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Cold Stress Testing in Medical Thermal Imaging

Robert Glenn Schwartz[1], Marcos Brioschi[2], Tashof Bernton[3], Jim Campbell[4], Carol Chandler[5], Jan Crawford[6], Christine Horner[7], Alex Mustovoy[8], Tracy Turner[9]

[1] MD, Board of Directors, American Academy of Thermology, Greenville, SC and Piedmont Physical Medicine and Rehabilitation, PA, Greenville, SC
[2] MD, PhD, Universidade de São Paulo, Faculdade de Medicina da Universidade de São Paulo, Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo
[3] MD, Board of Directors, American Academy of Thermology, Greenville, SC and Colorado Rehabilitation and Occupational Medicine, Aurora, CO
[4] MD, Board of Directors, American Academy of Thermology, Greenville, SC, and Integrative Life Solutions, Clemmons, NC
[5] DOM, Med-Hot Thermal Imaging, Lakeland, Florida
[6] RN, Board of Directors, American Academy of Thermology, Greenville, SC, and Infrared Thermal Imaging, Rockford, IL
[7] MD, Board of Directors, American Academy of Thermology, Greenville, SC, and Christine Horner, MD Enterprises, San Diego, CA
[8] ND, Thermography Clinical, Inc, Toronto, Cananda
[9] DVM, Board of Directors, American Academy of Thermology, Greenville, SC, and Anoka Equine Veterinary Services, Elk River, MN

Resumo — Na comunidade da termologia médica existe algumas controvérsias quanto aos métodos aceitáveis de equalização térmica e teste de *cold stress*. Isso é compreensível uma vez que existem diferentes protocolos para realizar a equalização térmica e o *cold stress* dependendo do tipo de estudo que está sendo feito. Este artigo traz a análise de alguns dos métodos mais comumente empregados tanto para o equilíbrio térmico quanto para o teste de *cold stress* em várias áreas, incluindo estudos neuromusculoesqueléticos (NMSK), de mama, veterinária e odontologia. Também é fornecido uma sinopse de como os laboratórios de imagem podem avaliar adequadamente se um teste de *cold stress* ao frio está sendo empregado adequadamente.

Palavras-chave: cold stress test; cold stress.

Abstract — Within the thermal imaging community misunderstanding exists as to what constitutes acceptable methods for equilibration and cold stress testing. Since there are different protocols to accomplish equilibration and cold stress depending upon the type of study being done this is understandable. This paper will review some of the more common methods employed for both equilibration and cold stress testing across several disciplines including neuromusculoskeletal (NMSK), breast, veterinary, and oral-systemic studies. A framework will also be provided so that individual imaging labs may properly assess if an adequate cold pressor test was actually employed.

Keywords: cold stress test; cold stress

SKIN TEMPERATURE PHYSIOLOGY

It has been well established that mammalian skin temperature is largely controlled by the autonomic nervous system. While several other factors such as visceral cutaneous reflexes, inflammation, infection, lymphatic congestion, and where the skin is located on the body is irrelevant to this determination. That means that the tenants of skin temperature physiology remain the same across the spectrum of neuromusculoskeletal, breast, veterinary, and oral-systemic studies.[1,2,3,4,5] Because study type impacts which thermographic findings have relevance, an in-depth understanding of the factors that produce those physiologic findings is essential for the interpreting physician and performing technician.

EQUILIBRATION PROBLEMS IN MEDICAL THERMAL IMAGING STUDIES

While several internationally peer reviewed guidelines have been written regarding the reasons for an equilibration period prior to performing a medical thermal imaging examination[2,3,4,5] often times it purpose is misconstrued and thus despite good intentions a technician may unwittingly fail to properly perform the same

For example, a female who is prepared for a thermal breast risk assessment is instructed to sit in front of a portable air conditioning unit for one minute prior to image acquisition or to wear a gown for eight minutes in a room with no independent temperature control only to remove the gown just prior to image acquisition. While the technician may believe that an equilibration period was performed in truth no such thing occurred rendering the findings incompatible with performance of a medical study.

In other instances a well-intended physician plans to open up a new thermal imaging lab and simply wants to do it right. It can be confusing for a new comer to the field to know what acceptable equilibration protocols are and how to properly perform a cold stress test by study type as no single reference has been written to provide direction regarding the same.

Finally, there are interpreters that have no way to quality control what was actually done out in the field during image acquisition. It can be problematic to the thermologist when interpretations are based upon findings that follow unreliable equilibration protocols. Clinical decision making for the treating by physician is also hampered when the report of findings are based upon a study that did not incorporate a true equilibration period.

PROPER EQUILIBRATION TECHNIQUES

With the exception of post sympatholytic blockade studies, any study that is not preceded by a proper equilibration study should not be held out to be a medical thermography study. Since physiologic vasoconstriction is absolutely necessary for almost all thermographic examinations, all patients, with the exception of limits placed upon veterinarian subjects, should at a minimum have an equilibration period that provides physiologic vasoconstriction (for example, exposure for a 15-minute period to a cool 20°C still-air environment). Equilibration periods that do not include cold stress testing are not intended to cause significant pain or blood pressure elevation. With the exception of certain early injury detection assessments, thermographic studies that do not employ an adequate equilibration period should only be represented as thermal images that may be of interest but have no medical utility.

Regarding equilibration, according to American Academy of Thermology (AAT) NMSK Guidelines ventilation systems should be designed to avoid direct airflow onto the patient through-out the duration of the study. The patient should be standing on a carpeted floor. Exposing the patient's feet may assist with equilibration, even with upper extremity examinations. Ventilation systems should be designed to avoid direct airflow onto the patient. The patient should not be placed near or under any light fixture that itself emits heat. Standard fluorescent and/or LED lights are appropriate. Infrared studies performed in a steady state 20°C (±1°C) environment can be accomplished with one set of images, providing the patient has equilibrated for 15-20 minutes prior to imaging.[2]

Regarding breast studies the patient should be asked to disrobe their upper body completely and not to stand in a corner of the room. Ventilation systems should be designed to avoid direct airflow onto the patient. An equilibration time of fifteen minutes is deemed appropriate prior to obtaining the images. The patient will be asked not to have any contact with their breasts during this equilibration time. During the last 5 minutes the patient should be asked to raise their hands above their head and to maintain this posture throughout the remainder of the examination. If the patient is unable to raise their arms, appropriate measures may be taken to insure proper imaging.[3]

For Oral-Systemic Studies ventilation systems should be designed to avoid direct airflow onto the patient. The patient should be standing on a carpeted floor. Exposing the patient's feet may assist with equilibration, even with upper extremity examinations. Standard fluorescent lights are appropriate. The patient should not be placed near or under any light fixture that itself emits heat. Standard fluorescent and/or LED lights are appropriate. Infrared studies performed in a steady state 20°C (±1°C) environment can be accomplished with one set of images, providing the patient equilibrated for 15-20 minutes prior to imaging.[5]

In post sympatholytic blockade, patients across the spectrum of studies equilibration is not required nor is the imaging suite temperature critical.[2,3,4,5]

In the case of Veterinary studies all examinations should be performed in an environment where, to the extent possible, ambient temperature is controlled, free from drafts and where there is no exposure to infrared rays, such as incandescent lights or sunlight that may result in heating or reflective artifacts. The imaging room should be comfortably cool to allow for dissipation of superficial heat which may produce artifact from the skin. Ideally the ambient temperature range for IR imaging suite should be between 20° to 25°C. However, as long as it is below 30ºC and sweating is not induced, thermal imaging may be performed.[4]

COLD PRESSOR TESTING

Sudden, painful, cold stress causes massive discharge of the sympathetic nervous system and release of norepinephrine. This sympathetic discharge triggers responses in the cardiovascular (CV) system including arteriolar constriction, increased heart rate (HR), and increased cardiac contractility. These responses combine to increase blood pressure (BP). This is known as the pressor response.[6]

While the performance of cold pressure testing has been written about extensively there are variances with respect what constitutes a cold pressor

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test and what physiologic parameters might be used to confirm that an adequate stress test was actually accomplished.[7] There are multiple reasons and methods for assessing response to cold and no single method has been shown to be superior.[8] Since thermal imaging labs should use of cold stress testing in the performance of many medically based studies it is important that the protocol they employ does in fact meet this basic requirement. Hence, when evaluating types of cold pressor tests, it is necessary to define both the protocol employed and the physiologic parameter measured to confirm the test.

The most commonly referenced cold pressor test is the Ice Water Immersion test. This usually consists of subject hand immersion in an ice water bath kept at or near 1-15°C for a period of 0.5-10 minutes. While there is no uniformity within the literature regarding the optimal time for immersion, temperature of the bath, or time of measurement of subject physiologic parameters attempts to standardize this in the past have been made. They have largely been unsuccessful however since factors such as local geography (what is might be considered typically cold in one climate may not be considered cold in a second), wetness, dampness, physical fatigue and poor conditioning, medical conditions such as hypertension, hypothyroidism and diabetes, and environmental stress can all have an impact on what actually constitutes cold stress to any particular individual.[7, 9]

Several other cold pressor test variants to the Ice Water Immersion Test have also been described including the Deep Cold Water Immersion, Cold Pressor Arm Wrap, Continuous Cold Stress Environment, Holding Ice Packs, and Pre and Post Full Body Water Immersion. In all instances, what these tests methods hold in common is the application of a cold stress great enough to elicit a physiologic stress on the subject involved.[10, 11, 12]

As a result of the lack of uniformity on what constitutes a cold pressor test the parameters used to measure physiologic response to cold stress are even more important than they might be otherwise. None the less, not unlike variability in how cold pressor tests are administered, there is also variability in which parameters have been used to measure physiologic responses to cold stress. Despite that variability blood pressure measurement is by far the most commonly accepted and consistently reliable tool to assess if a true pressor test was done. Normally when someone is subject to cold stress blood pressure is expected to rise. In abnormal patients, however, hypersensitive (excess) responsiveness may occur. Paradoxical responses have been demonstrated in normal individuals as well.[13, 14, 15]

Examples of parameters other than blood pressure that have been used to measure physiologic responses to cold pressor testing that have been cited in the literature include heart rate (considered to be less reliable then blood pressure due to high inter-individual variability), pain numeric rating scales, thermal imaging of the hands or fingers, salivary cortisol levels, functional MRI, and grip-strength testing.[16, 17, 18, 19, 20, 21, 22]

VALIDATION AND GUIDELINES FOR COLD STRESS TESTING IN MEDICAL THERMAL IMAGING

Because of the challenges clinicians who interpret medical thermal imaging face, The American Academy of Thermology has referenced performance of Cold Stress Testing in each of their Guidelines for Medical Thermal Imaging.[2,3,4,5] While the exact method of cold challenge testing may vary depending upon the study type being performed the underlying principle that the cold stress applied must be enough to create a physiologic challenge remains constant (hence they are often referred to as Cold Challenge Tests).[23, 24, 25, 26]

For example, following a 15-minute equilibration period in NMSK studies at 18°C it is recommended that the patient remain in a cold stress environment over 45 minutes with image acquisition at 15 minute intervals (note: if cold stress is great enough then it may be employed as part of the equilibration period). While thermal imaging alone has been used to confirm the presence of cold stress testing since the purpose of the NMSK study is to measure autonomic function as assessed by skin temperature under cold stress it is recommended that each lab perform its own blood pressure standardization protocol prior to performing any test so as to assure that a cold pressor test was indeed performed.[2, 13, 27]

In our lab, we applied an SPO_2 monitor to 5 control subjects prior to testing and then again at 15 minute intervals to confirm that the lab's temperature was cool enough to cause an elevation in blood pressure as compared to base line in asymptomatic patients. While each lab must perform its own internal evaluation to assure that a cold pressor challenge test is actually being performed the task does not have to be arduous. By way of example in our laboratory pre-testing and 15-minute post-cold stress exposure blood pressure recordings were obtained with a digital Contec CMS-50E fingertip pulse oximeter as follows:

Start	At 15 Minutes	At 30 Minutes	At 45 Minutes
BP: 109/81	BP: 119/82	BP: 122/86	BP: 124/86
BP: 121/86	BP: 130/86	BP: 135/92	BP: 135/92
BP: 124/85	BP: 134/87	BP: 137/92	BP: 138/92
BP: 98/68	BP: 105/70	BP: 106/74	BP: 108/75
BP: 100/72	BP: 110/72	BP: 112/76	BP: 114/76

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We found that over time systolic blood pressure recordings tended to increase more on a percentage basis than diastolic blood pressure recordings did. Laboratory temperature was held constant at 66°F (18,9°C). The subjects who showed a rise in systolic blood pressure of less than 20 mm of Hg and rise in diastolic blood pressure of less than 15 mm of Hg following cold stress were considered normoreactors whereas subjects whose systolic BP increased by 25 or more mmHg or whose diastolic BP increased by 20 or more mmHg are considered to be hyper reactive[14, 28, 29] Like other previous publications we found blood pressure to be a more reliable indicator of cold pressor testing then heart rate.[24]

It is important to remember that no thermal imaging study can be called a medical thermal imaging study if proper protocols are not followed, including those as defined for laboratory preparation itself.

COLD STRESS STUDIES

Since the reproducibility of images obtained is important most studies should consist of more than one set of images taken under the same conditions. If the thermologist desires to assess either reproducibility, sympathetic skin response, or progressive physiologic change with increased exposure to a cold ambient temperature, then repeating the study two times at fifteen minute intervals should be performed (another acceptable cold pressor test may be substututed).[2, 30, 31]

available, can be helpful to compare starting (reference) findings with later images acquired post cold stress. Digital subtraction analysis of decreased (normal vasoconstriction) or increased (paradoxal abnormal response) temperature can be visualized through color pixel temperature display.[12]

While for NSMK, facial, head, and neck studies cold stress testing is mandatory in order to assess sympathetic skin response, thermographic evaluations of the torso viscera do not as clearly assess autonomic effects of cold stress upon the internal organs. Since thermographic torso studies do however measure surface skin temperature it is very important to evaluate the impact of cold stress so as to differentiate between autonomic related skin temperature findings and those findings that may be due to an external expression from viscera upon the skin. The AAT Oral-Systemic Guidelines address systemic cold stress evaluation indications in more detail, however in these cases, since the cold challenge is typically only a limited assessment as compared to what is typically done in a NMSK study, they should not be referred to as bone fide sympathetic stress response studies.[2, 3, 5]

While sympathetic skin response testing and cold stress studies can provide clear utility in veterinary medicine, especially as it relates to assessment of autonomic impacts on the musculoskeletal system, due to the inherent nature of the subject matter, greater latitude must be afforded to the interpreting

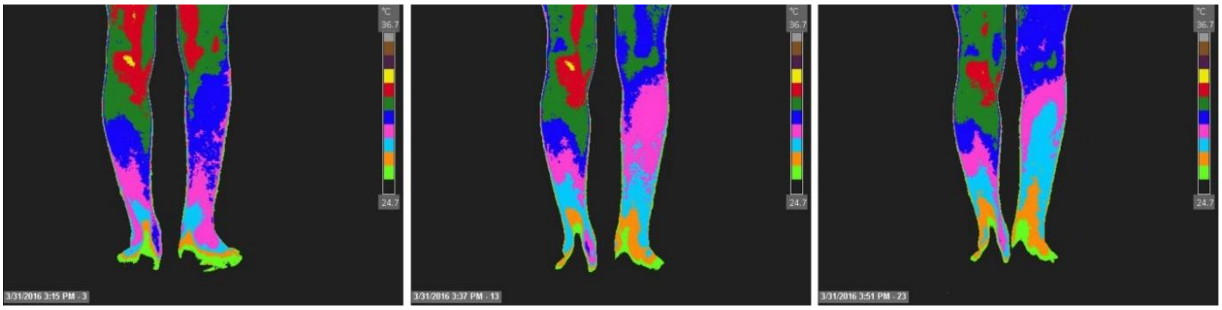

Image 1 Impact of cold pressor challenge testing upon the right lower extremity. The longer the limbs are exposed to cold stress (from left to right) the more obvious the asymmetry pattern becomes.

The Functional Cold Water Autonomic Stress Test is another variant of cold pressor test. It evaluates the function of the cutaneous sympathetic vasoconstrictor reflex by measuring the vasomotor response of the symptomatic extremity to cold water stimulus of an asymptomatic extremity. It can be done with a non-involved extremity immersed in a 16°C cold water bath. This methodology spares the other extremities from water artifact during image acquisition. Though area average temperature measurements taken from serial radiometric images of the sites of interest are an accurate way to document the subtle temperature changes encountered in such studies, dynamic subtraction imaging software, if

themologist regarding the performance of cold stress testing of any kind. Since safety of the technician and animal under study are always primary concerns, a different level of jurisprudence in required when determining risk versus reward and intensity of service versus severity of illness in animal populations.[4]

The role of cold stress testing for Breast studies is also not clear cut, but for different reasons. On one extreme, frequently cited complaints against the application of cold stress testing for breast patients include the creation of unneeded patient duress, increase in time necessary to perform the test, and increase expense for study interpretation. On the other

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extreme breast thermologisits make note that cold stress assessments were incorporated into all published studies that support the utility of thermography as a breast risk health assessment and to exclude that part of the examination is equivalent to performing an assessment without any basis what so ever.

For example, it is known that a breast tumor may be so small that the only way to visualize it is through imaging of vascular ectasia as documented by thermography. When the image acquisition is simply not sensitive enough to see what is required to be read however it is imperative to do a cold stress test to visualize it. In this instance, the cold stress test is a way of assessing if the breast risk assessment is more clearly placed in a higher TH category or not. The cold stress test helps to differentiate unique and isolated abnormal vascular structure from normal structure. It is also indicated in some situations when there are pseudopatterns of vascular abnormality, when there is a hot spot tumor masking the presence of a “vascular ring” or “tumor star”, and to separate findings due to hyperradiation of the papilla.

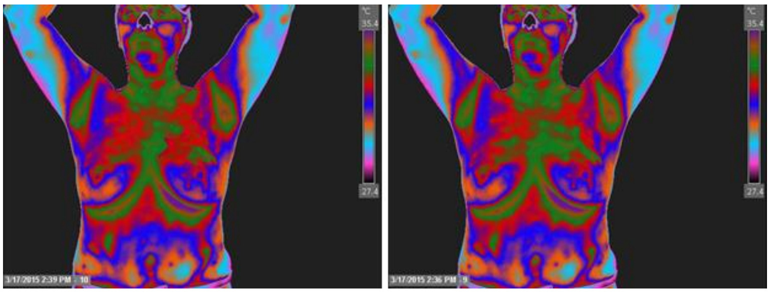

Image 2 Pre (left) and post (right) cold stress test assessment comparison. Findings around the nipple, areola, and axilla are more clearly visualized post cold stress test imaging on right

Hands in cold water at 41˚F (5°C) for 1 min was the cold pressor test utilized in the images above however holding a cold pack for one minute is often commonly employed. Other cold pressor test methods have been reported as well. For example, some clinics have reported greater reproducibility and utility with breast cold stress examinations by hand immersion in water cooled to 60°F (15,5°C) for a minimum of four minutes. Whichever method is employed it is important to remember that it is up to the interpreting thermologist to state with confidence that a true cold stress test was actually performed.

When there is assurance that a cold pressor test was performed then NMSK physiologic responses to the same can have a profound impact upon the interpretation of thermographic breast findings. In the images that follow by appreciating the hyperthermic region to the left of the posterior thoracics there is at least a suggestion that NMSK and breast findings might be related. A physician’s clinical impression would clearly be influenced if the result of post-cold stress imaging showed resolution of suspicious findings.

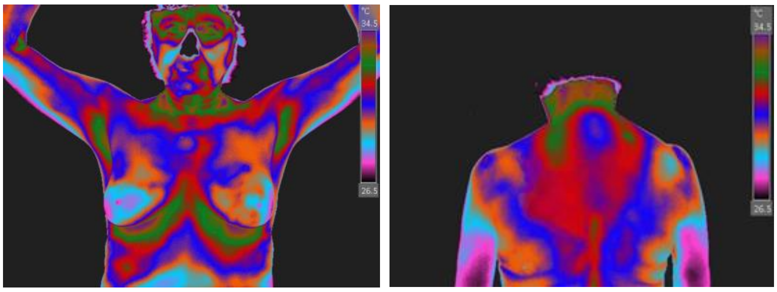

Image 3 Hyperthermia in in the left breast (left image) and thoracics (right image)

That being said many breast thermologists today do not consider the autonomic manifestations upon the NMSK, cardiovascular, and lymphatic systems to be relevant to the needs of breast patients and they frequently advise their technicians that cold stress testing can be omitted. Further they do not disclose that the study performed omitted what might otherwise be referred to as a conventionally acceptable cold pressor assessment. It least one explanation that has been offered to explain this disparity is that medical thermographic studies are an extension of the physician’s physical exam however popular thermography is more focused upon encouraging patient engagement.

When performing medical thermographic breast studies the interpreting is encouraged to look beyond pathophysiologic findings related solely to the breast and to include cold stress testing along with additional views that can help them in clinical decision making.

In the case of mobile breast examinations were the interpreting physician is not on site, it is up the interpreting thermologist to assure that the thermographic technician has in fact followed proper techniques and protocols to accomplish both equilibration and, if requested, cold stress testing. Asking a client to “equilibrate” with a gown on for eight minutes and then removing the gown just prior to image acquisition is neither proper equilibration nor an adequate cold stress test.

REPORT OF FINDINGS

Questions frequently arise regarding the correct way to document thermographic findings obtained from cold stress examinations. When describing thermographic findings, it is always important to remember that findings are simply intended to confer to a third party what the interpreting thermologist sees. They are not comments on what the interpreting physician thinks those findings might be consistent with or what the treating physician believes might be going on with that patient.

Typically, when cold stress is applied to a living tissue we expect the surface of that tissue to get colder. If that does not occur either the cold stress was not great enough to elicit a response or the object under study either did not or could not respond to the stress. As such it is quite safe to simply describe cold stress examination findings as either physiologic (cooling occurred), non-responsive, or paradoxical (warming occurred instead of cooling as expected). In addition, the location (region(s) of interest) that the findings were found should also be documented.

Thermographic impressions can only be created when there is a known thermographic signature for a constellation of findings. When considering cold stress examinations, it easier to define thermographic signatures with NMSK studies then for breast and systemic studies. For example, an entire limb that is cold in a NMSK study is consistent with RSD/CRPS signature however the thermographic impression for a cold region in the breast at 3pm in the lateral, outer ring with a corresponding hot or cold region along the T6 intercostals on the ipsilateral posterior view and that worsens with cold stress might simply state “NMSK findings in a T6 distribution are present”. In other instances, all that can be done is to restate the findings; an interpreting thermologist can never go wrong with this approach.

Clinical impressions should be reserved for those cases where the interpreting thermologist has a high degree of confidence that he/she is familiar with the history and physical examination of the subject under study and is able to recommend a plan of care that can legally be defended by what is locally determined to be the standard of care. If the interpreting physician does not feel all of the elements needed to do the same are present it is far better to err on the side of safety and to defer from providing any clinical impression[32 33, 34]

IMPORTANCE OF TECHNOLOGY

Despite having an infrared imaging camera with a Guideline compliant focal plane array (640x480 or enhanced 320x240), software that allows for proper palette formation, temperature range and demarcation, and a properly conducted protocol for acquisition, if the imager’s sensitivity and associated optics are not adequate to clearly visualize the thermographic findings required to properly read a study then the interpreting thermologist should not hesitate to report that the study is simply not of the necessary quality required to provide an interpretation.

At least one common reason that a reading physician might not feel comfortable reporting cold stress findings is that they have been looking at images that were taken with equipment configured such that image acquisition is simply not sensitive enough to see what is required to be read. If the reader is used to only seeing low quality images then he/she cannot appreciate what would have been visible if a better quality image had been provided. By way of analogy, if a black and white photograph is taken of the forest it might be possible to report that leaves are visible on the trees however once exposed to color acquisition the reader could now also report if the leaves were green.

It really does not take any more time to provide this report of findings. With skill development, cold stress testing findings can be reported quickly as well. And doing so can completely change the treating physician’s clinical impression and resultant treatment plan.

It should also go without saying that in all instances when reporting the presence of physiologic, paradoxical, or non-responsive results, the interpreting thermologist is simply reporting findings. Likewise, if a classic signature is present then one might be able to provide a thermographic impression. For example, leaves on trees have varied colors then stating that thermographic findings are consistent with the fall season. Any comments (or clinical impressions) regarding what one does in the fall to prepare for the winter however should be reserved for the treating physician.

CONCLUSION

When documenting findings and impressions from any thermographic imaging study, it is important for the interpreting medical thermologist to assure that a proper equilibration period was provided prior to the examination and that camera sensitivity is high enough to adequately display all findings necessary for proper report generation. The addition of cold stress studies and any required associated views can provide important information to the treating physician. By paying attention to the results of cold stress studies the interpreting thermologist is challenged to broaden his/her base of understanding of the physiology that thermal imaging captures. That in turn enhances the value of the study to the field of medicine and elevates the profession of medical thermology.

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