Medical Infrared Thermal Imaging

Clinical Fitness Theory & Practice

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Introduction

To be objective, actions need to be measured, and professionals who are paid for a service must be accountable. In the industry we call fitness, millions are spent on training equipment, but little interest and capital are applied toward assessment and tools of measurement. In a 1993 prospective study on cancer pain management, 63% of 1,170 physicians surveyed stated that inadequate pain assessment skills was the primary reason for sub-optimal outcomes and generally incomplete pain management in their practice settings.[1] Although the percentage may vary slightly, the same can be said about the injury rehabilitation and general fitness industries. There must be sufficient quality assessment conducted regularly to determine what is going on with an individual mentally and physically, and then make changes to a program if necessary; otherwise, concrete goals cannot be established or achieved except by random luck.

Basic tools of measurement include (trustworthy) body composition devices, EMG, force gauges, photography (for comparison photos), the use of a flexible steel measuring tape rather than a potentially stretched or contracted plastic or cloth tape, body part depth/width calipers, etc. More advanced tools include the Nerve Express technology (to track recovery and stress responses of the sympathetic and parasympathetic nervous systems), VO2max devices, and thermal imaging, the latter of which can detect problems from exercise *before* a person is even aware of a problem.

Thermal imaging has been around since WWII, although live (real-time) video thermal imaging has been in existence since only the late 1970s. Its uses are extensive, originally limited as a 'secret' in Military operations (i.e., night-vision technology), and currently in astrophysics, microbiology, and building construction inspections to distinguish where heat or cold is entering and leaving. In fact, most information and certifications in the area of infrared imaging is in the construction and electrical industries to determine both hot and cold spots, but also the location of wet or damp areas, mold and damaging pests.

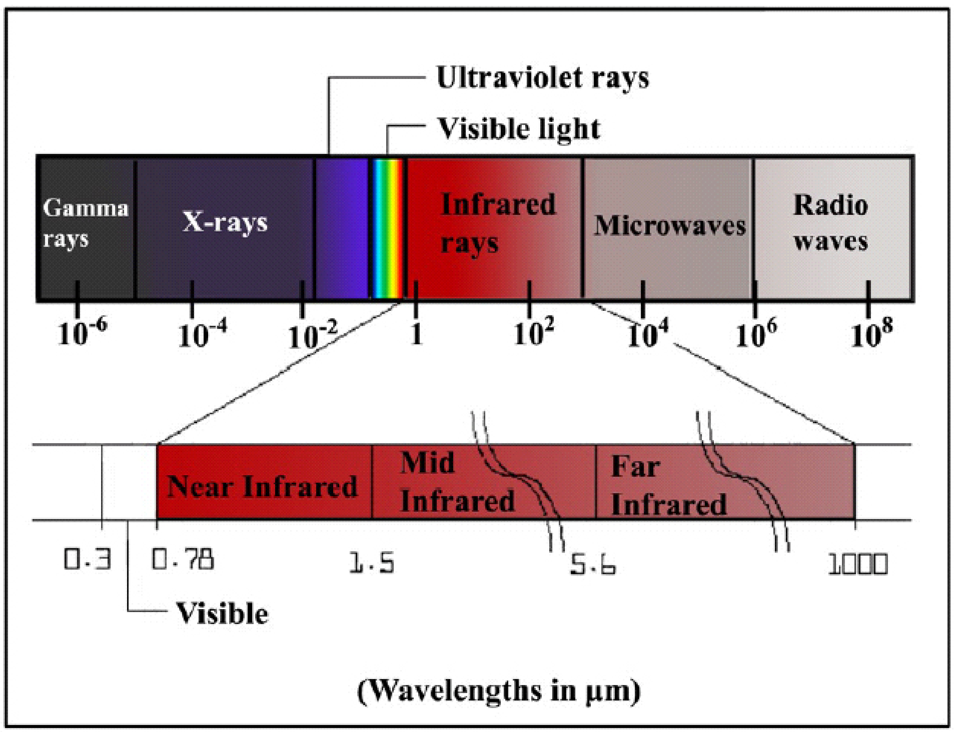
However, thermography[2] or medical thermal imaging (MII) is becoming more common in human and animal physiology research (common among competitive horse owners and credible veterinarians who deal with costly exotic animals), and as a very viable and accurate screening modality for detecting neuromusculoskeletal injury, cancer, and circulatory pathology. In a clinical setting, MII is used to detect, record, and produce images of thermal patterns that resemble the likeness of anatomic areas. Understanding its implications in the medical field eventually will open doors in the fitness industry, at least in regard to research and with higher-end fitness professionals who deal with injury rehabilitation and competitive athletes. Consequently, this paper will provide both overview and in-field examples of current work being done at the I.A.R.T. research facility.

[1] Von Roenn JH, Cleeland CS, Gonin R, et al: Physician attitudes and practice in cancer pain management: a survey from the Eastern Cooperative Oncology Group. Ann Intern Med 119:121, 1993.
[2] The detection of the heat present in body parts, such as blood vessels, muscles and tendons, or skin (Taber's Cyclopedic Medical Dictionary, 20th edition), which images produced represent surface thermal distribution of a physiological body.

Infrared Image Theory: An Overview*

All materials, which are above 0 degrees Kelvin (-273 degrees C), emit infrared energy. The infrared energy emitted from the measured object is converted into an electrical signal by the imaging sensor (microbolometer) in the camera and displayed on a monitor as a color or monochrome thermal image. The basic principle is explained as follows:

The infrared ray is a form of electromagnetic radiation, the same as radio waves, microwaves, ultraviolet rays, visible light, X-rays, and gamma rays. All these forms, which collectively make up the electromagnetic spectrum, are similar in that they emit energy in the form of electromagnetic waves traveling at the speed of light. The major difference between each 'band' in the spectrum is in their wavelength, which correlates to the amount of energy the waves carry. For example, while gamma rays have wavelengths millions of times smaller than those of visible light, radio waves have wavelengths that are billions of times longer than those of visible light.



A Spectrum of Electromagnetic Radiation

The wavelength of the infrared radiation 'band' is 0.78 to 1000µm (micrometers). This is longer than the wavelength of visible light yet shorter that radio waves. The wavelengths of infrared radiation are classified from the near infrared to the far infrared.

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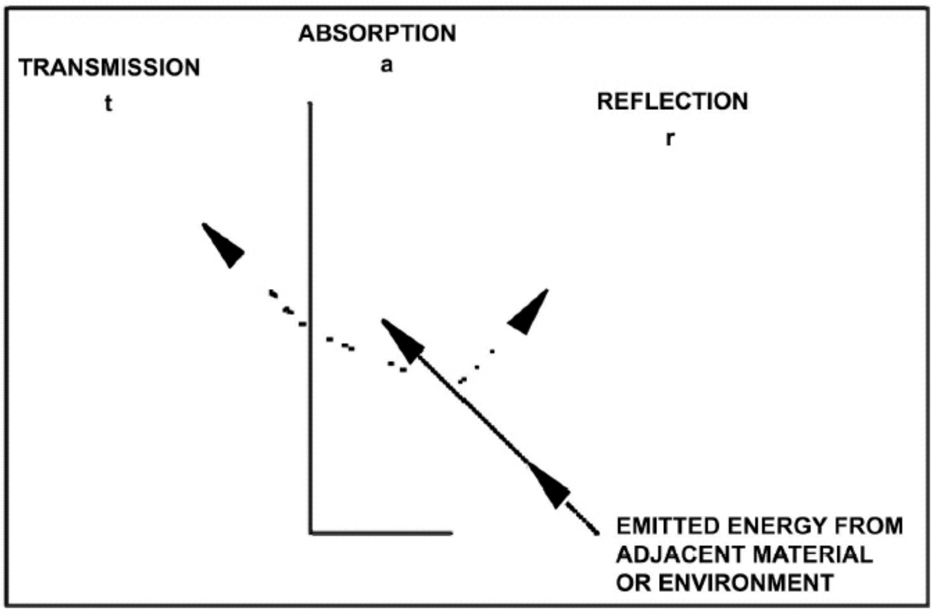
Emissivity

Infrared radiation is energy radiated by the motion of atoms and molecules on the surface of object, where the temperature of the object is more than absolute zero. The intensity of the emittance is a function of the temperature of the material. In other words, the higher the temperature, the greater the intensity of infrared energy that is emitted[3]. As well as emitting infrared energy, materials also reflect infrared, absorb infrared and, in some cases, transmit infrared. When the temperature of the material equals that of its surroundings, the amount of thermal radiation absorbed by the object equals the amount emitted by the object.



Transmission, Absorption, and Reflection of Infrared Energy

The figure above shows the three modes by which the radiant energy striking an object may be dissipated. These modes of dissipation are:

a = absorption   t = transmission   r = reflection

The fractions of the total radiant energy, which are associated with each of the above modes of dissipation, are referred to as the absorptivity (a) transmissivity (t) and the reflectivity (r) of the body. According to the theory of conservation of energy, the extent to which materials reflect, absorb and transmit IR energy is known as the emissivity of the material.

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[3] A ‘blackbody’ source (which is a theoretical state, like the concept of absolute zero) has a perfect emissivity of 1.0, whereas the human body has an average emissivity of .98, a highly reflective state that makes thermal imaging ideal in human study.

Clinical Practice for Fitness Professionals

Use of Medical Infrared Imaging: General Implications

Medical Infrared Imaging (MII) is highly accurate, completely safe (with no radiation or contact), and which produce visual maps of skin surface temperature. As a result, MII is an effective modality to assess body function, thus signifying developing disease states during examination, from something as simple as tendonitis to more evolved diseases such as cancer. In fact, if a disease is present and in process, MII can detect it before symptoms become apparent, enabling early intervention and proactive treatment – a significant factor for athletes and fitness enthusiasts pushing the envelope, and as a breast-screening device for women[4], with early breast cancer detection even with a negative mammogram[5] (as well as to monitor testicular changes in men). Moreover, infrared imaging can expose injuries although X-ray and MRI show no structural damage.[6]

Besides detecting abnormalities in the body, MII can be used to identify pain sources (particularly those involving the circulatory and neuromuscular systems), for pain mapping[7], and to monitor treatment effectiveness. For instance, if a person shows an inflamed area because of injury, and anti-inflammatories are prescribed, MII images can be produced at regular intervals, say every 12-24 hours, and there should be evidence of a corresponding decrease in heat and blood flow to the inflamed area, thus indicating an active healing process. And because of its sensitivity, using MII in this respect is a valuable adjunct to anyone working with the injured or with athletes.

For hundreds of years, physicians have observed the signs of inflammation, being pain, swelling, redness, heat, and loss of function. When a joint is acutely inflamed, an increase in heat can be identified by touch; but subtle changes in temperature undetectable by touch do occur and this can have a direct bearing on the degree of inflammation and whether there is improvement. That is where MII comes in.

In brief, MII identifies pathological conditions (viz., the image is a function of one's metabolism) affecting blood flow at the body surface. Although MII reads surface temperature, bear in mind that 0.1 mm skin thickness does not involve temperature changes; rather, any modulations in skin temperature is the result of subcutaneous tissues, including blood vessels, conducted to the skin's surface and as a result of cardiogenic pulses and neurological modulation of the vascular tone (i.e., vasodilatation and vasoconstriction).

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[4] The FDA approved the technology for adjunctive breast cancer screening in 1982, and it has been recognized as a viable diagnostic tool since 1987 by the AMA council on Scientific Affairs, the ACA Council on Diagnostic Imaging and the Congress of Neuro-Surgeons since 1988, and the American Academy of Physical Medicine and Rehabilitation since 1990.

[5] Gamagami, P., Indirect signs of breast cancer: Angiogenesis study. In *Atlas of Mammagraphy.* Blackwell Science, Cambridge, MA, pp. 231-36, 1996.

[6] Pascoe, David D., Mercer, James B., and de Weerd, Lois. Physiology of Thermal Signals. *Medical Infrared Imaging,* CRC Press: 2006. p. 6-15.

[7] It is extremely effective in diagnosing most types of back, neck, and limb pain, especially latent (lying hidden) or intractable (incurable or resistant to therapy) types of pain syndromes.

The principle is that there will be chemical and blood vessel activity in injuries, including cancers; thus, affected tissue is almost always higher in temperature than in non-affected tissue, and the worse the condition (injury, disease, or intensity of exercise), the hotter the area. However, problem areas also can be the result of decreased blood flow, thus producing 'cold spots' in MII. To explain, chronic or long lasting injuries often result in scar tissue that cause reduced muscle contraction and, therefore, reduced heat production. Reduced heat also occurs adjacent to peripheral joints with reduced range of motion due to inflammation or pain.

Pre-cancerous and cancerous masses are highly metabolic tissues and need an abundant supply of nutrients to maintain growth, which factor increases circulation to the affected cells by secreting chemicals to keep existing blood vessels open, recruit dormant vessels, and create new ones (neoangiogenesis). With typical weight training injuries, a similar process occurs in order to heal an area that was under strain. Either process, from something as complex as cancer to simple weight training injuries, results in increases of regional surface temperatures, and they become visibly obvious when viewed with MII during exercise and as blood engorge an area.

The heat lost through the body comes in different forms, including evaporation (25%), conduction to objects (3%), conduction to air (12%), and radiation (heat waves; 60%). It is heat loss from radiation that represents the thermal emission patterns recognized thermographically; thus, MII becomes a qualitative assessment of the vasculature and blood flow to tissues. Capillary blood flow determines thermal emission patterns seen in MII, which is regulated by the autonomic (sympathetic) nervous system.[8] For instance, interruption of a nerve supply, as a result of a lesion, decreases sympathetic tone to the capillary beds and vasodilatation occurs; if not corrected, there is a pathologic persistence of an autonomic defense mechanism, e.g., swelling and inflammation.

If studying the effects of exercise, be aware that muscle work produces the greatest source for metabolic heat. Hence, physical activity (muscle contraction) contributes significantly to temperature distribution of a person's body surface. Likewise, often muscle spasms or 'trigger points' become visible with MII since those intense contractions produce and exhibit greater heat production that relaxed tissues.

Knowing when to detect a problem is of significance. The 'grey zone' exists when a failure first manifests itself and when it first is detectable clinically. The goal, then, is to determine if heat is present when it is not apparent. In other words, a person may feel fine and not notice any problems or heat in the area, and yet MII can pick it up as a red flag (in fact, tendons and joints will show inflammatory changes up to two weeks before a person feels any tenderness or problem). If discovering areas of heat, a clinician would determine if said areas of palpable soreness are associated with any heat or inflammation detected. If not, the area(s) should be monitored daily with photographic images compared regularly.

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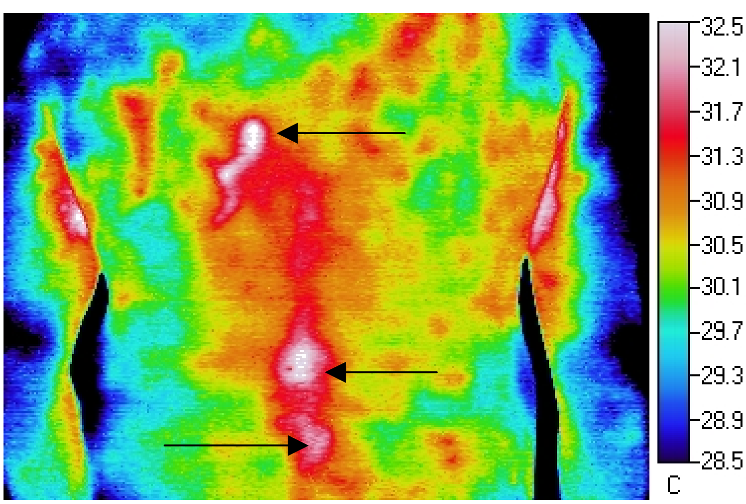
[8] Sympathetic effects are general rather than specific and prepare the body to cope with stressful situations (e.g., fight or flight responses); some effects of sympathetic stimulation are increased heart rate and vasodilatation in skeletal muscles, both of which increase heat production and particularly in areas affected by the stress response. Skin blood flow relies on both sympathetic vasoconstrictor and vasodilator controls to modulate internal heat temperature transfers to the skin.

A key to making use of MII is the interpretation of what is being seen. As Dr. Kent Allen stated, *"in diagnostic imaging, if you know normal and artifact everything else is pathology."* Therefore, it is important to realize that lateral aspects are cooler than medial aspects due to increased vasculature medially. As well, the face of joints will appear cooler than the surrounding tissue, normal tendons should appear cooler than the surrounding tissue and free of breaks in their thermal pattern, and a normal person will have symmetrical thermal patterns (which mean the clinician must make comparisons between both sides of the body). Obviously it is necessary to learn normal vascular patterns and to know the nervous system so that normal heat distribution is identified. As well, once images are taken of a person, that person becomes his or her own control, viz., clinicians compare that person only to him or her self, although relative to what is considered normal across the board.

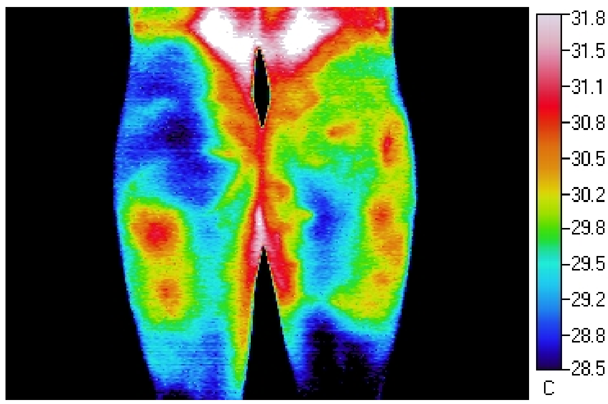
Rehabilitation and Injury Prevention Use of Thermal Imaging

Rehabilitation and injury prevention are correlated. In one instance the goal is to increase physiological function in order to re-establish a state toward normalcy (or beyond, if possible), whereas injury prevention strives to avoid tissue damage while increasing physiological function. In either instance, the objective is to alter tissue architecture in a positive way. A fitness enthusiast who strength trains is an obvious example, whereby s/he attempts to improve muscle strength and size but while pushing the envelope – and there will be an increase risk of tissue damage every time limits are reached or exceeded from past experiences. And if tissue damage does occur, then that person must strive to prevent further damage of the same area or elsewhere, while correcting the impairment that did occur. Given enough time, most trainees will experience this predicament at some point, with tendonitis being a most common affliction.

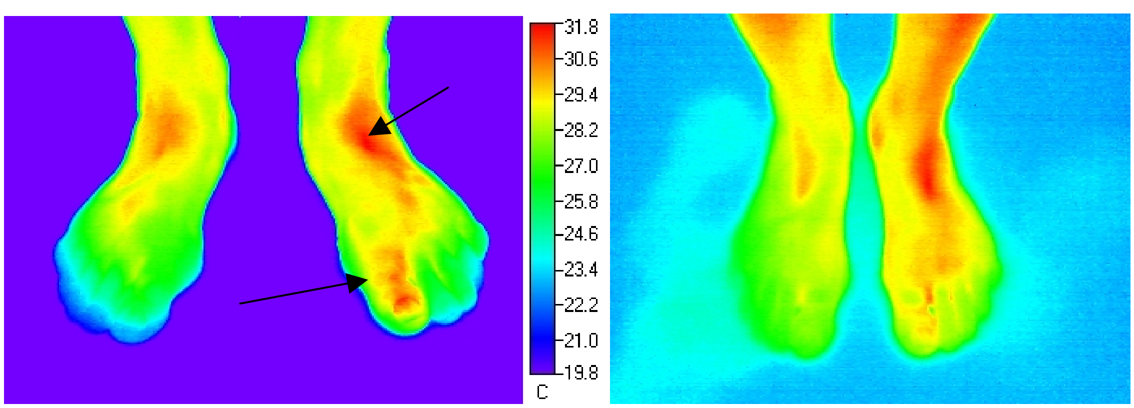
Thermal imaging is a tool that offers many uses in rehabilitation and injury prevention. With an injured person, you can validate the pain being experienced and, consequently, you can see where there are problems. Below is an image of a person's back; he complained of low and upper back pain, as a result of an industrial mining accident (a rock fell on him), but did not indicate where exactly. While looking through the camera's LCD screen, the author touched his finger where he believe the client was feeling pain, which area was confirmed (see the 'hot spots' referenced with arrows).



Another value of MII is that a clinician can establish problem areas in advance and integrate proactive treatment before they become worse. Below is an image of a woman's calves. About 1.5 years ago she tore her right calf while running bases in softball. The image below was taken a day after a 5 km walk, in September 2007, to raise funds for breast cancer research. The woman indicated that her right calf felt tight and not recovered, and it can be seen from the image that the point of origin of the right calf is about 1.5 degrees hotter than the left side. There also are unusual non-contiguous hot spots on both calves that should be diagnosed. Thus, we have another use for thermal imaging: to make lateral comparisons in regard to normalcy (e.g., blood flow, response to exercise, and injury potential/abnormalities), which enable us to pinpoint abnormalities much easier.

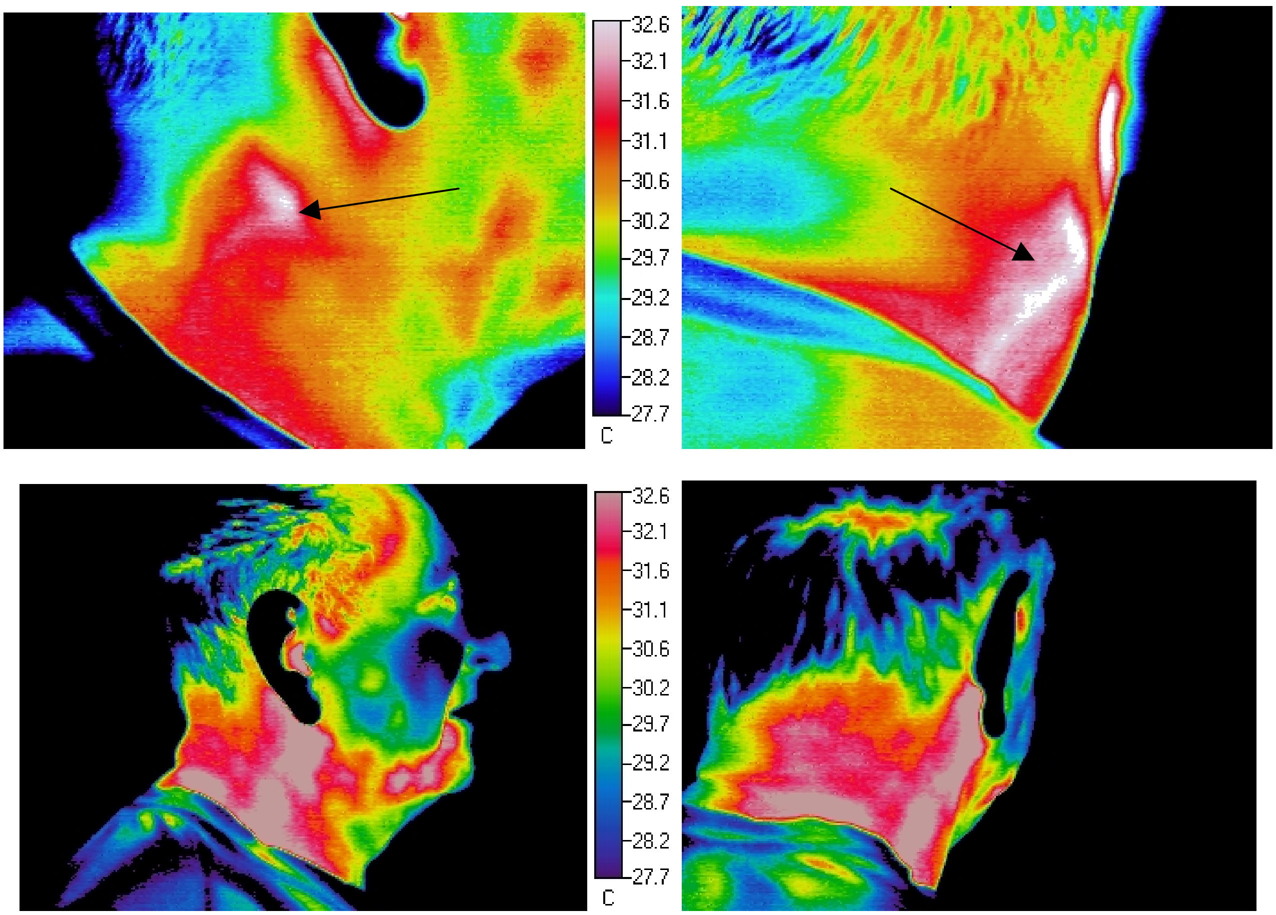


The photos below are of a different woman who enjoys running at least one hour a few times per week. She has completed half-marathons in the past and has been enjoying the activity for the past four years. Lately she has complained of a sore left big toe and instep, both of which show up hot with thermal imaging (left). She then invested in a new pair of shoe orthodics, which reduced her pain and which can be seen in the photo at right. (Note: the photos were taken on two different floor surfaces, which accounts for the background color differences – a hard cool surface as opposed to a carpeted floor.)

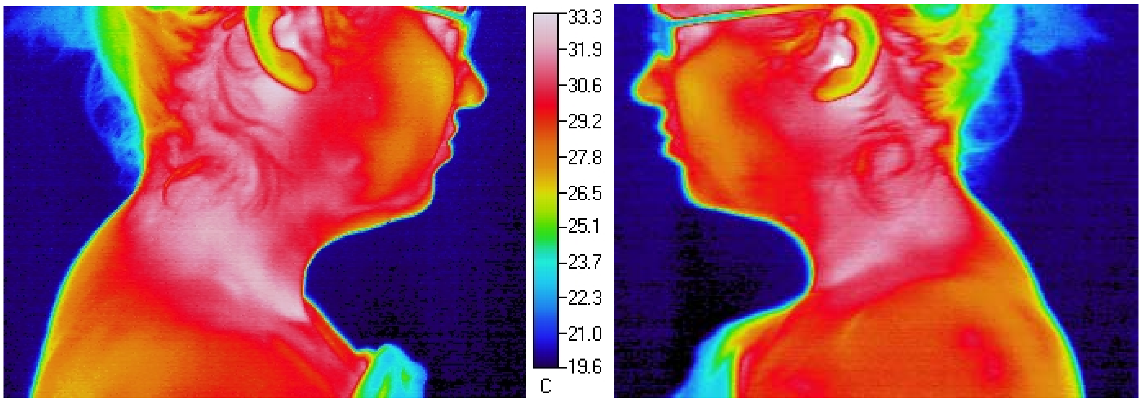


Although both cases represent injuries that already occurred or are in possible process of worsening, it is clear that conditions do exist in both individuals that need to be treated before they become worse.

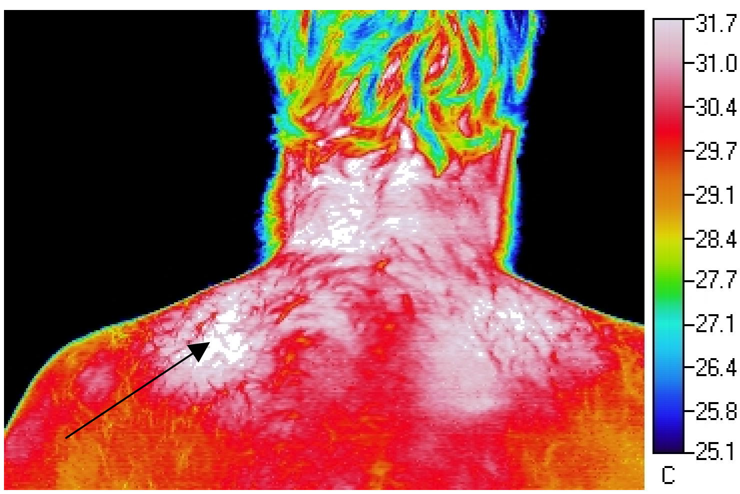
Another use for MII is to monitor changes, for better or worse as time progresses, and to determine if a protocol is working. Below is an elderly gentleman who had cancer in his neck, identified by the arrows. The top two photographs were taken at the start of his radiation treatment, whereas the bottom two photographs were taken a week after his last radiation treatment, which show a decrease in the hot spot where the cancer emerged. The objective, then, as far as MII is concerned, is to take future images at regular intervals to establish the rate and effectiveness of treatment, and as improvement is being made there should be a corresponding reduction in the man's pain.



The next two photos are of a young woman who sustained an automobile accident two years previous. She has pain in her knees and low back, but with the greatest pain around her neck. Without indicating in advance which side was most painful, her right side (left image) shows hotter; she later confirmed that her right side was the tender side.

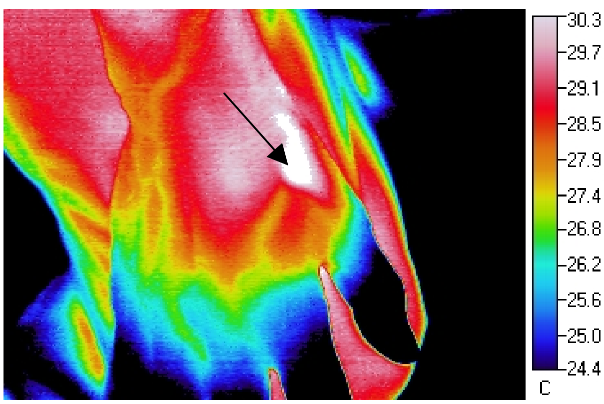


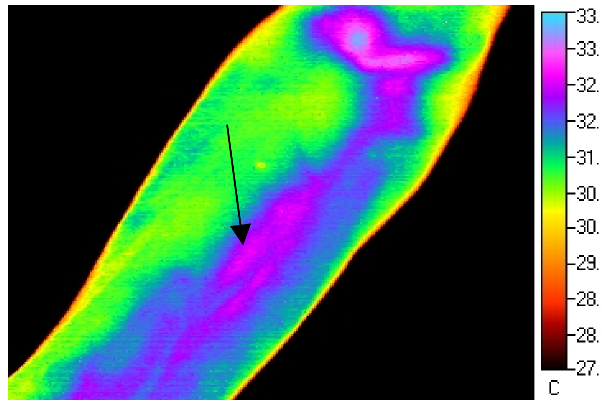
Below is another neck injury as a result of a vehicle accident. This person complained of pain around the neck and down his trapezius, but with greater pain on the left side. Both factors can be seen in this image with a greater concentration of heat on the left side.



Finally, the images below are of a woman's right hand and forearm; again, as a result of a vehicle accident. The images were taken about 5 weeks into her therapy at the I.A.R.T. facility. Although she is becoming stronger and more capable, her pain has not reduced much. (Although there is a strong correlation between an increase in function and a decrease in pain, this is not the case always; some nerve damage can be extensive enough that muscular development and strength can increase without a concomitant change in pain.)

She repeatedly complained of a sore spot on her hand, which is evident in the first image (as well, notice how cold her fingers are, a full six degrees cooler, which may suggest impaired blood flow). The other area of pain runs the full length of her forearm, as shown in the second image (<u>note</u>: greater heat at the elbow joint is normal, as is true of other joints, and this must not be misinterpreted, necessarily, as areas of concern or injury; the elbow joint, where the skin folds, would have to be straight and unclothed for 15 minutes to allow for cooling to ascertain whether there is a hot spot worthy of concern).





Fitness Use of Thermal Imaging

Certainly fitness is a branch of medicine, and one commonality between the two disciplines is early detection of injury and tracking responses to exercise rehabilitation[9], as discussed above. However, there are certain aspects that are specific to fitness, in regard to establishing quality, productivity and effectiveness of exercises and exercise modalities (although effectiveness of exercise modalities has a medical and prescriptive component to it). Insofar as mainstream exercise research is concerned, Arthur Jones likely was one of the first to integrate MII to discover or confirm muscle activation, as per the article *Increasing Neck Strength for the Prevention of Injury*.[10] With this technology, we also can determine the effectiveness of one exercise over another, or one exercise machine over another by way of heat production of the trained or targeted muscle. This was one reason why Jones used MII, to support the effectiveness of his Nautilus machines over similar and traditional free weight movements.

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[9] As a side note, I wish to discuss in brief the role of exercise in pain management and rehabilitation, or its lack thereof. Most rehab clients who come to me share very similar experiences, viz., during physical therapy there was very little aggressive treatment (intense exercise), and when exercise did occur, it was very lax and unsupervised. As well, an article on *Pain*, in American Scientific Medicine refers to modalities of pain management; however, activity (and more specifically organized, controlled and vigorous exercise) and its purpose and value were not mentioned. My success in pain reduction and improved function surpasses that of licensed physiotherapists in my area, and likely elsewhere, and for good reason: my clients train hard, yet safe, and with appropriate equipment relative to individual needs (e.g., a MedX Lumbar Extension machine to target low back injuries) and tolerances.

[10] Refer to the *Athletic Journal* articles section at Hwww.ArthurJonesExercise.comH

Understand that exercise is a stimulus to develop muscular strength and size, among other objectives. It stimulates the body – it gives reason – to adapt to a higher state of function, or to maintain or slow the loss of function as we age. Thus, it is rational to exercise in such a manner that productivity of exercise is highest relative to the time invested, as per the Principle of Diminishing Returns (that is, if optimization of an exercise effect is a goal; some people are content with mediocrity and will utilize just about any manner of exercise that produces some component of progress).

If bodybuilding is one's goal – bearing in mind the term refers to the 'development' of the muscles for reason of aesthetics, rehabilitation or strength, for example, and not the current public perception of drug-using behemoths who pose on stage – then there are certain tale-tell signs of productivity that can be witnessed firsthand. In effect, in order to stimulate change in muscle architecture, the demands of exercise must be high enough to warrant a change… to force a change toward improved adaptation. As demands increase while exercising, more blood will rush into the area – the area being worked or targeted. This occurs since the body is attempting to deliver nutrients while removing metabolic waste byproducts. Greater blood flow also occurs as a means to provide greater heat dissipating capacity[11,12,13,14,15]. Thus, the more demanding exercise becomes, the greater the blood flow[16] – and the greater the muscle pump and heat production because of blood flow – and potentially the more productive the exercise in stimulating change. Based on that known premise, consider Experiment #1 below.

Experiment #1

Simple experiments can be conducted with MII to determine the quality of stimulus. For instance, the photos below are the result of a leg extension experiment comparing full range exercise to that of Zone Training™ (whereby the full range was divided into two halves; the bottom half worked first, followed by the top half for 12 repetitions each). In this experiment, both legs were afforded the same warm-up of 10 full range repetitions while utilizing 60% of the intended workload. The right leg (left photo) was exercised first with 200 pounds to muscular fatigue, at a cadence of 5-5 for 60 seconds or 6 repetitions; a photo was taken immediately after the set. The left leg (right photo) was exercised shortly thereafter with 180 pounds to muscular fatigue in the 'halves' manner, and a photo also taken immediately thereafter.

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[11] Mabuchi, K. et al. Development of a data processing system for a high-speed thermographic camera and its uses in analysis of dynamic thermal phenomena of the living body, in The Thermal Image in Medicine and Biology, Ammer, K., and Ring., E.F.J., Eds. Uhlen-Verlag, Wien, 1995, p. 56.

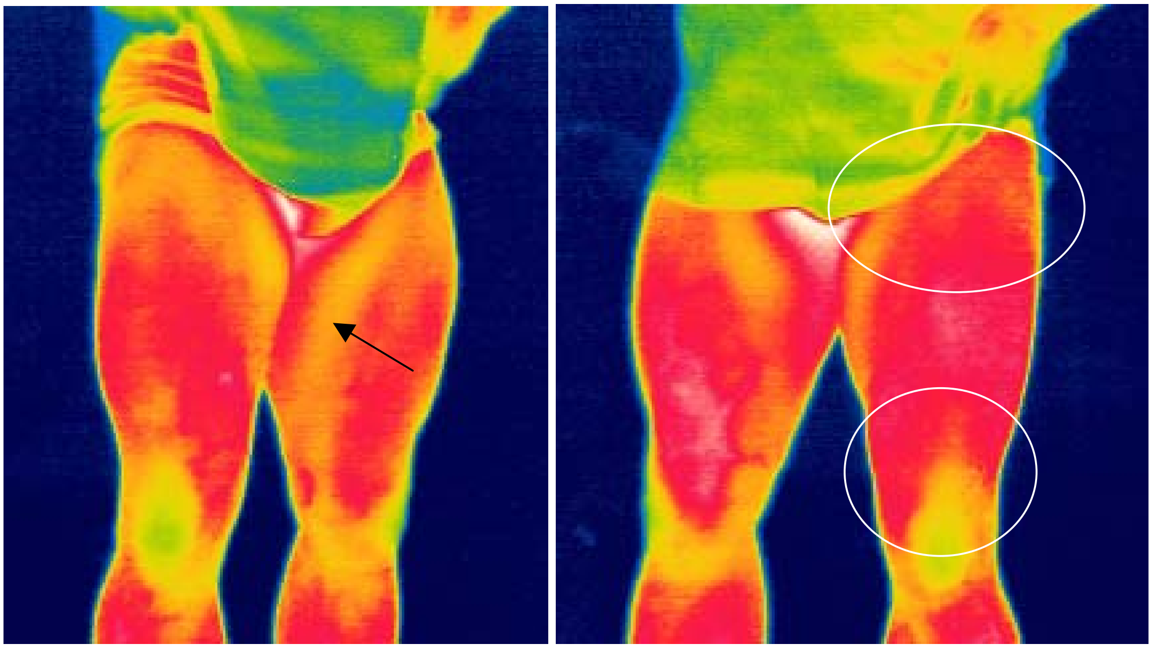
[12] Konermann, H. and Koob, E. Infrarotthermographiische Kontrolle der Effektivität krankengymnastischer Behandlungsmaßnahmen. Krankengymnastik, 27, 39, 1975.

[13] Smith, B.L., Bandler, M.K., and Goodman, P.H. Dominant forearm hyperthermia; a study of fifteen athletes. Thermology, 2, 25, 1986.

[14] Melnizky, P., Ammer, K., and Schartelmüller, T. Thermographische Überprüfung der Heilgymnastik bei Patienten mit Peroneusparese. Thermol. Österr., 5, 97, 1995.

[15] Ammer, K. Low muscular activity of the lower leg in patients with a painful ankle. Thermol. Österr., 5, 103, 1995.

[16] I am speaking in regard to all factors remaining equal. Aerobic exercise is not very demanding and there may a great deal of blood flow in the exercised area(s), but relative to the time factor, it takes much longer to achieve, and may never achieve the same degree of blood flow as an intense set of exercise that exhausts a muscle within anaerobic limitations.



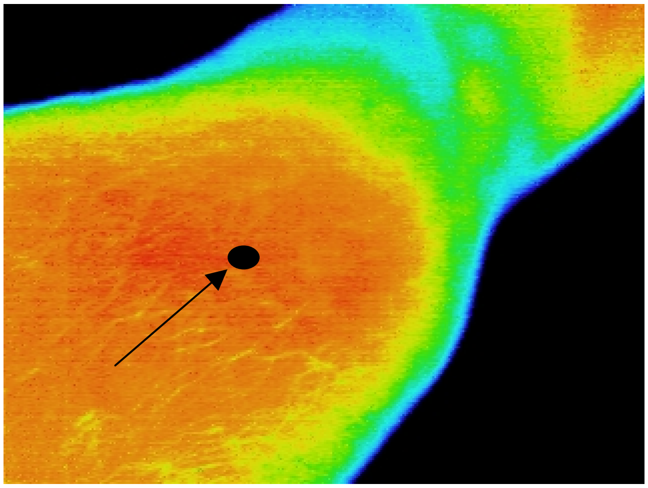
Pre- and post-exercise skin temperatures can assess the amount of blood flow qualitatively. In the above example, the left leg (right photo) indicates greater heat and blood flow overall, covering a far greater area and intensity of effect than is seen in the right leg (left photo). Both legs were exercised to muscular fatigue for one set each on a leg extension machine, and for 60-seconds each set. However, *how* they were exercised differed, thus demonstrating a superior inroad and overall demands experienced with the left leg and its 'method' when compared to the right leg. The arrow in the left photo is pointing at the Sartorius muscle, which indicates no activation since its blood flow (and thermal color) did not change as a result of exercise.

It can be seen that the blood flow is more extensive with the Zone Training™ 'halves' set. More importantly, if increased blood flow indicates the extent of muscle fiber activation, then it can be seen that there are areas of improved activation in the left leg not seen in the right leg – more toward the knee and upper thigh. This fact can be demonstrated further with the Sartorius muscle (see arrow in the above photo set), the long band running down the inner thigh, from groin to knee and as shown in yellow (in this instance, the color denotes lower heat production). If the Sartorius was affected by leg extensions, more blood would flow to the area and it would appear reddish or red, but that is not the case. Hence, the fibers in that muscle were not activated. Thus, it can be concluded as a fact that more heat and blood flow to an area indicates greater or more complete muscle fiber activation.

Now, look again at the upper thighs and around the knees of the right and left legs and an improved effect can be seen in the left leg. This suggests an increase in fiber activation, and possibly as a result of a greater number of contractions within targeted zones as per the Zone Training™ method.[17] It also should be stated that executing an exercise in 'halves' does not produce the greatest inroad or level of demands within the Zone method of training, but was chosen for this experiment since it is the most easily applied and for demonstrative purposes when compared to full-range training.

Experiment #2

A subject undertook a very intense thigh workout, involving leg extensions, Roman chair squats, leg presses, and barbell squats; a week prior, he conducted what he considered a 'moderate' workout, followed by a full week of rest (no intensive thigh training). Thus, his legs were 'fresh' and ready for a hard workout. Within one hour of awaking, at 8 AM, a black dot was inscribed on his thigh with a permanent marker toward the middle of the vastus medialis muscle, to act as an exacting point of reference whenever thigh surface temperature was to be taken (see photo below). The temperature at that exact point and at that time of day was 29.4 degrees Celsius. For visual clarification, the cooler blue area toward the top of the photograph is his knee joint.



A reference point, for regular temperature measurement over a two-day period, was made with a permanent marker on a subject's thigh.

His workout began at 9:30 AM and completed by 9:50. The referenced point temperature was measured immediately after his final set at 31.4 degrees Celsius. Twenty-minutes later it still measured 31.4 degrees. Sixty and ninety-minutes later it measured 30.3 degrees. Two hours later it measured 30 degrees, thus far indicating a slow decrease in temperature to normal values. However, 22 hours later, the next morning, the spot still measured 30.2 degrees, possibly suggesting that although body temperature after the workout was returning to normal, inflammation from tissue damage, as a result of intense exercise in the targeted area, sustained a higher-than-normal temperature (and do note that body temperature is lowest in the morning).

[17] It is suspected that the reason for greater blood flow and heat production is the result of a higher number of contractions per unit of time since the 'halves' set used LESS load, and so it is not an issue of how much weight one uses that causes greater fiber activation and blood flow, but how it is used. (Obviously there needs to be enough load to stimulate change and that issue is not in contention.) Furthermore, if there were less muscle fiber activation, from the use of a lighter load, then the area would not be 'hotter' or more complete in its activation than what occurred with the right leg.

Almost two days later, 46 hours after the workout, the temperature at that exact spot was again 29.4 degrees. This would indicate that most inflammation subsided in and around that point of reference.

A few things need to be considered with this experiment. First, only one point of reference was measured, and it is possible that other areas of the thigh worked harder or less intensely. If some areas worked more intensely, then inflammation and increased temperature likely would have persisted for longer, although the length of such time is unknown.

Second, lack of inflammation, as a result of normal surface temperature, does not indicate, necessarily, that the trained muscles are ready or capable of exercising again – that full recovery exists – and particularly when trained at a high degree of intensity. Certainly other indicators, of when to exercise the same muscle again need to be considered. Further, the positive training effects induced by a workout persist for several days once full recovery is achieved, thus negating the need for another workout just because the muscles may be ready sooner.

In conclusion, using infrared imaging to help ascertain recovery of muscles for weight training may have little value, although the above experiment was very limited in application and not integrated long-term during more strenuous or demanding cycles of exercise. However, there potentially may be greater value when working with some strength athletes who train several times per day, such as Olympic lifters, and with other competitive athletes who train for longer periods and more often than is found with typical fitness enthusiasts.

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Are there other uses for MII in fitness assessment? One's imagination will set the limits, but consider that the appropriateness of athletic equipment can be determined by observing pressure points on the body. In horse racing, a saddle needs to sit properly, to avoid pressure sores; this is done by way of design and having sufficient distribution points of pressure throughout the entire saddle. Thermal imaging has been used in this regard and the same can be applied with humans wearing athletic gear – from helmets, to shoulder pads, to footwear.

For example, an athlete would remain barefoot for about 20-minutes, to cool the feet to allow normal heat distribution, and a photo would be taken just prior to putting on shoes. Then, s/he would wear the shoes in question during practice and go about his or her business as usual. Immediately thereafter, the athlete would remove the shoes and more images would be taken and compared to the previous set. Ill-fitted shoes would indicate excessive pressure points (hot spots) somewhere along the feet or ankles. However, it should be noted that hot spots could be the result of injuries developing or established fully, which become more prominent after activity, and that must be factored in the diagnosis.

And here's another example: blood flow quality, efficiency and response in the injured and in athletes (who may be complaining of a physical anomaly) can be measured by way of heat and cold application. For instance, a body part can be submerged in ice water for 20-30 seconds and then removed; heat distribution, in response to the cold, then can be monitored in real time. Unobstructed blood flow will demonstrate even heating throughout and with no unusual cold spots remaining. Testing can be applied on the other end of the spectrum by submerging a body part in 'comfortably' hot water; once removed, the body part should show even cooling without any remaining and unusual 'hot' spots.

Final Advice

For physiological purposes, thermal cameras must have a resolution of 320 x 240 pixels or greater (less expensive cameras will not provide the necessary resolution to see temperature variances). The purchased camera should be tightly calibrated for use with human subjects to reduce error rate. To elaborate, the infrared camera industry has an accuracy of 2%± because of the large range being measured in different fields (e.g., electrical and industrial, medical, etc.), which usually are from -40 °C (-40°F) to 500°C (932°F). The camera used at the I.A.R.T. facility is a Mikron M7815 (www.mikroninfrared.com), calibrated and designed for many uses, including biological research.

Whether investing in a Mikron camera, or other make, clarify with the manufacturer that the camera will be used with human subjects and that it must be calibrated tightly for such use; otherwise, there could be up to a 2% error rating in temperature readings.

Using the camera properly and effectively must take into account a number of factors. For instance, ambient temperatures can alter the fraction of flow shared between the musculature and the skin[18]; 18-25° Celsius is recommended while avoiding too hot or too cold an environment. As well, one must understand anatomy and physiology enough to know that veins and arteries produce hot spots, where normal hot spots arise, etc., and that hot showers, baths, alcohol, clothing, and certain drugs – among other factors – will affect overall body temperature and the variances among areas of the body. Consequently, the author recommends the reader investigate more advanced literature on this subject, including the book *Medical Infrared Imaging* by Nicholas A. Diakides and Joseph D. Bronzino, ISBN 13: 978-0-8493-9027-2. www.crcpress.com

Supporting Arguments and Discussions

For discussions on Zone Training, refer to Book II of the volume *Fitness Logistics* in the Fitness Science Library, or visit www.Zone-Training.net

For discussions on data collection and evaluation (and the use of measurement tools), refer to Chapter 7, Book I of the volume *ExerScience Research* in the Fitness Science Library.

[18] Johnson J.M. Exercise and the cutaneous circulation. *Exercise Sports Sci. Rev.* 20, 59-97, 1992.