Use of Infrared Thermography in Early Diagnosis of Pathologies in Asian Elephants *(Elephas maximus)*

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ABSTRACT

Thermography is an imaging technique using a specialized heat sensitive infrared camera, mapping body surface temperature changes which may indicate inflammatory, vascular or neurological disorders. Thermal images were collected over three months from four Asian elephants at the Tisch Family Zoological Gardens in Jerusalem in which 935 body regions were identified with possible inflammatory pathologies. Suspected thermal areas were divided into three groups according to the appearance of inflammatory processes in a clinical examination: negative, positive and a pre-inflammatory group, which showed a thermal change while imaging, with clinical signs appearing only later on. An analysis of the documented regions it was found that in areas with a clinical signs delta temperatures were significantly higher compared to areas with no clinical signs. It was also found that pre-clinical areas showed a significantly higher temperature compared with that of the clinical and non-clinical areas. Receiver operating characteristic (ROC) test results showed an area under curve (AUC) of 0.91 with sensitivity values of 89.2% and a specificity of 83.4%. In addition, positive predictive value and negative predictive value received were: NPPV = 99.4%, PPV = 19.3%. It was concluded that thermography can be an effective diagnostic tool for early diagnosis of inflammatory processes and useful for regular and continuous monitoring of zoo elephants in general. Early detection of inflammatory processes using this technique makes it possible to prevent unnecessary stress that often accompanies veterinary examinations and to accelerate recovery.

Keywords: Infrared Thermography; Diagnosis; Inflammation; Asian Elephant; *Elephas maximus*.

INTRODUCTION

Infrared thermography is a noninvasive method for remote sensing of temperature distribution pattern on the surface of the body. Infrared thermography (IRT) makes use of the physical characteristics of bodies or materials to emit electromagnetic waves, and with the aid of a special detector, these rays are visible (1).

Infrared thermography systems use a detector, thermal scanner and image projection screen. The obtained image can be analyzed, using appropriate software, to measure the temperature values in the given area of the object in question (2). Such systems have long been used in industry, construction, astronomy and security services (1). Recently, use of this technology has been adapted to human and veterinary medicine, animal husbandry, biology and ecology (1). In human medicine, IRT has been successfully used in diagnosis of breast cancer, diabetes neuropathy and peripheral vascular disorders. It has also been used to detect problems associated with gynecology, kidney transplantation, dermatology, heart, neonatal physiology, fever screening and brain imaging (3).

In studies of animals, thermal imaging cameras are used remotely, and the observed subject does not have to be restricted or sedated, which significantly reduces stress levels. Infrared thermography is a useful tool in studies of livestock (without compromising their welfare), wild animals (detection of animal habitats, estimation of the population size), and zoo animals (4). Recently, Soroko and Howell published a guidelines for the appropriate use of thermography in equine medicine (5).

There are several reports on the use of thermography on wild animals: Dunar *et al.* used infrared thermography to detect temperature changes in mule deer (*Odocoileus hemionus*) infected with foot-and-mouth disease (6), Arenas *et al.* applied IRT imaging to diagnose sarcoptic mange in wild Spanish ibex (*Capra pyrenaica*) (7). Dunbar and MacCarthy used IRT to detect the signs of rabies infection in raccoons (*Procyon lotor*) (8). Hilsberg-Merz relied on IRT to diagnose ovulation in captive Asian elephants and black rhinoceros (9). Studies of thermoregulation using IRT in different species include: African elephants (10), Eurasian otter (*Lutra lutra*), giant otter (*Pteronura brasiliensis*) (11) and three fox species (12).

The IRT technique has certain limitations that must be taken into consideration. Weather condition factors such as solar radiation, precipitation, wind, and ambient humidity significantly affect measurement results (1). The distance between the object and the thermal imaging camera can influence results and rounded surfaces may lead to images of colder borders due to non-equal distances from the camera which can be corrected by the computer program (9). Physical properties of the animal coat, the thickness and quality of a hair or feather coat may significantly affect the temperature on the outer surface of the body. Both internal and external factors have a significant effect on body surface temperature. The proper use of thermography to evaluate surface thermal patterns therefore requires a controlled environment. The physiological state as well as the physical activity of the animal must also be considered to reduce variability and eliminate errors of interpretation (13).

Heat production is one of the cardinal symptoms of inflammation. Tracking inflammatory processes in both wild animals and zoo animals is a major advantage of the IRT method. It is best used in animals without long hair such as elephants, giraffes and other large herbivores (9). This study focuses on the use of thermal imaging in the progression of inflammation of the integuments and the feet of Asian elephants (*Elephas maximus*).

Pathologies reported in captive elephants that are related to the integuments are common and encompass one-third of all medical events reported in a retrospective study from North America (14). Common skin disorders listed for elephants in captivity include: parasitic dermatitis, superficial bacterial dermatitis, skin wounds, lacerations, ulcers and abscesses (15). There is a high prevalence of foot problems in elephants. In a retrospective study of 379 elephants, 50% were affected by foot disorders (14). Non-resolvable foot infection and arthritis are major causes of euthanasia in elephants (16). Foot pathologies include: pododermatitis from different etiologies, toenail cracks, subsolar abscesses, osteomyelitis and infected arthritis (17).

Early diagnoses of pathologies are critical in order to initiate treatment and prevent deterioration. Many problems are very difficult to detect in elephants, as there are no clinical signs during visual inspection but they are visible in the early stages when using IRT (9). In a preliminary study performed at the Tisch Family Zoological Gardens in Jerusalem, IRT images were taken during a case of a trunk abscess and revealed the extensiveness and the severity of inflammation prior to the clinical manifestation (unpublished data).

The aim of this study was to evaluate whether the thermal camera can be used as a screening tool to identify pathologies in Asian elephants.

METHODS AND MATERIALS

The study was approved by the ethics committee of the Tisch Family Zoological Gardens in Jerusalem, following all current national and international animal welfare recommendations.

Animals

The study included four Asian Elephants resident at the Tisch Family Zoological Gardens in Jerusalem: three cows (aged 28-33 years) and one bull (aged 21 years). The elephants were trained with routine activities (morning yard walk, hosed down in the night house and feeding). In order to minimize the environmental impact, animals were adapted to environmental conditions for a minimum of 30 minutes before imaging (1).

Imaging

Images were taken, around a fixed physical point, once a week, over a three months period. Two to three images were taken of each animal consisting of the head, ears, body and legs (Figure 1). Distance from camera to subject was between 2-3 m. When pathology was suspected, the frequency of imaging was raised to twice a week. In order to minimize the effects of the environment, measurements of the differences between the maximum temperatures (Tmax) to the minimum temperatures (Tmin) in the suspected thermal areas were calculated (ΔT).

Suspected thermal areas were divided into three groups according to appearance of inflammatory pathologies in a clinical examination; negative, positive and a pre-clinical group that showed a thermal change while acquiring the image however clinical signs appeared only on physical examination later on.

Photographs were taken with JENOPTIK infrared high resolution camera VarioCAM® (Germany). Thermal photographs were analyzed using computer software Irbis View which is provided with the thermal camera (Figure 2).

Statistical Analysis

The findings were examined for statistical correlation between clinical signs and thermal evidence; a statistical correlation between a clinical signs with a high ΔT and the preclinical phase with high ΔT, and healthy tissue with low ΔT. In order to compare quantitative variable between two groups the independent t test was used.

Quantitative comparisons of changes between 3 groups or more was performed using one-way analysis of variance (one way ANOVA) with paired comparisons; Dunnett's test with repair multiple significance levels. Simultaneously, examination of the influence of two factors, and the interaction between them with the quantities varying depending on whether the model used is a two-way analysis of variance (Two Way ANOVA).

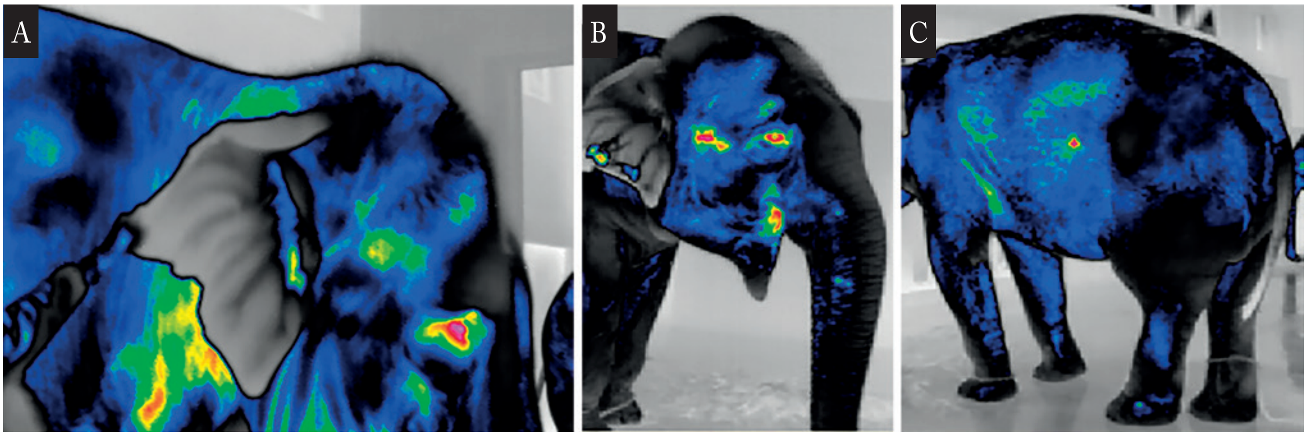


Figure 1: Elephant thermal images: A: ears, B: head, C: body and leg

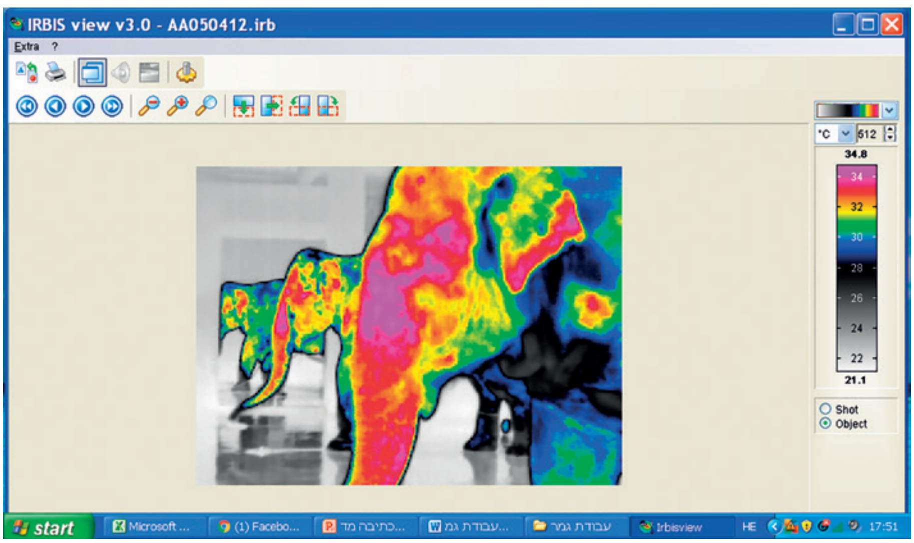


Figure 2: An example of the analysis using computer software Irbis View

Receiver Operating Characteristic (ROC) analysis was applied to find the optimal cut point (with high sensitivity and specificity) for quantitative changes that would allow differentiating between two different categories. All statistical tests were two-directional and a P value equal to or less than 5% was considered to be of statistical significance.

RESULTS

During the study period, 935 areas suspected for presence of inflammatory pathologies were recorded. Fifty areas were defined as preclinical and 68 areas defined as clinical. When checking the pathologies scattering body zones as shown in Table 1, all clinical changes were recorded in the ears and all the other body parts were found free of pathologies. Pathology found in the ears consistently comprised of edema with purulent pustules located on the edges of the ears.

A review of TΔ according to regions (Table 2) showed that TΔ (delta values) was significantly higher, with an average of two degrees in areas with clinical signs compared to areas without clinical signs. Figure 3 displays the graphical differences between the regions.

When comparing the differences TΔ in areas without pathology, with clinical and preclinical signs, (Table 3), the average TΔ pre-clinical areas was the highest (9.52) followed by clinical areas (7.56) and the non-pathological TΔ areas which were lowest (5.27). These differences were found to

Table 1: Scatter pathologies according to body regions

	Without pathologies	With Pathologies	Total
Head	425	0	425
Body	156	0	156
Legs	230	0	230
Ears	56	68	124
Total	867	68	935

Table 2: delta temperature values to accordance pathologies

Group/Parameter	Without pathologies	With Pathologies	T(935)
Differential (TΔ)	(2.32)7.56	(2.4)5.45	(P<0.001)6.97

Table 3: values of the temperature difference (TΔ) according to pathology

Area/Parameter	Average	SD
Without pathologies	5.27	2.24
Preclinical pathologies	9.52	2.23
With pathologies	7.56	2.32

Figure 3: Delta values of temperatures according to pathology

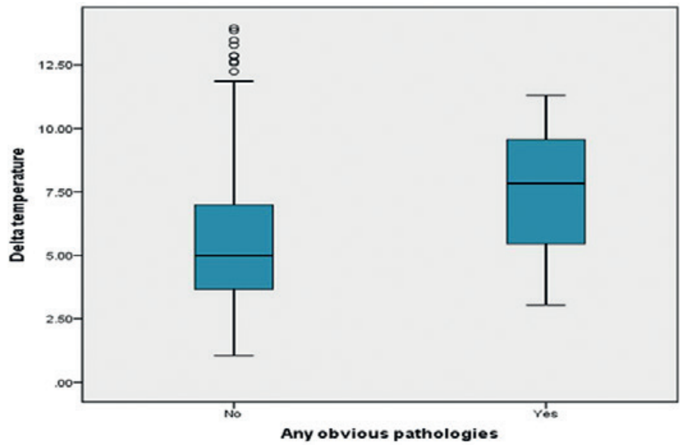


Figure 4: Delta temperature values according to pathology

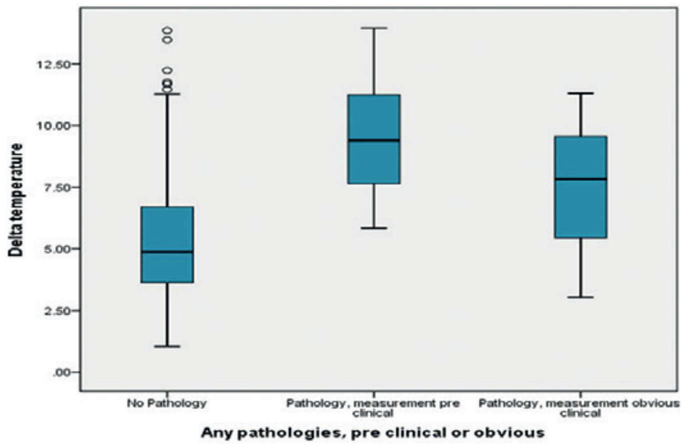
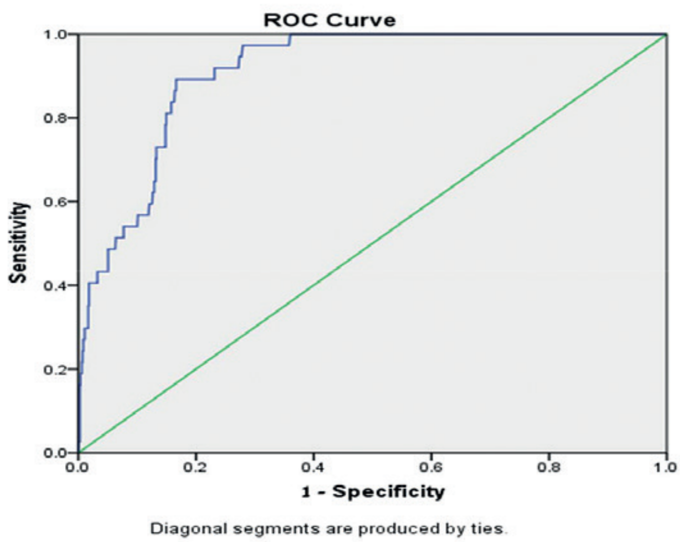


Figure 5: ROC curve test comparing the difference in temperature (TΔ) between the no pathology group with the preclinical pathology group.



be statistically significant using the One Way ANOVA test {F (2,932) = 90.78, p<0.001}.

Significant differences were found when comparing any pair of combination between the three areas. The largest and most significant difference was between the areas with no pathologies and areas with preclinical signs. The TΔ was higher in areas with preclinical signs. (Figure 4)

In order to determine the sensitivity and specificity values for using a thermal camera as a diagnostic technique, the ROC test was used. Comparing the differences in temperature (TΔ) between the non-pathology group (0) with the preclinical signs group (1) (Figure 5), results showed an area under curve (AUC) of 0.91 with sensitivity values of 89.2% and a specificity of 83.4%. In addition, positive predictive value and negative predictive value received were: NPPV = 99.4%, PPV = 19.3%.

DISCUSSION

During this study, elephants were studied over a period during which they developed pathological inflammatory lesions in their ears. A good correlation was found between the inflammatory lesions diagnosed clinically and the area suspected of pathology determined by the thermal camera. The thermograms show differences of approximately 2 degrees, between a clinical (with ΔT higher) and a non-clinical area (with low ΔT) (Figure 3). Distribution of pathologies according to the appearance of clinical signs (without pathology, preclinical and clinical) found a significant difference between the preclinical phase and the clinical phase with high ΔT and the non-clinical phase having a low ΔT.

The results indicated that the thermal camera was able to identify the temperature increases in the elephant's ears before clinical identification. An analysis of the documented pathologies found that in areas with clinical signs, delta temperature was significantly higher compared to areas without clinical signs. It was also found that pre-clinical areas showed a significantly higher temperature compared with that of the clinical and non-clinical areas (Figure 4).

The fact that clinical disease was recorded in the ears and other body areas with no pathologies may lead to some falsification. The changes in the ears may be explained by the difference in the quantity of heat emitted from inflammatory process and vascularization that exists in the ears due to their thermoregulatory function (1, 11, 12). These findings should be analyzed in the light of the infrared camera limitations.

When evaluating thermal imaging as a diagnostic tool, it appears to be sensitive (89.2%), specific (83.4%), with very good negative predictive value (NPPV = 99.4) and very low positive predictive value (PPV = 19.3). High sensitivity makes diagnostic thermal imaging an efficient screening test, however the low PPV of this tool implies that more diagnostic procedures will be needed to confirm diagnosis of the suspected pathologies. This research supports the use of thermal camera as a routine method in early detection of pathologies in elephants and potentially in other wildlife.

One important limitation of the current study is the small population evaluated (4 elephants) thus more studies should evaluate DTI using other species in order to broaden the spectrum of use and validate the results. Future studies are important to confirm validation of this tool for use in diagnosing different pathologies in a variety of animals.

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