InfraMation

Infrared Imaging of the Diabetic Foot

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ABSTRACT

Circulatory changes (angiopathy, microangiopathy, and neuropathy induced angiopathy) play an important role in the pathogenesis of the diabetic foot. They are responsible for subtle skin temperature changes, which can be detected using infrared thermography.

Thermography is used in detecting osteomyelitis that complicates the ulcerated diabetic foot, and also in determining the amputation line and the viability of the cutaneous skin flap.

The authors present the results of a study of 42 patients with diabetes, examined clinically and using thermography.

Thermography is becoming the investigation of choice in the evaluation of the diabetic foot.

INTRODUCTION

An estimated number of 16 million Americans are diabetic. Approximately 15% develop a foot ulcer and 6-8 for every 1000 will require amputation, as a consequence of the long-term complications (diabetic foot syndrome).

Some of the most important factors that are implicated in pathogenesis of the diabetic foot are represented by peripheral vascular changes, such as macroangiopathy, microangiopathy and neuropathy-induced capillary circulation changes.

These factors produce skin temperature variations which can be detected using thermography.

A LITTLE HISTORY

In one of the first studies reporting the use of thermography in the diabetic foot (1), 16 patients (12 women and 4 men), mean age 28 years, with long standing diabetes mellitus (average disease length of 13 years), underwent infrared thermography foot examinations. In the images recorded, the emission (temperature) over the toes and metatarso-phalangeal regions was distinctly decreased and gave a sharp transverse boundary. Little or no reduction of the emission (temperature) was shown over the dorsum of the foot and tibia. The patterns were symmetric with the exception of the only diabetic patient with local gangrene.

The thermographic images from this early study have remained representative for the diabetic foot examined with infra-red, even though they were recorded at 18 ºC (room temperature), which is no longer accepted as the standard for examinations of vascular pathology.

Today, more than forty years later, this 3D image of the diabetic foot (obtained with infrared and regular camera) may become the representative thermographic image of the diabetic foot for the next decades (2).

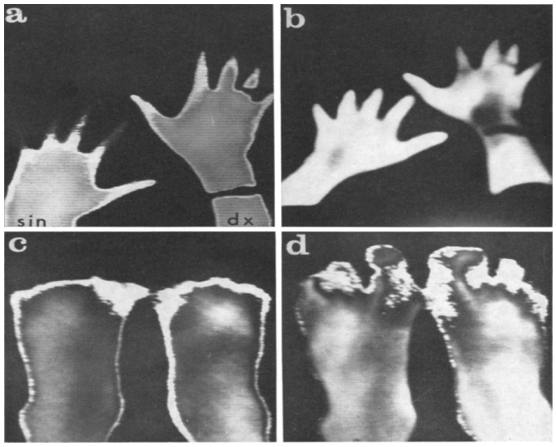

Figure 1. One of the first images of a diabetic foot seen in infrared thermography

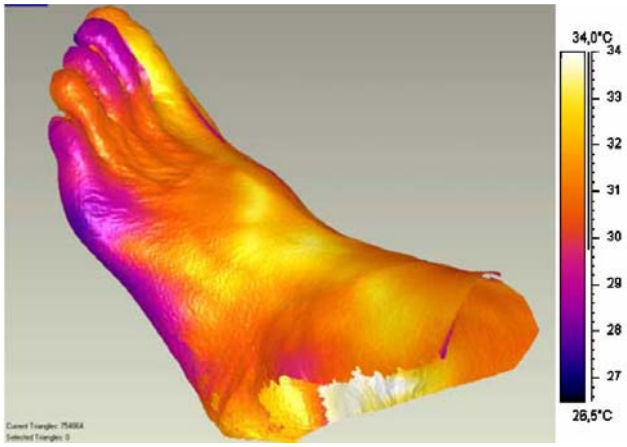

Figure 2. 3D image of the diabetic foot. Reprinted with the permission of Sara Colantonio (2).

THERMOGRAPHY IN THE DIABETIC FOOT EVALUATION

Even though controversial, most authors agree that the infrared examination of the diabetic foot can be very informative in assessing to following:

- Disturbances in the arterial circulation
- Assessment of microangiopathy and other vascular changes caused by diabetic neuropathy
- Detection of areas at high risk for ulceration or re-ulceration
- Assessment of tissue vitality, amputation level, and the intra-operative skin flap viability
- Diagnosis of osteomyelitis
- Monitoring the response to medical treatment

EXAMINATION OF THE DIABETIC FOOT

To obtain reliable and reproducible data, several recording requirements have to be met:

* room temperature: 24 ºC
* acclimatization time: 20 minutes
* leg clothing removed
* the patient should be either standing or sitting with the lower extremities hanging freely

It is very important that these requirements be followed correctly. In patients suffering from neuropathy, the skin temperature varies according to the ambient temperature. Also, the lower extremity images should be recorded from the front (front view) at a preset distance, and the feet from above (top view). A hot spot is defined as an area that is at least 0.5 warmer than the adjacent structures. The thermal gradient represents the difference between the skin temperature values recorded at the knee and at the dorsum of the foot

CHANGES IN ARTERIAL CIRCULATION

Macroangiopathic vascular changes in the foot can be assessed using the following investigations:

* eco-Doppler
* angiography

Thermography is especially useful to differentiate between the “ischemic foot” (cold) and the “neuropathic foot” (warm). Thermography has also been reported to be useful in detecting areas of critical ischemia.

- There are several considerations in the examination of the diabetic foot using thermography: The “macro-circulation” pathology localizes more often at, or below the popliteal fossa, than at the level of the aorta or iliac vessels
- The atheromatous plaques are mono-segmental, present in the tibial and peroneal arteries, and are usually absent in the more proximal or distal (pedal) arteries.
- The changes are usually asymmetric, the tibial – peroneal triangle being the most commonly affected.

Figure 3 represents the thermographic image of an «ischemic foot » in a patient with diabetes. The asymmetric appearance, classic for atherosclerotic lesions, is caused by hypothermia on the right posterior tibialis trajectory.

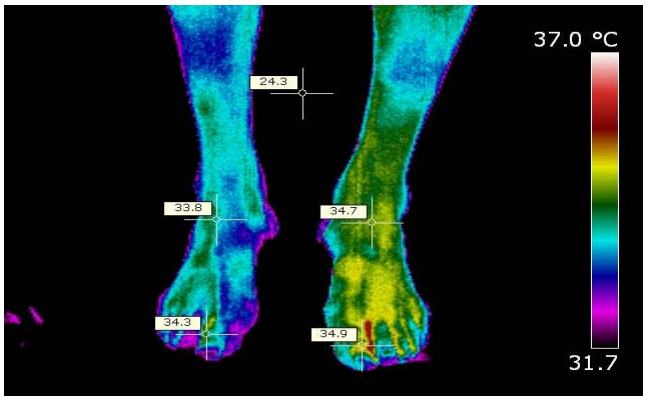

Figure 3. Asymmetric appearance of an "ischemic foot"

CRITICAL ISCHEMIA NEEDING URGENT ATTENTION

Thermography is very useful in the detection of critical ischemia involving small arterial territories, which cannot be explored otherwise.

Case 1:

A 72 year old man with a 32 year history of type two diabetes and left foot amputation presents for evaluation of recent right calf pain. On the thermographic examination (performed with a nitrogen cooled camera, manufactured in Russia), Figure 4, in addition to the typical changes commonly found in a diabetic foot, there is evidence of an intense hypothermic area situated above the right medial malleolus, with an important temperature gradient of +3.5 ºC.

The thermographic diagnosis of "possible critical ischemia of a posterior tibialis artery branch" was confirmed by angiography, which revealed "severe atheromatosis affecting the entire length of the tibial-peroneal trunk". After several plastic and vascular surgeries, the limb was salvaged from amputation (Figure 5).

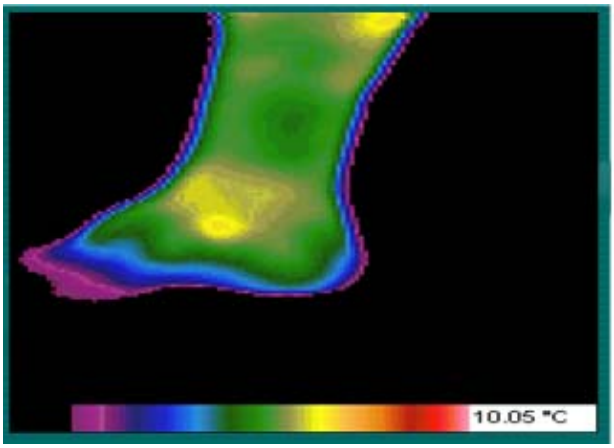

Figure 4.Critical ischemia – hypothermic area situated above the right medial malleolus

Figure 5. Diabetic foot with critical ischemia after 2 months

MICROANGIOPATHY

Changes in the cutaneous circulation induced by diabetic microangiophathy, which are responsible for ulcer formation, are difficult to explore by non-invasive methods. The characteristic thermographic image of microangiophathy is the result of the symmetric decrease in Infrared radiation in the distal regions of the feet and hands. This aspect is known as "thermographic amputation" (Figure 6).

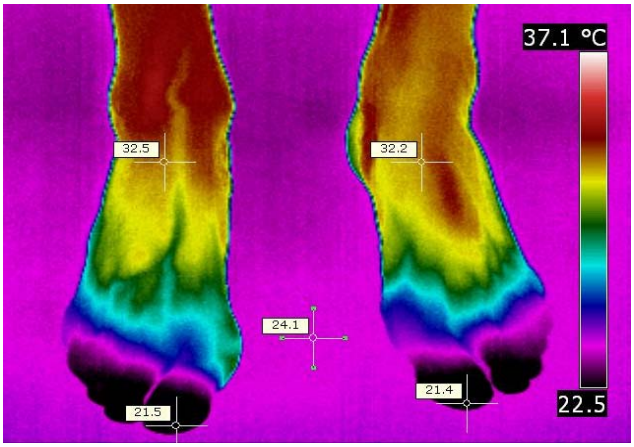

Figure 6. Microangiopathy: symmetric decrease of infrared radiation in the distal regions of the feet

NEUROPATHY

While controversy still exists, there is a consensus that the baseline skin temperature is higher in diabetic patients with neuropathy, explained by sympathetic hypofunction resulting in opening of the arteriovenous anastamoses. Thus, measuring the basal skin temperature can be useful in the neuropathy evaluation, specifically small fiber sensory neuropathy, since the small fibers rather than the large fibers are involved in skin thermoregulation.

The skin temperature of the foot is higher in patients with diabetes and neuropathy than in healthy controls. Also, it has been suggested that the diabetic patients could be screened for ulceration risk, elevated temperatures correlating with a higher risk of ulceration (Figure 7).

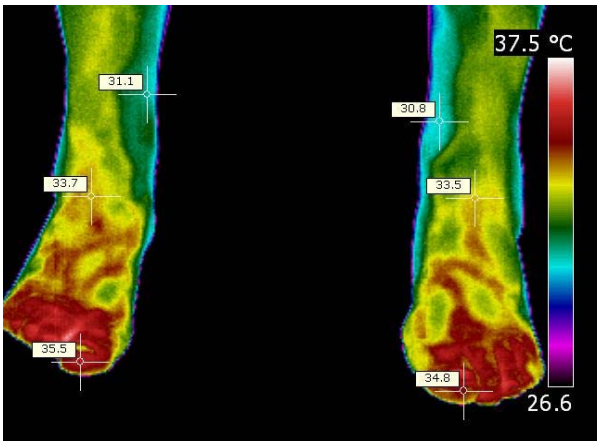

Figure 7.Hypertermia of the 1/3 distal aspect of the foot and the toes in a patient with neuropathy

In our study, 42 patients with type II diabetes were examined using microfilament and temperature testing, 19 patients being diagnosed with peripheral neuropathy. The average skin temperature was calculated using the following cutaneous temperature values: 1st and 5th toe, 1st and 5th distal metatarsal, heel and the dorsum of the foot.

The average temperature of the neuropathy patients was 32.8 ºC, compared to 27.9 ºC in diabetic patients without neuropathy.

Also, in all patients with neuropathy without other pathology, involving the feet the thermographic plantar aspect was found to be symmetric.

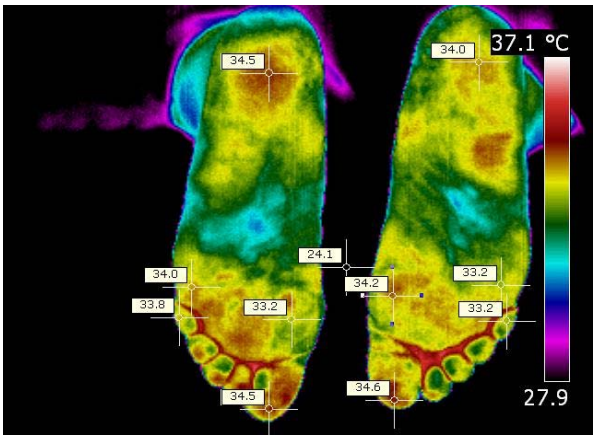

Figure 8. The fifth points of the plantar temperature determination

ULCERATION

The diabetic foot ulceration can be classified as neuropathic, neuro-ischemic, and ischemic. On average, the occurrence rate for neuropathic ulcers is 40%, compared to the ischemic ulcers, which is 10%, the differentiation between the two being important.

In our sample of 47 diabetic patients, three had ulcerations at the initial evaluation. Figure 9 presents two neuro-ischemic ulcerations localized in the cold area caused by ischemia; the hyperthermia affecting the rest of the foot is a result of the neuropathy induced circulatory changes.

The ulceration in figure 10 is probably purely neuropathic, because of predominantly neuropathic hyperthermia in the adjacent areas.

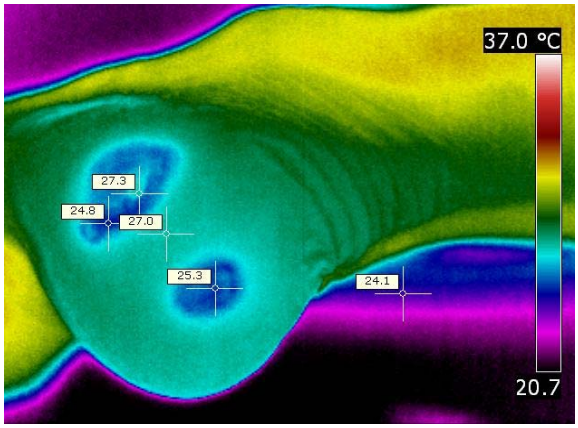

Figure9. Neuro-ischemic ulcerations.

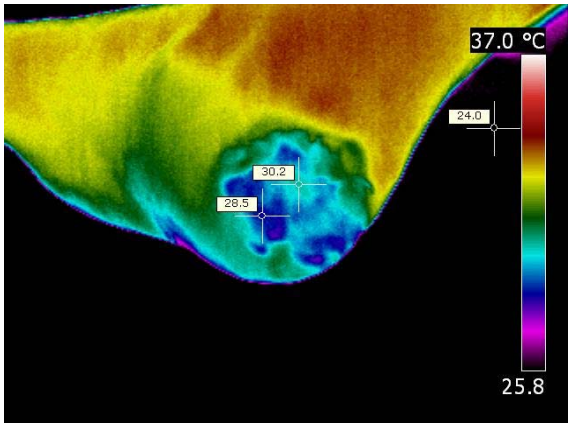

Figure10. Neuropathic ulceration.

DETECTION OF AREA AT HIGH RISK FOR ULCERATION OR RE-ULCERATION

Comparing the skin temperature with the adjacent structures (gradients higher than 0.5 ºC are considered significant) may bring valuable information, even before other clinical signs become evident.

Monitoring patients may prevent ulcerations, the presence of elevated skin temperatures predicting ulceration or re-ulceration risk (20-58% of patients will develop a subsequent ulcer within one year).

The temperature monitoring is also recommended in patients with Charcot's fractures, in the post-acute

phase, after the inflammation subsides. Thermography is also useful in detecting subtle temperature changes that may persist in the post acute phase, a premature reactivation indicating reoccurrence.

However, even though an elevated temperature ascertains and localizes the pathologic process, it may not be specific enough to elucidate its exact cause.

Case 2:

One of our patients, a 64 year old woman with a 12 year history of type 2 diabetes, had evidence of areas of intense hyperthermia (risk spots) in the left 5th distal metatarsal bones (Figure 10), which four months later progressed to an ulcer.

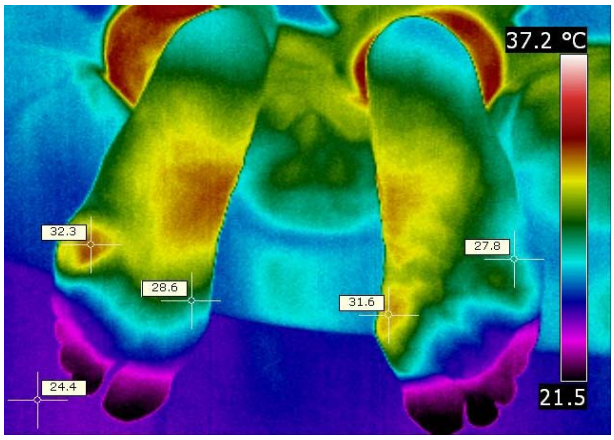

Figure11. "Risk spot" in the left fifth distal metatarsal bone

THERMOGRAPHY CAN BE VERY USEFUL IN PATIENT COUNSELING

Figure 12 shows a thermographic image of the foot of a diabetic patient presenting with paradoxical symptoms of burning feet alternating with paresthesias and feelings of "cold" feet. The thermographic diagnosis is a "neuro-ischemic foot," explained by the combination of neuropathy induced toe hyperthermia (34.5 ºC) and arteriopathy (posterior tibialis artery) induced hypothermia of the posterior aspect of the foot (30.2 ºC).

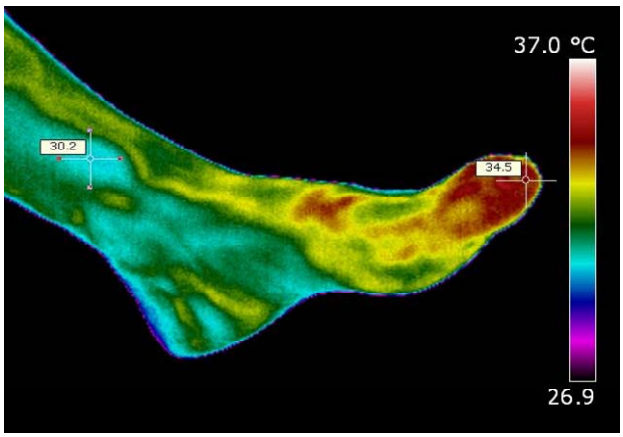

Figure12.Neuro-ischemic foot

Providing patients with such thermographic images, documenting the coexistence of neuropathy induced hyperthermia and angiopathy induced hypothermia resulting in important skin temperature variations of up to 4 ºC on very confined areas, can be very useful in patient counseling, enhancing their understanding of the disease process.

CONCLUSION

The majority of factors that generate "the diabetic foot" are based on circulation problems that induce temperature variations, and these can be evaluated by infrared thermographic examination which has the advantage of being noninvasive, fast and absolutely safe for patients and doctors. This method is useful also as a patient education tool, because they can "see" these changes on a diabetic foot; therefore they can better understand their disease and become more compliant.

REFERENCES

1) P.-I. Branemark, S.-E. Fagerberg, L. Langer and J.Save-Sonderbergh: Infrared Thermography in Diabetes Mellitus. Diabetologia 3, 529-532(1967).
2) S. Colantonio, G.Pieri, O. Salvett, M. Benvenuti, S.Barone and Carassale: A method to integrate thermographic data and 3D shapes for Diabetic Foot Disease. Proceedings of the 8th International Conference on Quantitative Infrared Thermography - QIRT'06 (ITC-CNR Padova, Italy, 28-30 June, 2006).

ACKNOWLEDGMENTS

The author would like to thank Prof. Sara Colantonio for granting permission to use the image in Figure 2.

Images 3, 6-12 were taken with FLIR ThermaCAM® B4 camera.

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