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Determining the emissivity of pig skin for accurate infrared thermography

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ABSTRACT

Infrared thermography may be used for pig health screening and fever detection. In order to achieve the necessary accuracy for this purpose, it is necessary to know emissivity of the skin surface. Previous investigations attempting to find the emissivity of pig skin revealed numbers from 0.8 to 0.955. Such discrepancies can result in measured surface temperatures differing by several degrees Celsius. An unacceptable discrepancy if used for fever screening.

In this study we determined the emissivity of three skin locations in ten sows when they were alive and dead: the ear base, udder and shoulder. The shoulder was investigated with and without (clipped) hairs.

Emissivity for ear base, udder, and shoulder (hairy) was 0.978 ± 0.006, 0.975 ± 0.006 and 0.946 ± 0.006, respectively. Clipping the hairs of the shoulder tended to increase the emissivity ($p = 0.07$). Emissivity of the hairy shoulder was significantly lower than for the ear base ($p < 0.001$) and the udder ($p < 0.005$). Emissivity of the three skin areas with no blood perfusion (after euthanasia) tended to be lower ($p = 0.06$) compared with the emissivity of the skin areas when perfused with blood. The results of this study confirm that it is valid to use the human skin emissivity value of 0.98 for infrared skin measurements on sows. However, when studying hairy skin areas or skin with no blood perfusion, the emissivity value is lower.

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1. Introduction

Automatic and rapid evaluation of pig health is of increasing interest in the pig production industry. Infrared thermography (IRT) is one of the promising technologies for performing automatic surveillance of pigs for health screening. IRT offers major advantages for measuring temperature in pigs compared to other techniques, such as rectal and contact skin thermometers or ingestible/implantable thermal sensors. It is a non-obtrusive, non-invasive method, where restraint of the pigs is unnecessary with no risk of infection spread during the screening process.

Knowing the emissivity (ε) of the skin is required for correct, absolute temperature measurements using IRT. This number describes a materials ability to emit energy by radiation. Using an incorrect emissivity value when measuring, for example, pig skin temperature with an IR camera (IRC) can result in serious measurement error. Only a few studies have investigated the emissivity of pig skin. Metternick-Jones and Skevington (1992) found the emissivity of pig skin to be between 0.92 and 0.93 using auto-emissivity adjustment in an IR thermometer based on surface temperature measured by an RTD thermal sensor, while it was 0.8 using the manual emissivity adjustment in the IR thermometer until matching surface temperature measured by the aforementioned RTD thermal sensor. Gariepy et al. (1989) found the skin in the dorsal area to have an emissivity of 0.95. Kelly et al. (1954) used a radiometer and found the emissivity of a hairy pig skin area to be 0.93, a value they later decided to adjust to 0.955, based on findings on human skin (Hardy, 1934). Actually, many of the studies measuring the skin temperature in pigs using IRT have used the emissivity of human skin, observed to range between 0.93 and 1.00 (Gartner et al., 1964; Hardy, 1934; Sanchez-Marin et al., 2009; Steketee, 1973; Togawa, 1989; Villasenor-Mora et al., 2009). It is fair to say that the consensus is that the emissivity of human skin is 0.98, which is also the value most researchers have used in the pig studies.

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The aforementioned study by Metternick-Jones and Skevington (1992) investigated the emissivity of pig skin using dead pigs and reported the lowest pig skin emissivity of 0.8. Human studies investigated the skin emissivity changes due to blood perfusion (Gartner and Gopfert, 1964; Gartner et al., 1964) and showed a reduction in emissivity by as much as 0.04 when restricting blood perfusion to the human forearm. This raises the question if blood perfusion affects the pig skin emissivity?

Some studies investigated the correlation between rectal temperature and IRT measured surface temperatures at various sites, including the eyes, ears, vulva, udder, axilla, side, loin/back, shoulder, and snout (Chung et al., 2010; Dewulf et al., 2003; Loughmiller et al., 2001; Magnani et al., 2011; Malmkvist et al., 2012; Schmidt et al., 2013; Sykes et al., 2012; Tabuaciri et al., 2012; Traulsen et al., 2010; Warriss et al., 2006; Wendt et al., 1997; Zinn et al., 1985). The relationship between ambient air temperature and pig surface temperatures at different sites, including eyes, ears, loin/lumbal area, shoulder region, legs, abdomen, udder, and snout, have also been investigated (Collin et al., 2002; Henken et al., 1991; Loughmiller et al., 2001; Malmkvist et al., 2012; Nanni Costa et al., 2010; Savary et al., 2008; Wendt et al., 1997). However, some of the mentioned studies were, in part (Wendt et al., 1997) or completely (Collin et al., 2002; Henken et al., 1991; Loughmiller et al., 2001; Magnani et al., 2011; Nanni Costa et al., 2010; Tabuaciri et al., 2012), performed on pigs weighing 35 kg or below, which have different thermoregulatory mechanisms than those of sows and therefore may not be a good model for sow studies. From the surface areas chosen in the mentioned studies, the most reliable and accessible in practical measurement scenarios for sows are probably the ear base, shoulder and udder. Especially during the lactation period, which is arguably the most interesting period for sow health screening. The orbital area (inner canthus) may be a better site as suggested for humans in the International Electrotechnical Commission 80601-2-59 standard (IEC, 2008). However, it is impractical in sow studies, since sows are usually stalled facing toward walls when in farrowing crates, making it difficult to get good measurements with an IRC. Furthermore, sows move their heads quite frequently, and slight movements during IRT acquisition will cause averaging of the relatively small area covering the inner canthus and the surrounding area.

The purpose of this study was to determine the emissivity of adult pig skin at the shoulder, ear base, and caudal part of the udder, and determine if there is an effect of hairiness and blood perfusion on the emissivity.

2. Materials and methods

The basis for determining the emissivity of pig skin in this study was by measuring the skin temperature with an accurate reference PT-100 sensor (model Dostmann sharp tip 6000-1023S sensor, ThermoWorks Inc., Lindon, UT, USA) and comparing it to the corresponding skin temperature measured by IRT. Ideally, the difference would be attributed to the emissivity of the skin. All temperature measurement devices used in this work were calibrated accredited at the Danish National Reference Laboratory for Non-contact Thermometry at The Technical University of Denmark, Roskilde, Denmark.

2.1. Infrared camera calibration

To ensure accurate IR measurements the recommendations described in the International Electrotechnical Commission 80601-2-59 standard (IEC, 2008) were followed wherever possible. IRCs require, like other electronic measurement equipment, regular calibrations and corrections (Plassmann et al., 2006). Issues like stability, start-up drift, long-term drift, offset variation over temperature measurement range, image non-uniformity and flooding are known to affect infrared thermography measurements (Jiang et al., 2005; Machin and Chu, 2000; Plassmann et al., 2006; Ring et al., 2007). Measurements prior to the experiments had shown that the IRC required an hour to stabilize after being turned on. Before any IRC measurements in this study, the IRC had been on for more than an hour.

Calibration using a black body cavity ($\varepsilon > 0.999$) at the Danish National Reference Laboratory for Non-contact Thermometry (Technical University of Denmark, Roskilde, Denmark) revealed that the IRC measured 0.20 °C less than the black body cavity at 40.00 °C in the center of the field of view (FOV). As the skin area region of interest (ROI) was in the center of the FOV in all measurements, a correction factor of 0.20 °C was added to all thermal images in the post processing analyses.

2.2. Measurements

2.2.1. Animal handling

Multiparous Danish Landrace × Yorkshire sows (4–8 parturitions, $N = 10$) were selected for this study. The study was approved by the Danish Animal Experiments Inspectorate according to the permission given September 2013 (J.nr.: 2013-15-2934-00932/JANNI).

The sows were anesthetized by intramuscular injection with a mixed solution consisting of 1 bottle of Zoletil dry matter (mix of 125 mg Tilematin and 125 mg Zolazepam) dissolved in 2.5 ml Torbugesic, 1.25 ml Ketaminol (100 mg/ml), and 6.25 ml Rompun. The dosage was 1 ml/10 kg. Knowing that stress reduces the impact of the anesthesia, the sows were led calmly into the room where the experiments were undertaken prior to the injection. The sows were allowed to walk freely in the room (approx. 3 by 5 m) until the anesthesia took effect and they lied down. If their eyes and/or eyelids moved after an additional wait time of 15 min, the sows were injected with an additional 5–10 ml of Zoletil-mix. When the eyelids were no longer moving and the breathing was relaxed, the sow was moved away from the wall if necessary and laid on their side allowing visual access to the ear base, shoulder and the caudal part of the udder for the IRC and also to provide space for the IR acquisitions. If any of the measurement sites were dirty or otherwise deemed unsuited for the measurements, the sow was turned to the other side. All measurement sites were dry when measured.

2.2.2. Ambient setting

All experiments were conducted in the same room. The windows were covered with sheets of cloth to minimize the effect of incoming sun radiation, that when absorbed, may heat up the irradiated surfaces. Most experiments were conducted on cloudy days. The room size was approx. 5 m × 7 m, but a large 1 m high double-plated plastic wall was set up to reduce the size of the area to 3 m × 5 m and to further reduce the sunlight radiation impact to a minimum and to prevent draft from the windows. All doors were kept shut and there were no ventilation ducts in the room. The room was clean, with no visible dust or perceivable odor of ammonia in the air. Ammonia has an absorption peak at approx. 10 μm, which could influence the IR measurements (Soerensen et al., 2011). Air movement was minimal (<0.02 m/s), which was confirmed by measurement taken approx. 5 cm above the concrete floor using a hot wire anemometer (Testo 425, Testo AG, Lenzkirch, Germany) before start of the measurements on each sow. Relative humidity was logged every minute (THS-296-061 ThermaData Logger, ThermoWorks, Lindon, UT, USA). This logger has a humidity accuracy of ±2%RH. The logged data was retrieved after each

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