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Abstract

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Keywords

mass, maggot, documenting, temperatures, tool, infrared, invasive, non, imaging

Disciplines

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Infrared imaging as a non-invasive tool for documenting maggot mass temperatures

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Abstract

Forensic entomology relies on the ability to predict the temperatures to which maggots have been exposed, due to the resultant impact on their growth rate. Mercury thermometers and electrical temperature sensors have traditionally been used to record temperatures of maggot masses, cadavers and the surrounding soil and air. However, these techniques are limited to one measurement at a time and thus may not accurately describe the complexities of the thermal environment of the cadaver. Infrared imaging has gained increasing popularity because of its resolution, affordability and portability. Using decomposing pig carcasses, the current study showed that surface temperature measurements recorded using temperature loggers are able to be successfully replicated by taking spot measurements from an infrared image. Additionally, by recording the maximum temperature observed within each infrared image, an accurate proxy was achieved for internal temperatures of a carcass placed outdoors ($R^2=0.46$, $p<0.001$). By studying a pig in a temperature-controlled room and thus removing external environmental factors, the strength of the relationship between maximum infrared temperature and internal carcass temperatures was increased ($R^2=0.98$, $P<0.001$). This successful characterisation of maggot mass temperatures within carcasses should encourage the application of infrared imaging in forensic entomology research and casework.

Keywords

Forensic entomology, blow flies, minimum post-mortem interval, *Chrysomya rufifacies*.

Introduction

Forensic entomologists utilise the predictable growth rate of blowfly (Diptera: Calliphoridae) larvae to estimate the minimum post-mortem interval (PMI) in homicide cases¹⁻². Because growth rate of maggots is influenced heavily by temperature, the entomologist must first estimate ambient temperatures, generally by correlating nearby automated weather station data with temperature loggers placed at the crime scene³⁻⁴. Growth rate data of the blowfly species identified on the corpse, for this estimated average temperature, can then be used to provide an estimate of the maggot's age and therefore a minimum PMI¹⁻². However, forensic entomologists recognise the need to incorporate the temperatures reached within a maggot mass, which can be in excess of 30°C above ambient, into maggot age calculations⁵⁻⁶.

Many studies have tried to predict mass temperatures based on mass size, density, ambient temperature, and species and instar composition^{e.g. 7-8}. Slone and Gruner estimated mathematically that mass size was a key component in the temperatures generated by the larvae, with masses over 20 cm³ self-regulating and not influenced by the surrounding air or soil temperatures⁷. The formulae derived by Slone and Gruner were calculated for external, surface masses only, for which mass size could be easily measured⁷. However, this limits the application of this approach in research and casework, as masses generally form in orifices and in unexposed areas of the body. Charabidze et al. showed that the density of maggots feeding on meat also influenced mass temperatures, with heating maximised when maggots were fed on 50–100% of their weight in meat⁸. Furthermore, it was found that a mass of third-instar larvae will heat 2–4°C higher than the same number of second-instar larvae. However, when the overall weight of the larvae was considered, it was found that this temperature increase could be explained by the difference in weight between the second- and third-instar masses, and if masses of the second- and third-instar maggots were of the same weight, then equivalent temperatures were generated⁸. While such studies aid in understanding the factors contributing to temperatures generated within a maggot mass, methodology suited to casework must be established for estimating accurate mass temperatures.

Infrared imaging has been used in medical and industrial settings for decades⁹⁻¹⁰. It is becoming more widely used across diverse research fields as the affordability, resolution and portability of the technology improves⁹⁻¹¹. In the field of invertebrate biology, infrared imaging was recently used in observational and thermal manipulation experiments^{e.g. 9, 12-13}. Within the forensic sciences, infrared technology has been utilised in analysis of blood spatter¹⁴, location of indoor cannabis growing operations and sums of cash or drugs hidden within walls or floors, and has also been used to assist in locating buried bodies in recently disturbed soil¹¹. However, to date, there appear to have been no published forensic entomology studies that have utilised this technique. Given the important role that temperature plays within this field, the use of non-destructive infrared imaging should be applied primarily to research, but should also begin to be considered as a tool to further aid in PMI estimation.

Although not specifically applied previously to forensic entomology, infrared imaging has been used to observe the heating of carcasses during decomposition¹⁵. Furthermore, preliminary observations carried out by the current authors of a stillborn piglet over 5 days revealed clear indicators from infrared imaging of maggot mass heating. A 'hot spot' originated in the head and shifted into the chest cavity, corresponding with the observed activity of the maggot mass (Figure 1). However, until now such anecdotal observations have not been explored further to develop infrared

imaging techniques to predict actual maggot mass temperatures. In order to establish the value of this technique as a research tool in forensic entomology, we therefore present further observations from carrion using such technology, drawn from separate, broader studies on decomposition and maggot thermogenesis. The general purpose of this brief communication is to document the use of infrared imaging and highlight its potential, pending further, more detailed experimental studies.

Infrared imaging records surface temperatures of a body, but cannot provide internal temperatures. Nevertheless, surface temperatures may be used to estimate internal temperatures during decomposition. There are several advantages of infrared imaging over traditional temperature recording devices, such as mercury thermometers and electrical temperature sensors: 1) it can record temperatures across a wide area (potentially a whole carcass or corpse) in a single image and thus does not require multiple measurements; 2) there is no associated risk of overlooking regions of the substrate that are undergoing heating due to maggot mass effects; 3) it may assist in locating the position of multiple maggot masses; and 4) it is non-invasive and non-destructive and therefore does not risk disrupting a maggot mass or disturbing evidence during data collection.

The specific aim of the current work was to establish that infrared imaging can be used to locate a maggot mass within a carcass and estimate associated maggot mass temperatures.

Methods

Outdoor observations

Infrared images taken during two separate sets of observations, one in the field and the other within a temperature-controlled room, were used to estimate maggot mass temperatures. In the field-based work, a single pig carcass weighing 25 kg was placed in an open grassed field near Mt. Stromlo, ACT during December 2009. The pig was shaded with 70% shade-cloth to prevent reflection interfering with the infrared temperature readings. An iBCod temperature logger (Thermodata, Australia) was inserted into the chest cavity of the pig via an oesophageal tube and two additional iBCod loggers were placed on the surface of the pig and on the surrounding cage to determine surface and ambient temperatures. These loggers recorded temperatures every 3 h. An infrared camera (S65 ThermoCAMTM, FLIR, Australia) was connected to a car battery and set up on a tripod to record an image of the pig every 30 mins for a period of 7 days. This pig was monitored as part of a larger, unpublished field study on decomposition being conducted by Catherine Fitzgerald (Australian National University).

Indoor observations

For the observations made in the temperature controlled room, a pig carcass weighing 10 kg was placed into a plastic tray (520 x 900 x 170 mm) and rested upon a 100 mm layer of wheaten chaff in a temperature controlled room in the Ecological Research Centre at the University of Wollongong during October 2010. The room was set to 23°C with a 12:12 light:dark cycle. Three batches of *Chrysomya rufifacies* (Macquart) eggs, from three separate laying events (approx 1000 eggs in each), were placed into the mouth of the pig carcass to provide a maggot mass. This species was chosen as it was the predominant species observed within the masses of the field carcass. A temperature probe connected to a TinyView temperature logger (Gemini Data Loggers, UK) was inserted into the

abdominal region of the pig via the rectum and an iBCod temperature logger (Thermodata, Australia) was placed in the mouth. Temperatures were logged every 15 mins. The whole pig carcass was also photographed using an infrared camera (S65 ThermoCAMTM, FLIR, Australia), as described for the carcass in the field, over a period of 9 days. This pig was investigated as part of a larger study on larval thermogenesis by the authors.

Analysis

Temperatures recorded by the loggers were plotted against time, along with maximum temperature and point temperatures for the location of the external logger recorded in the infrared image. Linear regressions between readings were conducted using JMP v9 (SAS systems) to assess how reliably infrared images could be utilised to predict surface and internal temperatures of carcasses.

Results and Discussion

Outdoor observations

The temperature recorded by the logger placed on the surface of the pig closely followed ambient temperatures. Temperatures experienced inside the pig carcass started to deviate from ambient after the third day, as temperatures were much warmer than ambient (Figure 2). This is a commonly observed phenomenon in larval aggregations, as maggot masses typically form within a carcass and associated heating thus occurs internally, while the surface temperatures of the carcass remain at ambient^{5-6, 16}.

Analysis of the infrared images revealed that infrared imaging is a useful tool in documenting the thermal environment within a carcass. The temperature recorded by the surface logger can be easily replicated by taking spot temperature measurements using the infrared images for the exact location where the logger was positioned. It is important to note that infrared cameras detect all infrared radiation coming from the object of interest, regardless of whether it is emitted or reflected by the object. It is therefore important, as was done for this pig, that the object be shaded to prevent solar reflection interfering with the temperature readings.

As expected, there was a significant relationship between the temperatures recorded by the logger and the infrared camera for the same location ($R^2=0.85$, $p<0.001$). Furthermore, the slope of the line was close to 1 (true slope 0.94) and the intercept close to 0 (true intercepting 0.5). This relationship indicates a 1:1 relationship, indicating that similar temperatures were recorded by the two devices, showing that infrared imaging can accurately record surface temperatures of carcasses.

Additionally, by recording the maximum temperature observed within each infrared image, an accurate proxy is achieved for predicting internal temperatures of the carcass, particularly after the initial heating peak. In support of this, a significant relationship was found between maximum infrared (IR) temperatures and internally recorded temperatures of the carcass ($R^2=0.46$, $p<0.001$).

Indoor observations

In order to remove the factors of solar radiation, fluctuating temperatures and convective cooling via wind, data from the pig carcass decomposed in a temperature-controlled room were also analysed to ensure that the abovementioned relationships held true. Maximum IR values peaked much earlier than those recorded by the internal probe; however this was likely due to the mass being introduced via the mouth of the pig. Therefore, the increased temperatures recorded by the IR camera reflected mass heating that occurred in the head of the pig but that was not consequently recorded by the abdominal probe (Figure 3a). This is evident by the temperatures recorded by the logger in the mouth, which peaked at the same time as the IR values, while declining much earlier as the mass moved further into the carcass. By day 6, the maggot mass had moved into the abdominal cavity (Figure 3b), after which the maximum IR temperatures and the internal temperatures had an almost perfect correlation ($R^2=0.98$, $P<0.001$) (Figure 4).

In conclusion, we have shown that infrared imaging can be successfully utilised as a non-invasive tool for identifying not only the location of maggot masses, but also the temperature of these masses, along with providing a holistic view of the thermal environment available to the maggots infesting a carcass. The technique would be enhanced by a better understanding of how clothing or other sources of insulation, such as fat layers, might affect the accuracy of infrared data for predicting internal carcass temperatures. Use of this technology should also help refine the temperature data available to entomologists for use in maggot growth rate predictions by more rigorously assessing the range of temperatures available for selection by maggots within a given mass. With ongoing development, infrared imaging should prove an invaluable asset in future forensic entomology research and casework.

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Ethical Standards

The pig carcasses used in this study either died of natural causes or were covered under Australian National University Animal Ethics Protocol Number S.AA.08.08.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Figure 1. Infrared image taken of a stillborn piglet, showing increased heating within the chest cavity, indicative of the position of a maggot mass.

Figure 2. Temperature data recorded using iBCod temperature loggers and an infrared camera to capture ambient, surface and internal temperatures of a pig carcass located in the field.

Figure 3. Infrared images showing the mass heating evident in the (a) head region on day 3 and (b) abdominal cavity on day 6 of a pig carcass kept in a 23°C constant temperature room.

Figure 4. Temperature data recorded using iBCod temperature loggers and an infrared camera to capture ambient and internal temperatures of a pig carcass kept in a 23°C constant temperature room.