Medical infrared thermal imaging of cats with hyperthyroidism

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OBJECTIVE
To determine the usefulness of medical infrared thermal imaging (MITI) as a screening tool for hyperthyroidism in cats, evaluate the need for hair clipping over the ventral aspect of the neck to achieve optimal images, and determine whether there is a change in thermal patterns at 1 and 3 months after radioactive sodium iodide I 131 treatment.

ANIMALS
17 cats with and 12 control cats without hyperthyroidism.

PROCEDURES
All cats underwent MITI first with the hair present and then after the hair was clipped. Each cat with hyperthyroidism was subsequently appropriately treated SC with radioiodide; reevaluations, including MITI before and after hair clipping and measurement of serum thyroxine concentration, were performed 1 and 3 months after treatment.

RESULTS
The MITI had 80.5% and 87.5% accuracy in differentiating hyperthyroid cats from clinically normal cats before and after the hair over the ventral aspect of the neck was clipped. Among cats with an initial serum thyroxine concentration > 4.0 µg/dL, the success rate for MITI-detected response to radioiodide treatment at the 1-month reevaluation was 92.86% in unshaved cats and 85.71% in shaved cats. The success rate for MITI-detected response to radioiodide treatment at the 3-month reevaluation was 100% in unshaved and shaved cats.

CONCLUSIONS AND CLINICAL RELEVANCE
Results indicated that MITI was successful in differentiating between hyperthyroid cats and clinically normal cats and identifying patients with thyroxine concentration within reference interval after radioactive sodium iodide I 131 treatment. (Am J Vet Res 2015;76:53–59)
These abnormalities can perpetuate multisystemic organ dysfunction.

Hyperthyroidism develops in cats > 6 years old, with a mean age of onset of 12.8 years. There is no known breed or sex predilection, unlike in humans, among whom females are 4.5 times as likely as males to develop hyperthyroidism. In cats, the most common clinical sign is polyphagia with concurrent weight loss. Approximately 10% of cats will have signs of depression, weakness, progressive weight loss, and anorexia, and often these signs are a consequence of concurrent nonthyroidal illness. In humans, this nonthyroidal illness is described as apathetic hyperthyroidism. Clinical signs and physical examination findings of cats with hyperthyroidism may include weight loss, polyphagia, hyperactivity, tachycardia, polyuria, polydipsia, cardiac murmurs, vomiting, diarrhea, increased fecal volume, anorexia, polyphagia, dyspnea, muscle weakness or tremors, and congestive heart failure. Poor coat quality (matting and shedding) have been described as well. Palpably enlarged thyroid gland lobes are evident in approximately 90% of hyperthyroid cats. Although normally sized thyroid glands have also been reported.

The clinical signs of hyperthyroidism in cats are considered nonspecific, and a variety of disease processes may possibly result in any combination of these signs. For most cats, establishing a diagnosis of hyperthyroidism is achieved by detection of clinical signs consistent with the disease, the presence of a palpably enlarged thyroid gland, and high serum thyroxine concentration (> 4.0 mg/dL). Other diagnostic techniques that may be used to evaluate a cat for hyperthyroidism include the triiodothyronine suppression test, thyrotropin-releasing hormone stimulation test, nuclear scintigraphy, thoracic radiography, thoracic or cervical CT, and cervical ultrasonography. The assessment of basal serum free thyroxine concentration by equilibrium dialysis, in combination with serum total thyroxine measurement, may aid in the diagnosis of hyperthyroidism in cats with mild disease, for which previous total thyroxine concentrations had remained within the reference range. Nuclear scintigraphy with technetium Tc 99m compounds and the use of a gamma camera is very effective in identifying hyperfunctioning thyroid glands as well as locating possible ectopic thyroid tissue; however, nuclear scintigraphy is expensive, requires patient quarantine, and necessitates regulatory controls to limit radiation exposure to both patient and operator.

Medical infrared thermal imaging may have potential as a noninvasive screening test for hyperthyroidism in cats. Studies involving MITI in humans with thyroid gland disease have revealed that this imaging technique is less expensive than scintigraphy (infrared cameras cost $8,000 to $18,000), noninvasive, and safe. Because MITI does not emit radiation, the procedure is not under legal regulation and does not require isolation of patients. The purpose of the study reported here was to determine the usefulness of MITI as a screening tool for hyperthyroidism in cats, evaluate the need for hair clipping over the ventral aspect of the neck to achieve optimal images, and determine whether there is a change in thermal patterns at 1 and 3 months after radioactive sodium iodide I 131 treatment.

Materials and Methods

Inclusion Criteria for Hyperthyroid Cats

All cats examined at Long Island Veterinary Specialists between October 2010 and February 2012 that had clinical signs consistent with hyperthyroidism and had a serum total thyroxine concentration > 4.0 mg/dL (reference range, 0.8 to 4.0 µg/dL) were included in the study. Written consent from the owner was acquired for each cat with hyperthyroidism in the study. Cats were excluded from the study when the physical examination revealed any comorbid disease associated with the ventral cervical area (eg, trauma or dermatitis) that may have affected image interpretation.

Control Cats

Healthy cats owned by employees of Long Island Veterinary Specialists that had no clinical signs compatible with hyperthyroidism and had serum thyroxine concentrations within the reference range provided by the laboratory performing the tests were selected for inclusion in the study. Written consent from the owner was acquired for each control cat’s study participation. Cats were excluded from the study if physical examination revealed any disease associated with the ventral cervical area.

Physical Examination and Serum Thyroxine Concentration Testing

All protocols for this study were approved by the department heads of surgery and internal medicine at Long Island Veterinary Specialists. Each cat underwent physical examination by a board-certified internist (JWT) at least 24 hours prior to admission for MITI and serum thyroxine concentration measurement. A blood sample (2 to 3 mL) was collected from the medial saphenous vein for biochemical testing. Control cats underwent MITI and serum thyroxine concentration measurement once; cats with hyperthyroidism underwent MITI and serum thyroxine concentration measurement 3 times (before and at 1 and 3 months after radioiodide treatment).

MITI

Prior to MITI, each cat had exercise restricted and was housed in a cage in a temperature-controlled (24°C), draft-free room for 30 minutes. The MITI was performed in another room (also maintained at 24°C). The MITI was performed in a room maintained at room temperature. A stand-mounted infrared camera with a focal plane array amorphous silicon microbolometer with an emissivity setting of 1 was used. For
real-time data analysis, the camera was connected to a laptop computer. To minimize thermal artifacts from manual contact, the cat was handled by the forelimbs and head by trained technicians who wore latex gloves at all times during handling. To minimize background artifact potentially created by temperature differences between exterior walls, each cat was positioned in front of a uniform interior wall with the camera placed 1 m in front of the cat. To expose the ventral aspect of the neck for MITI, the forelimbs were held and the head was extended dorsally (Figure 1). Image acquisition was instantaneous, similar to that achieved with a digital camera.

For each cat, the first set of infrared images was obtained with the coat intact. After the initial images of the unshaved cat were obtained, the hair of the ventral aspect of the neck was clipped with a No. 40 clipper blade in a manner consistent with surgical preparation (Figure 2). The imaging protocol used to obtain the initial images was again applied for each shaved cat 60 minutes after clipping, on the basis of previous research findings. A software program was used to save, analyze, and review the image data. Images were converted from black and white to a preset 8°C temperature scale and a 16-shade color map. White and red were selected to represent warmer temperatures and blue and black were selected to represent cooler temperatures. The program calculated the mean, maximum, and minimum temperatures of each image. Imaging processing software was used for pattern recognition and to analyze and evaluate thermographic patterns.

After the initial MITI data (obtained before and after hair clipping) for control and hyperthyroid cats were evaluated, the hyperthyroid cats underwent radioactive sodium iodide I 131 treatment. As part of posttreatment evaluations, MITI of cats with hyperthyroidism was performed in a similar manner (ie, before and after clipping of the hair on the ventral aspect of the neck) at 1 and 3 months after treatment. Control cats underwent MITI only once.

**RADIOACTIVE SODIUM IODIDE I 131 TREATMENT**

Cats with hyperthyroidism received radioiodide treatment in accordance with New York State regulations. The dose of radioactive iodine used to treat each cat was based on serum thyroxine concentrations. Each cat was brought to a lead-lined cat boarding room and given an SC injection (on the dorsum) of the appropriate radioiodide treatment. The cat was housed in an isolated feline boarding facility within the lead-lined room maintained at 24°C. Each cat remained in the hospital for a minimum of 5 days and was discharged only when the radiation level was < 0.5 mR/h. Each cat was discharged from the hospital with appropriate instructions for the owners regarding handling and discarding of litter in accordance with New York State regulations.

At 1 month after the initial examination, imaging, and radioactive sodium iodide I 131 treatment, treated cats were reevaluated. For each cat, the reevaluation included a complete history from the owners to evaluate clinical signs, a complete physical examination performed by a board-certified internist (JWT), and assessment of serum thyroxine concentration. Medical infrared thermal imaging was repeated (Figure 3).

**PRETREATMENT IMAGE ANALYSIS**

Ten sets of experiments were performed by applying 4 color transforms to the original images for both shaved and unshaved cats; 1 set of experiments corresponded to 1 set of images. After the color transforms, there were 5 sets of images obtained before shaving of the ventral aspect of the neck and 5 sets of images ob-
tained after shaving for each cat. An experiment consisted of a fixed set of image features with a data normalization method. Then, a leave-one-out cross-validation experiment was performed with the entire set of images by means of the $k$-nearest neighbors' algorithm for pattern classification. Percentage of correct classifications of images as being from a control or hyperthyroid cat for the leave-one-out pattern classification was the success rate. The temperature data were mapped to colors in the original images for visualization. To assure the pattern classification was unbiased, this visualization-based mapping was transformed into other mathematical color spaces to explore which mapping provided the best classification results. For this study, 4 color normalization methods (color normalization with luminance, grayscale color normalization, RGB color normalization, and RGB color normalization with luminance) along with the original RGB images were used to compose the 5 sets of experiments. To range-normalize the feature data before classification, 2 methods were used: softmax (or sigmoidal) normalization and standard normal density. The experiments were performed with computer vision and image processing software, and by means of the $k$-nearest neighbors algorithm for pattern classification, histographic, spectral, and texture features with a pixel distance of 6. Of these 16 sets, those with color transformations had 2,046 permutations; 4 sets, on the original data which did not include the mean feature, had 1,023 permutations.

Results

CLINICAL DATA

Seventeen cats with hyperthyroidism (consecutively examined) met the inclusion criteria. Their ages ranged from 9 to 17 years (mean, 12.6 years; median, 13 years). The cats’ weights ranged from 2.27 to 8.30 kg (mean, 5.67 kg; median, 4.69 kg). Before radioactive sodium iodide I 131 treatment, serum thyroxine concentrations in these cats ranged from 4.2 to 24 µg/dL (mean, 13.65 µg/dL; median, 12.3 µg/dL).

Twenty-eight cats were considered as controls. Sixteen cats were excluded because they were deemed too young to age match the clinically affected cats. One cat was excluded because of a high serum thyroxine concentration. Twelve cats confirmed to be healthy were included in the control group. These cats ranged from 6 to 18 years of age (mean, 10.75 years; median, 10 years). The cats’ weights ranged from 3.18 to 9.5 kg (mean, 4.9 kg; median, 4.5 kg). The serum thyroxine concentrations of the control cats ranged from 1.1 to 2.4 µg/dL (mean, 1.73 µg/dL; median, 1.8 µg/dL). Grayscale color normalization method analysis of images obtained prior to shaving of the ventral aspect of the neck provided an 80.5% accuracy in differentiating cats with high serum thyroxine concentrations (> 4.0 µg/dL) from the control population. Grayscale color normalization method analysis of images obtained after shaving of the ventral aspect of the neck and 10 sets of images obtained after shaving of the ventral aspect of the neck and 10 sets of images obtained after shaving for each cat. These experiment sets were the same as pretreatment images. Of those 10 sets of images for each cat, 5 sets of images comprised the 1-month recheck images and the other 5 sets comprised the 3-month recheck images. Additionally, 4 color normalization methods were used along with the original RGB images, as performed for pretreatment data. For the original data, 2 data normalizations were used: softmax normalization and standard normal density. Twenty sets of experiments were performed with the computer vision and image processing software, and by means of the $k$-nearest neighbors algorithm for pattern classification, histographic, spectral, and texture features with a pixel distance of 6. Of these 16 sets, those with color transformations had 2,046 permutations; 4 sets, on the original data which did not include the mean feature, had 1,023 permutations.

I- AND 3-MONTH RECHECK IMAGE ANALYSIS

Twenty sets of experiments were performed, with 10 sets of images obtained before shaving of the ventral aspect of the neck and 10 sets of images obtained after shaving for each cat. These experiment sets were the same as pretreatment images. Of those 10 sets of images for each cat, 5 sets of images comprised the 1-month recheck images and the other 5 sets comprised the 3-month recheck images. Additionally, 4 color normalization methods were used along with the original RGB images, as performed for pretreatment data. For the original data, 2 data normalizations were used: softmax normalization and standard normal density. Twenty sets of experiments were performed with the computer vision and image processing software, and by means of the $k$-nearest neighbors algorithm for pattern classification, histographic, spectral, and texture features with a pixel distance of 6. Of these 16 sets, those with color transformations had 2,046 permutations; 4 sets, on the original data which did not include the mean feature, had 1,023 permutations.

Results

CLINICAL DATA

Seventeen cats with hyperthyroidism (consecutively examined) met the inclusion criteria. Their ages ranged from 9 to 17 years (mean, 12.6 years; median, 13 years). The cats’ weights ranged from 2.27 to 8.30 kg (mean, 5.67 kg; median, 4.69 kg). Before radioactive sodium iodide I 131 treatment, serum thyroxine concentrations in these cats ranged from 4.2 to 24 µg/dL (mean, 13.65 µg/dL; median, 12.3 µg/dL).

Twenty-eight cats were considered as controls. Sixteen cats were excluded because they were deemed too young to age match the clinically affected cats. One cat was excluded because of a high serum thyroxine concentration. Twelve cats confirmed to be healthy were included in the control group. These cats ranged from 6 to 18 years of age (mean, 10.75 years; median, 10 years). The cats’ weights ranged from 3.18 to 9.5 kg (mean, 4.9 kg; median, 4.5 kg). The serum thyroxine concentrations of the control cats ranged from 1.1 to 2.4 µg/dL (mean, 1.73 µg/dL; median, 1.8 µg/dL). Grayscale color normalization method analysis of images obtained prior to shaving of the ventral aspect of the neck provided an 80.5% accuracy in differentiating cats with high serum thyroxine concentrations (> 4.0 µg/dL) from the control population. Grayscale color normalization method analysis of images obtained after shaving of the ventral aspect of the neck provided an 87.5% accuracy in differentiating cats with high serum thyroxine concentrations (> 4.0 µg/dL) from the control population.

Figure 3—Representative images of the unshaved ventral aspect of the neck of 2 cats obtained by MITI. A—Image obtained from a cat without hyperthyroidism. B—Image obtained from a cat with hyperthyroidism prior to radioactive sodium iodide I 131 treatment. C—Image obtained from the same cat in panel B 1 month after radioiodide treatment. D—Image obtained from the same cat in panel B 3 months after radioiodide treatment.
Cats with high serum thyroxine concentration (>4.0 µg/dL) that received radioactive sodium iodide 131 treatment and returned for re-evaluation 1 month later were all considered responsive to treatment, with improvement of clinical signs and reduction in serum thyroxine concentration. Fourteen cats (11 domestic shorthair, 2 domestic longhair, and 1 Siamese) underwent MITI 1 month after treatment. The 3 cats that were not re-evaluated at 1 month after treatment included a domestic shorthair that was euthanized at its regular veterinarian’s office because of metastatic lung disease, a domestic longhair that died of secondary heart disease at home, and a Himalayan that was euthanized at our facility because of renal failure. Of the 14 reevaluated cats, 10 had serum thyroxine concentrations within the reference interval (0.8 to 4.0 µg/dL), and 4 had serum thyroxine concentrations <0.8 µg/dL. Grayscale color normalization method analysis of images obtained before shaving of the ventral aspect of the treated cat’s necks at the 1-month recheck evaluation provided a 92.86% success rate in detecting cats with normal serum thyroxine concentration (<4.0 µg/dL). Grayscale color normalization method analysis of images obtained after shaving of the ventral aspect of the treated cat’s necks at the 1-month recheck evaluation provided an 85.71% success rate in detecting cats with normal serum thyroxine concentration (<4.0 µg/dL). At the 3-month recheck evaluation, 13 treated cats (11 domestic shorthair and 2 domestic longhair) were considered euthyroid with resolution of clinical signs and a return of serum thyroxine concentration within the reference interval. For these cats, the hyperthyroidism was considered successfully managed. Of those 13 cats, 11 had serum thyroxine concentrations within a range of 0.8 to 2.7 µg/dL, and 2 had serum thyroxine concentration <0.8 µg/dL (0.08 and 0.7 µg/dL). One cat was not returned for reevaluation. The RGB color normalization with luminance method analysis of images obtained before shaving of the ventral aspect of the treated cat’s necks at the 3-month recheck evaluation had a 100.00% success rate in detecting cats with normal serum thyroxine concentration (<4.0 µg/dL). Grayscale color normalization of the same images had a 85.71% success rate. The RGB color normalization with luminance method analysis of images obtained after shaving of the ventral aspect of the treated cat’s necks at the 3-month recheck evaluation had a 100.00% success rate for detecting cats with a normal serum thyroxine concentration (<4.0 µg/dL). Grayscale color normalization of the same images had a 92.86% success rate.

**Discussion**

In the present study, the computer recognition pattern analysis of the MITIs was successful in differentiating cats without hyperthyroidism from cats with hyperthyroidism. Results from images obtained from the shaved ventral aspect of the cats’ necks were better than those obtained prior to shaving, and grayscale color normalization was the best method of image analysis, with a success rate of 87.5%. The results of the present study are similar to results of human studies62-65 in which thermographic criteria were developed for euthyroidism, hypothyroidism, and hyperthyroidism. In 1 human study,66 thermal images of the thyroid gland of pregnant women were similar to the thermal images of euthyroid glands in other individuals, indicating the possible use of thermography as an objective method of diagnosis of thyroid gland disease in pregnant women. Detection of hyperthyroid cats can be difficult because serum thyroid hormone concentrations are in a constant state of fluctuation and cats with developing hyperfunctioning thyroid glands may have serum thyroxine concentration that is considered normal or equivocal at time of initial blood testing. As with any disease process, early detection and early initiation of treatment can affect the pathogenesis or outcome of the disease. Hyperthyroidism may either mask the presence of chronic kidney disease66 or contribute to the progression of chronic renal damage.66 It may also contribute to the development of cardiomyopathy (thyrotoxic cardiomyopathy)67 and result in systemic hypertension68 and the known constellation of hyperthyroidism-related clinical signs. It has been reported that treatment of the underlying disease of hyperthyroidism can reverse the changes in cardiac muscle66; however, if untreated, cardiac remodeling may become permanent, resulting in long-term (often progressive) clinical signs associated with cardiomyopathy. The secondary effect of systemic hypertension has also been reported to be reversible with treatment of the primary underlying disease process (hyperthyroidism).68 This suggests that early diagnosis and early treatment are beneficial. Medical infrared thermal imaging has also been successful in identifying cutaneous temperature changes associated with disease before onset of clinical signs.69 In the present study, several cats with slightly high serum thyroxine concentration had abnormal thermograms; therefore, MITI can be used to screen cats with borderline high serum thyroxine concentration for possible hyperthyroidism. Given the difficulty in shaving unsedated hyperthyroid cats, which can be fractious, and the success rate of 80.5% for MITI in cats with shaved neck regions, the need to shave the ventral aspect of a cat’s neck to achieve greater imaging success is questionable. The use of MITI as a screening test for hyperthyroidism in cats could be useful in areas with high cat populations, such as a feline shelter or cattery, or in rescue situations where cats are difficult to handle and costs of serologic evaluation are high. A quick, noninvasive test could separate clinically normal cats from high-risk cats and potentially decrease the time to diagnosis and treatment initiation. Medical infrared thermal imaging offers an ability to screen a large population...
of cats with less restraint of individuals and simple and fast image acquisition. Image generation is not complicated, and training of veterinary support staff is feasible; however, clinical pattern analysis software would be required.

In the present study, MITI analysis was also successful in identifying radioiodide-treated cats that had serum thyroxine concentration within the reference interval at the 1- and 3-month recheck evaluations. The 1-month MITI reevaluation analysis had a success rate of 92.86% in cats that were not shaved and a success rate of 85.71% in cats that were shaved. The results also supported the notion that shaving the ventral aspect of a cat’s neck for MITI may not be necessary. The 3-month MITI reevaluation analysis had even better results, with a 100% success rate for cats that were or were not shaved. Decreased handling of the cats that were not shaved may be responsible for the improved analysis success rates because of less stress and a diminished effect on the autonomic nervous system. These results have suggested that shaving the ventral aspect of a cat’s neck is not essential for noninvasive screening test for identification of cats likely with hyperthyroidism and monitor response to radio-iodide treatment; this was outside the scope of this investigation. Because no cats required a second or third radioactive sodium iodide I 131 treatment, it is unknown whether cats that do not fully respond to radioiodide treatment would have results of MITI analysis that correlated to serum thyroxine concentration.

Medical infrared thermal imaging could be a suitable noninvasive screening test for identification of cats likely to have overproductive thyroid glands. Results of the present study have indicated that MITI can detect cats with hyperthyroidism and monitor response to radioactive sodium iodide I 131 treatment. The method cannot be a specific test for diagnosis of hyperthyroidism because of other potential disease processes in the ventral cervical area. Other means of screening (ie, assessment of serum total and free thyroxine concentrations, triiodothyronine suppression testing, thyrotropin-releasing hormone stimulation tests, and scintigraphy) can be used to successfully evaluate a cat suspected of having hyperthyroidism.

Footnotes

b. CVIPools, Computer Vision and Image Processing Laboratory.

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References
