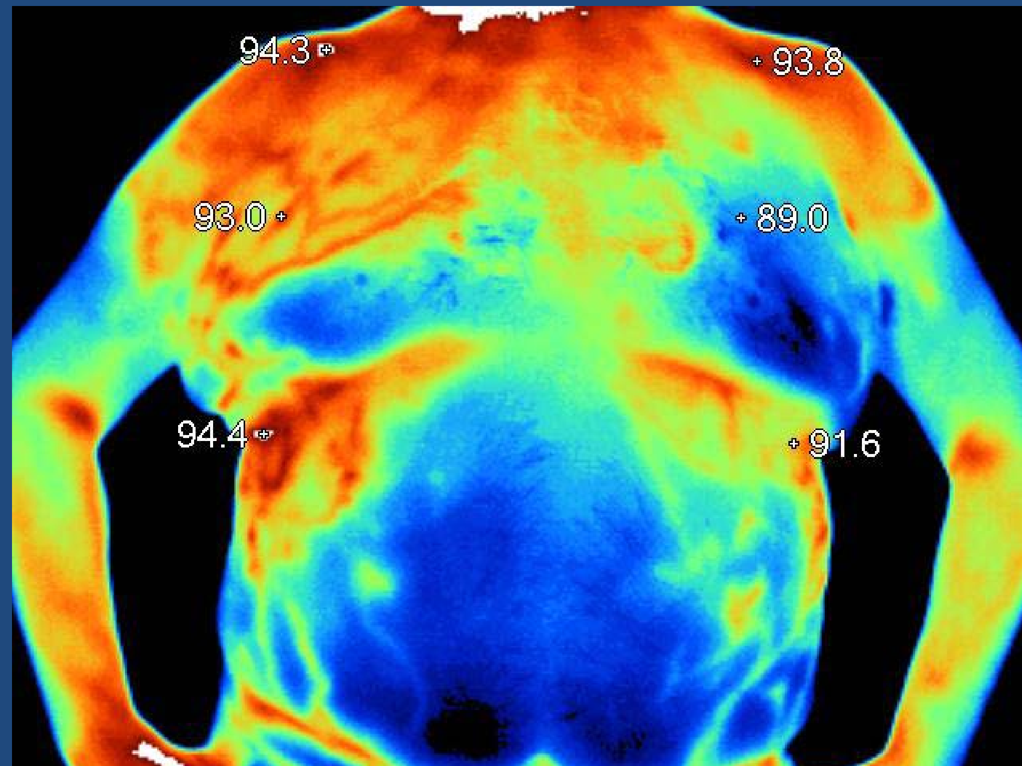
The suspensory ligaments of the breast (Cooper's Ligaments) are bilaterally inflamed from the weight of pendulous breasts.

A better bra or even breast reduction surgery may be indicated to relieve this inflammation.



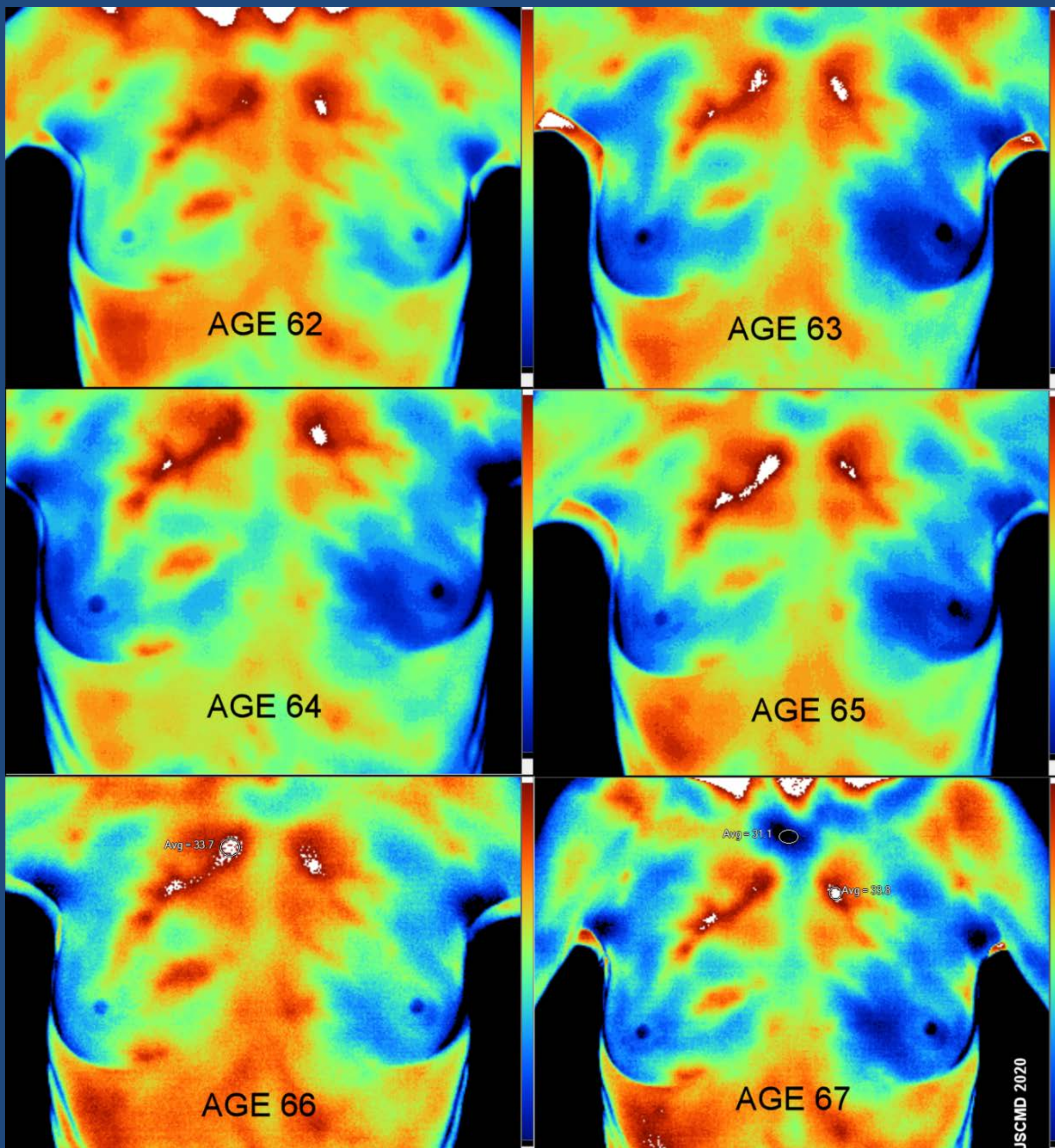
Lung Tumor in R Lower Lobe





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 vasculitis pattern is present over the upper R chest.

Chronic Radial Inflammation of the Breast (CRIB)



CRIB Patterns may be thermographically stable for many years. X-ray mammography is usually normal. Whether CRIB is a pre-malignant condition is not known.

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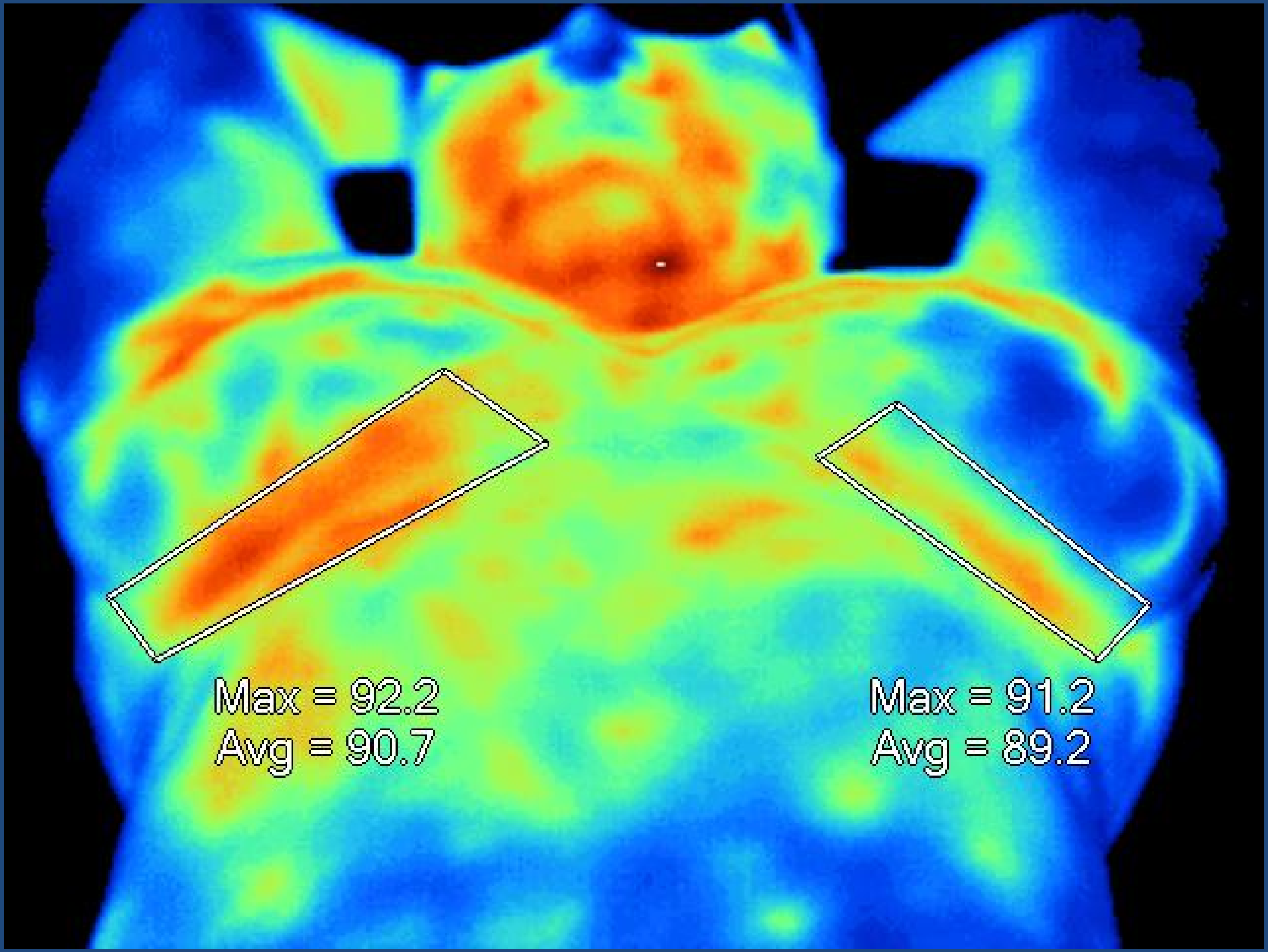
UnderWire Inflammation

Intercostal nerve inflammation due to pressure from wire bra stay.

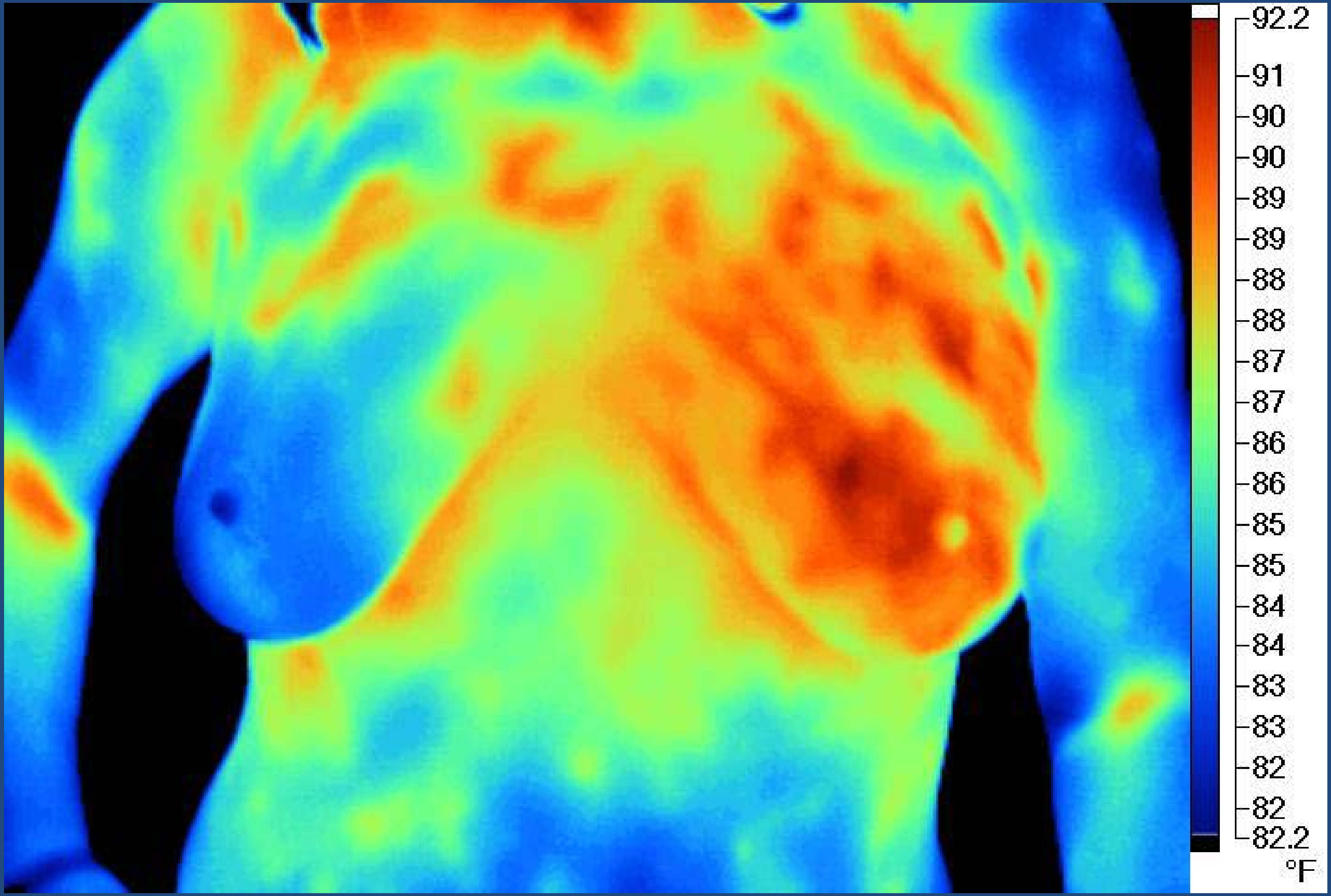
This woman was having intense pains under her Right Breast.

She wore underwire bras exclusively.



Post-Radiation Effects

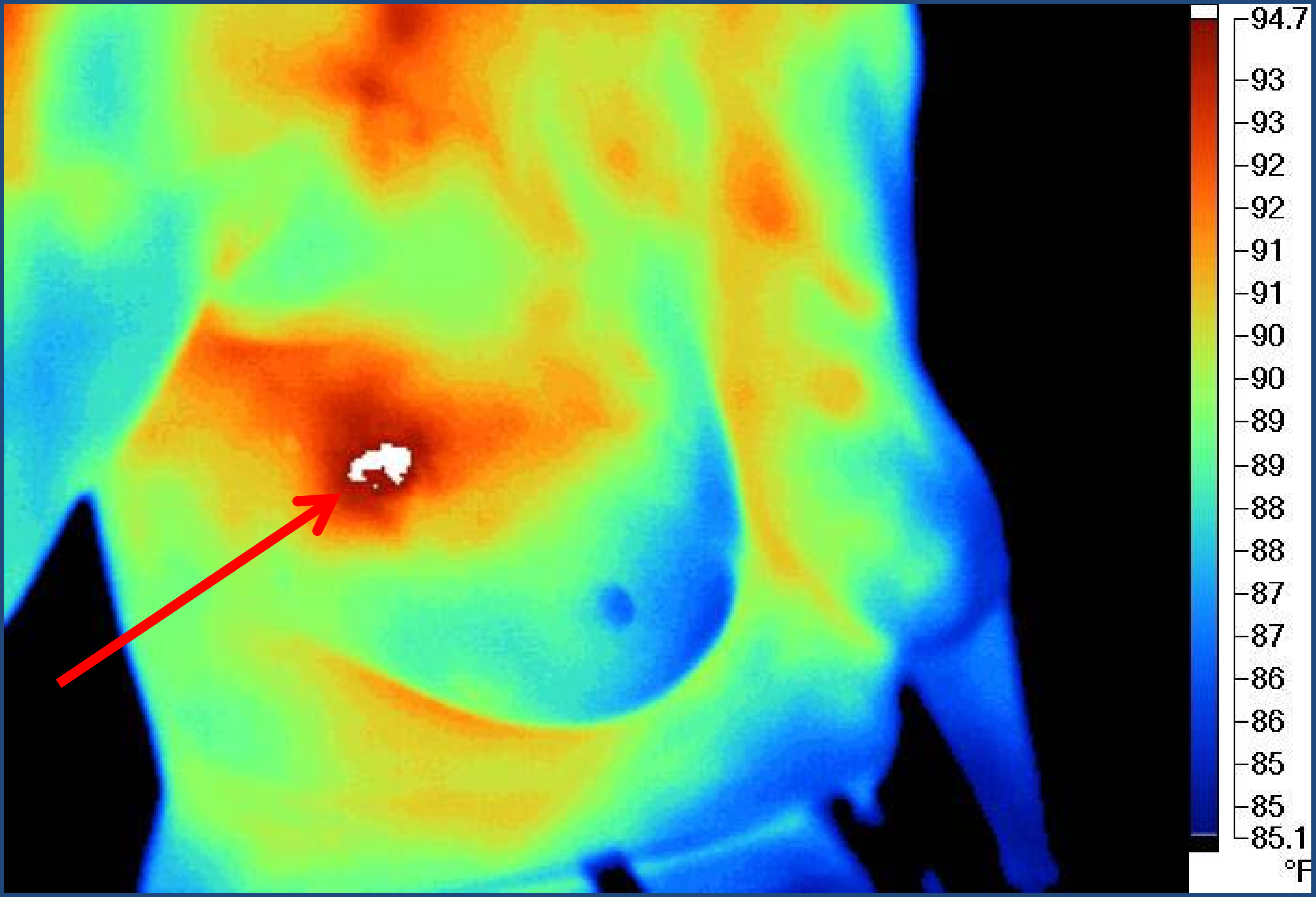
Four months after radiation therapy to Left breast.



MEDesign®

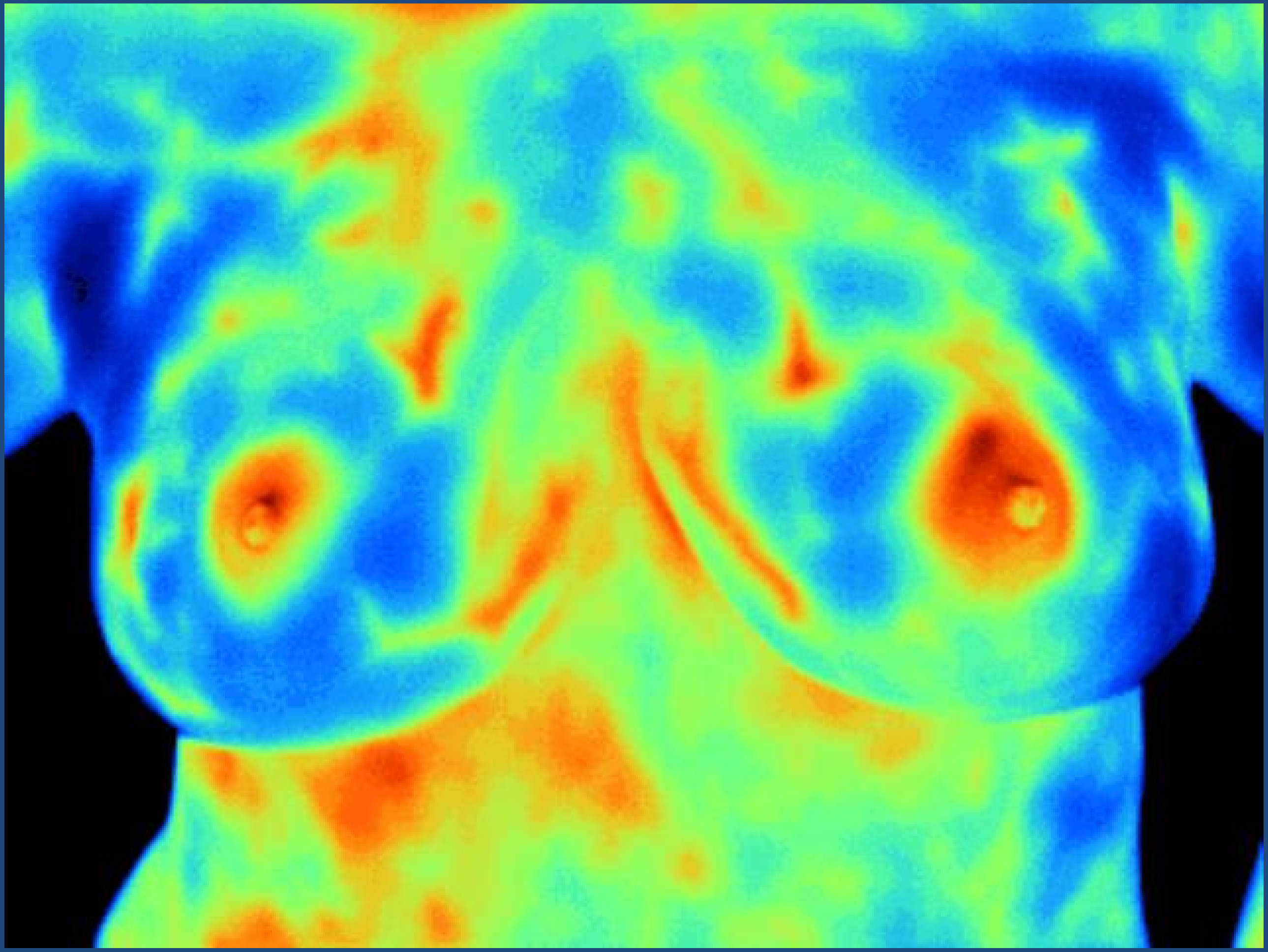
Escharotic Treatment Effect

"Black Salve" treatment may cause severe inflammation and necrosis of the skin.



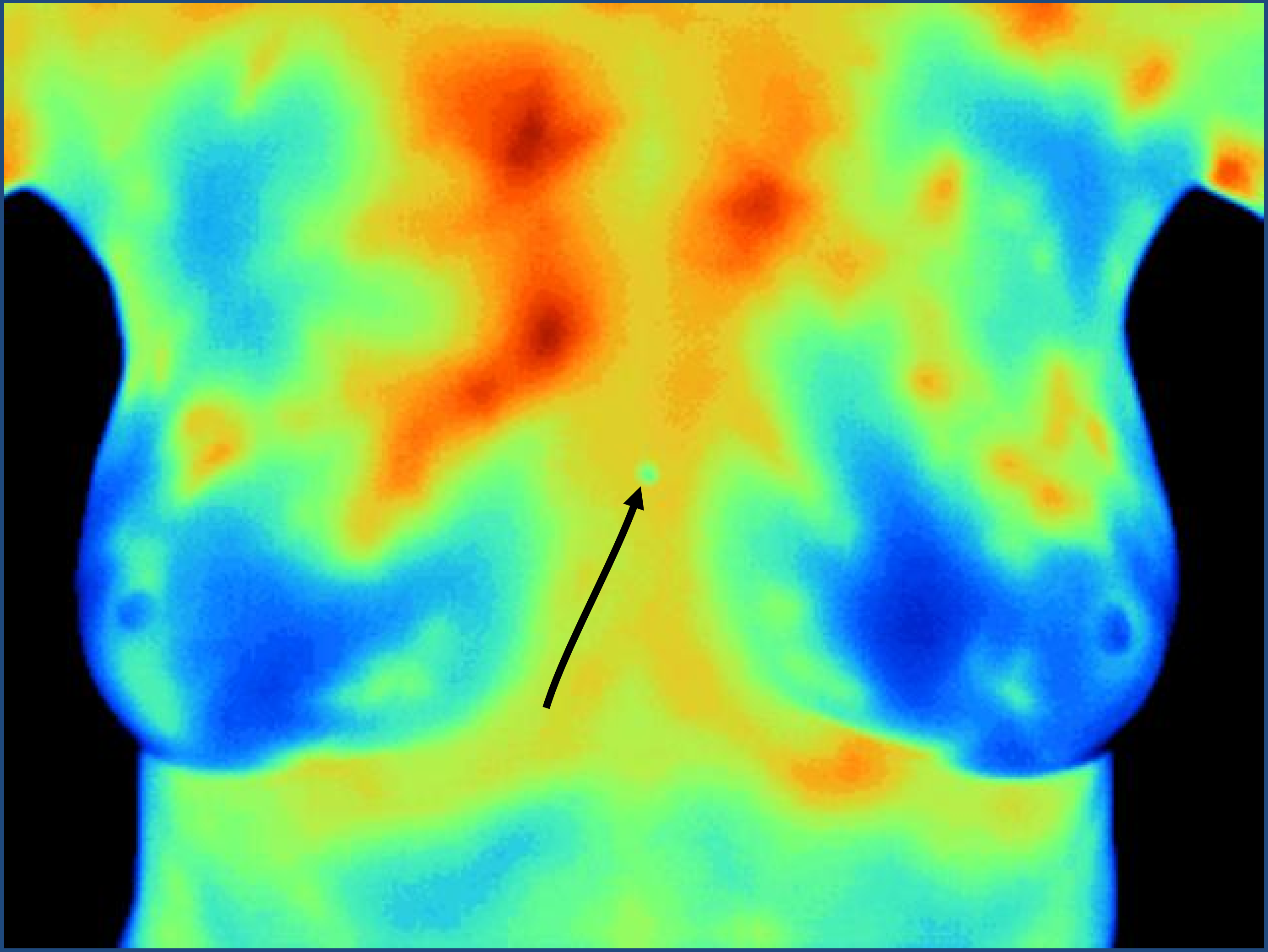
Nipples After Breast Reduction

Transplanting the nipples during reduction surgery may cut their nerves, the nipple area then cannot constrict the local arterioles when the body is cooled. If the subject has **not** had breast surgery, however, this pattern represents inflammation of Sappey's Plexus and may indicate breast malignancy.



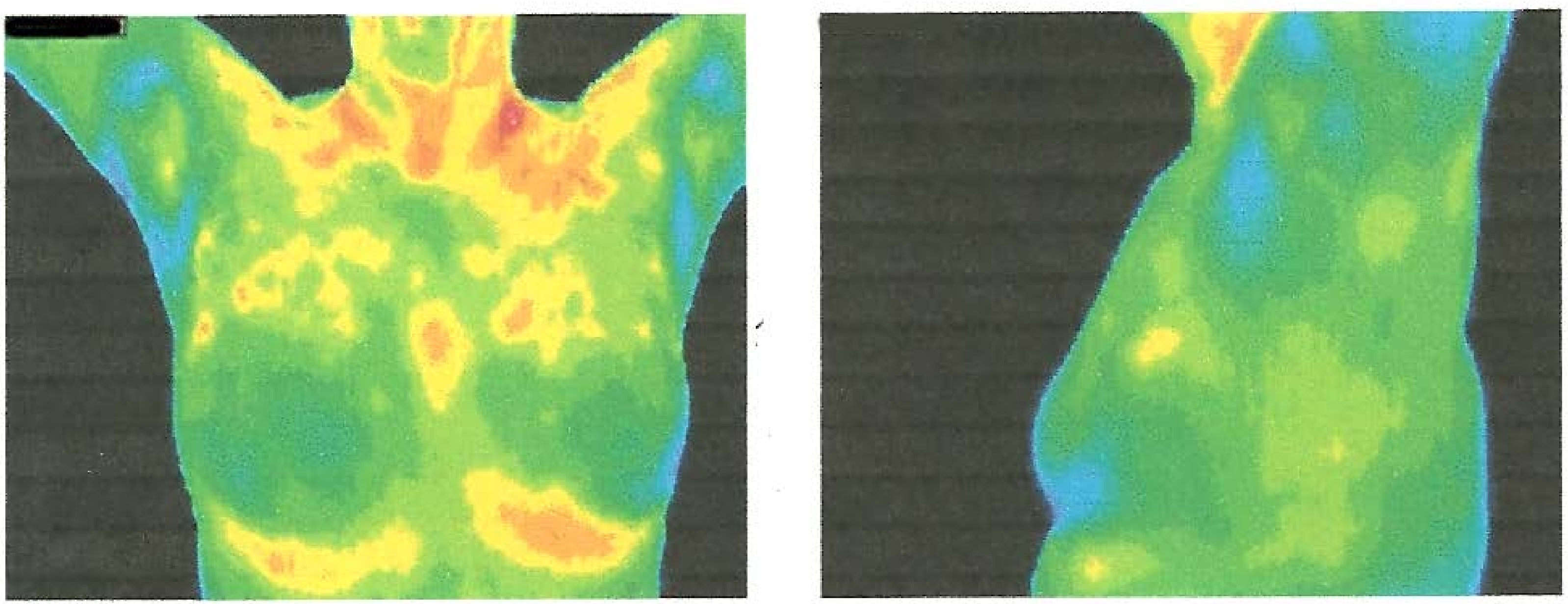
Moles May Appear Cool

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



Beware of Poor Thermography

- At present, there are few standards and training is hard to find – caveat emptor !
- If the subject is *not* cooled down before the image, it will not be diagnostic.
- If the subject wears *any* covering over the breasts during cooldown (including an exam gown or drape) the test will not be diagnostic.
- Be sure to get the actual images, either digitally or in print. These are important for later comparison. Always keep copies.

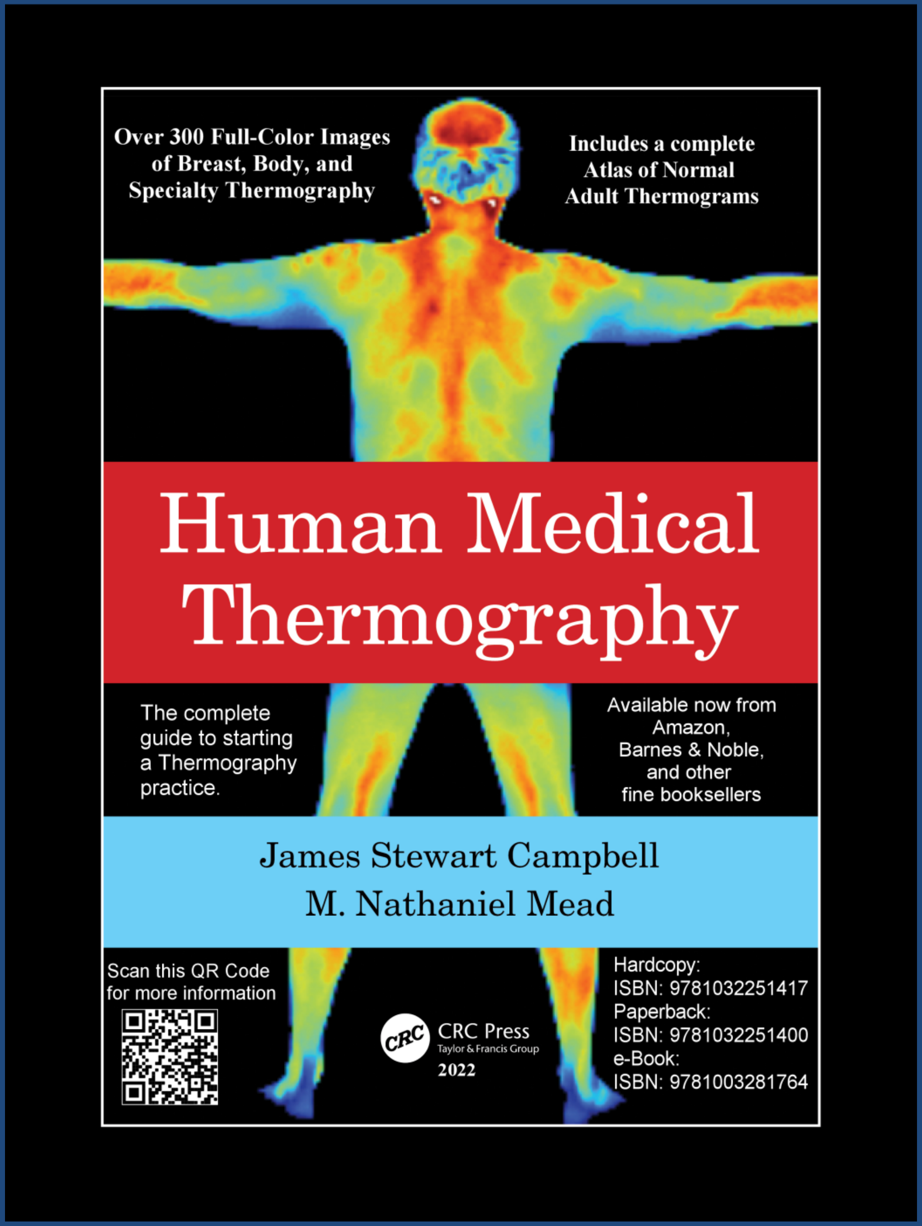


These images have poor spatial and thermal resolution.

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

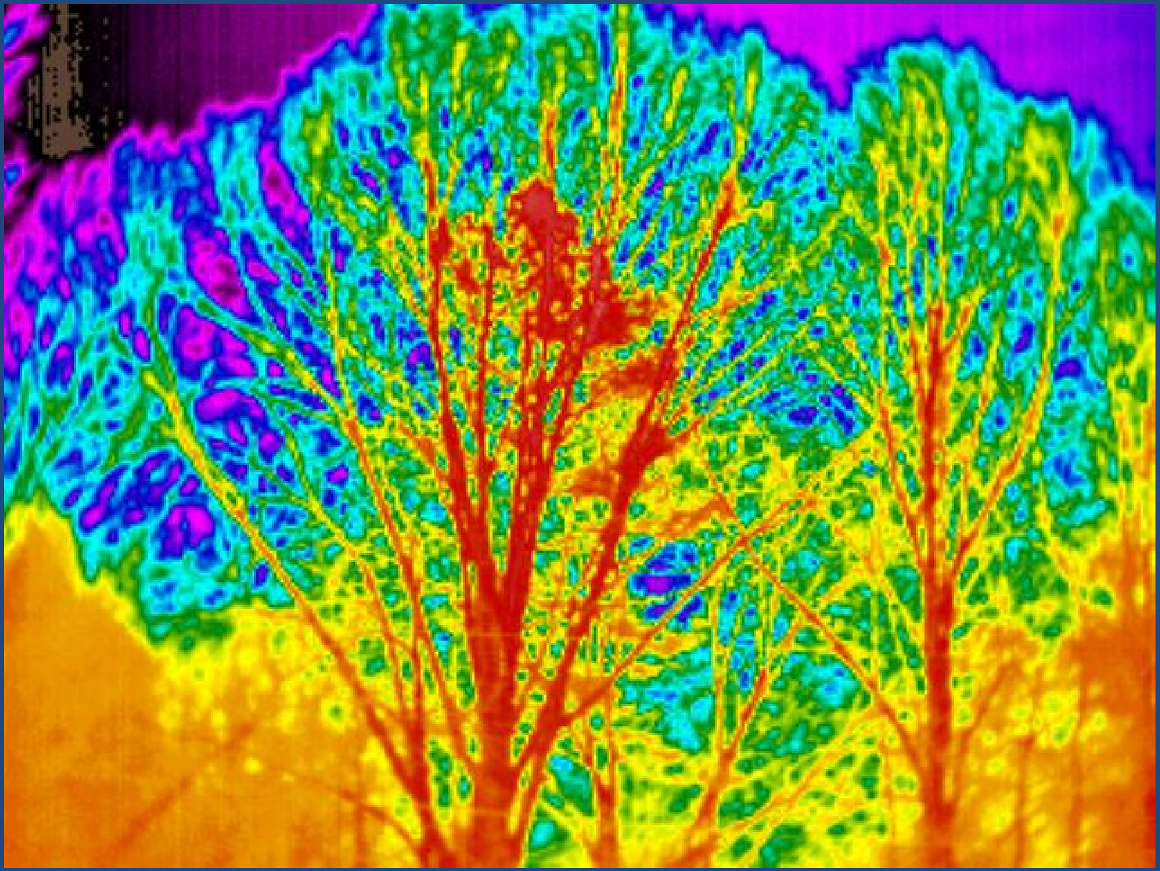
This presentation is only an introduction to the world of clinical thermography.

To learn more, please see this book – a complete guide to human medical thermography:



Human Medical Thermography

A technology update for professionals



The Secret Life of Trees (IR Thermogram) **JC,MD. '09**

James S. Campbell, EE, MD, MEDesign LLC, Pfafftown, NC.