Design and Validation of a Wireless Temperature Measurement System for Laboratory and Farm Animals

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Background

In animal research, reliable monitoring of physiological body parameters is essential for obtaining good scientific results. One of the more fundamental of those parameters is core body temperature. The traditional way of measuring temperature is using a standard thermometer, inserted rectally. The value measured in this way gives a good indication of the core body temperature. There are, however a number of drawbacks: the measurement procedure is highly interfering and may even influence the temperature; the procedure is time consuming, labour intensive and not without risk; the value measured may be influenced by the skill and the 'touch' of the person performing the measurement. It's also easy to see that rectal measurements are not suitable if:

- The group of animals is large.
- The duration of the test is long (more than a couple of weeks).
- More frequent data than, say, once per hour is required.

A possible solution to all these points is using a measurement device permanently inserted into the animal and arrange it so that this device communicates wirelessly with some receiving unit in the vicinity. Later on we will describe just such a system but first we will take a closer look at traditional temperature measurements involving piglets.

A specific case: manually measuring temperature in young pigs

An extensive study was carried out to test the following hypothesis:

Stress is an important interfering factor when measuring temperatures. When animals are stressed by fixating and animal handling, this will quickly result in a rise in body temperature (stress induced temperature rise).

Assuming that this hypothesis is true, it's reasonable to assume that socializing and training of piglets would reduce the stress of handling, resulting in a decrease in temperature rise during rectal temperature measurements.

In total 100 piglets were used, divided in two treatment groups:

1. Experimental group: Socialization on day (age) 4- 25, training on day 26 – 40.
2. Control group: No socialization and no training

Socialization meant that the piglets were picked up and held by different persons, allowing them to get used to the procedure of taking a temperature reading if not the actual measurement itself. In the training period, days 26-40, actual measurements were made, 3 times a day: 08:30, 12:00, 15:30.

In the Figure 1 below, we see the difference in temperature between the control group and the experimental group during a period of 3 days, followed by an injection of XXX and the resulting pronounced temperature change.

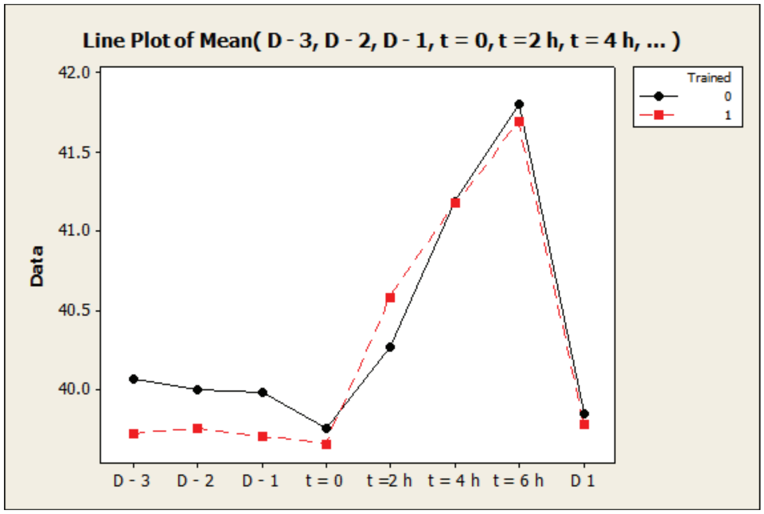

Figure 1. Mean temperature Experimental (1) vs Control (0) piglets.

Training particularly had an influence on the baseline temperature (mean temperature of 3 days prior to vaccination) and not on the temperature after vaccination.

Trained piglets: 39.7 ± 0.2 degrees Celsius
Control piglets: 40.0 ± 0.2 degrees Celsius $P<0.001$

At t=0 and after vaccination temperatures were alike. This means that also for the control group the temperatures were no longer elevated due to stress. It appears there is a training/habituation effect which occurs after three days.

The conclusion of this is that stress caused by handling and the rectal measurement itself only affects the body temperature for a short period of time, i.e. about 3 days. Furthermore, even during this habituation period, the temperature difference is small. Additionally, also an important finding, there was no correlation found between the rectal temperature and the order in which piglets were handled.

We will now move on to describe a similar study, albeit much smaller in terms of number of piglets involved, where telemetry was used side by side with rectal measurements.

Telemetry vs. rectal measurements: a validation study

The telemetry measurement system consisted of 4 implantable sensors, 1 receiver and software. By way of preparation, each implant had been programmed with a unique identification code and set to transmit each 60 seconds. After programming, the implants were encapsulated, resulting in 4 small cylinders, 35 by 15 mm.

Before insertion into the animals, each implant was calibrated in a warm water bath at 36, 39 and 42 degrees Celsius.

The test subjects were 4 young pigs, 5-8 weeks old. The implants were inserted subcutaneously (about 2cm deep) behind the ear in an operation taking roughly 45 minutes. A few days after the operation the scars had healed well.

Each piglet had its own pen, roughly 1.5 by 1.5 metres, but with the possibility of nose-to-nose contact with its neighbours. In two of the pens, receiving antennas were mounted and cabling run through the wall to an adjacent room where the receiver and PC were located. The antennas as well as the receiver have been designed and produced by TeleMetronics.

Figure 2. Encapsulated implant (SI ruler)..

Figure 3. Inserting the implant.

Figure 4. Back in the pen, with antenna.

The PC software, also developed by Telemetronics, was configured for 4 implants, using two antennas and one receiver. In fact, the software can handle any number of implants (limited by the speed of the PC) distributed across as many receivers as the PC can sustain. The total measurement ran for a period of more than two weeks, collecting some 20000 temperature readings per piglet. During the same period, about 100 manual readings per piglet were recorded. External 'noise' disturbed the measurements for parts of the period and for some of the implants. Why not all of the implants were affected in the same way is not clear but may be related to the different transmission frequencies used and the position of the antenna relative to the noise source (probable because implants sharing an antenna displayed roughly the same amount of disturbances).

After one week of measurements, one of the sensors stopped working. Examination afterwards showed that the wire to the battery had come loose. The following results therefore do not include this sensor since it wasn't present in the more important phase of the measurement.

Table 1. Correlation between rectal and telemetry for total measurement period including one week of disturbances (data filtered to remove obvious 'bad' readings).

Implant	Slope	Correlation
1	0.84	0.72
2	0.89	0.80
3	0.96	0.81

Table 2. Correlation for the last 4 days, free of disturbances.

Implant	Slope	Correlation
1	0.95	0.85
2	0.89	0.80
3	1.04	0.92

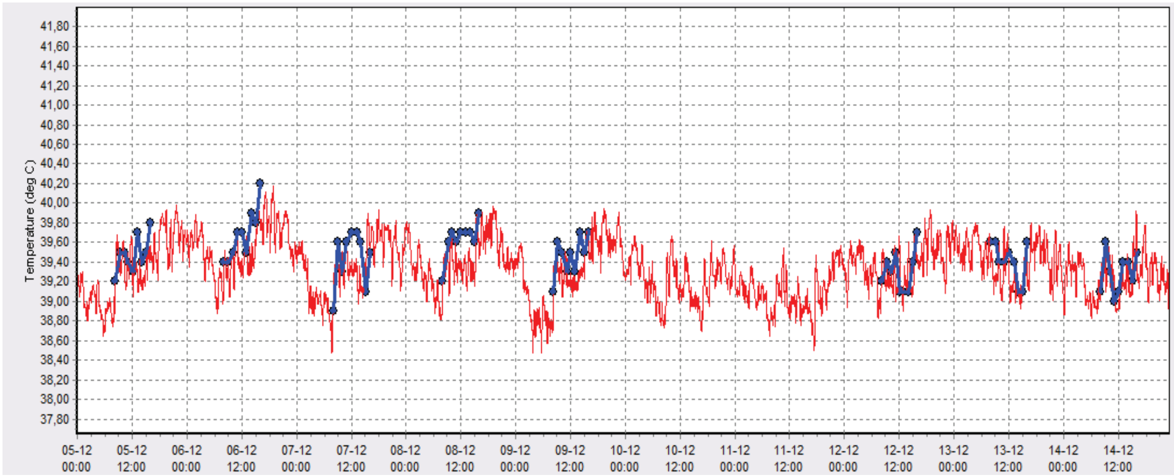

Figure 5. Sensor 3 (red) versus rectal measurements (blue).

As can be seen the slope is very close to 1, indicating that not only is rectal and telemetry correlating but producing the same absolute values, something further confirmed by figure 5

Conclusions

From the above we conclude that:

- The measurement principle used in the implant works well with a close to 1-to-1 relation and high correlation with rectal measurements

- Temperature measurements are as accurate as rectal probes

- Continuous measurement has several advantages: it is time-saving, shows effects that cannot be obtained with manual measurements, and goes on day and night 7 days a week

In the light of the first two points, i.e. the temperature measured by an implant in the neck agrees with rectal measurements, the last point becomes especially interesting. Using an implant and telemetry makes large scale studies over long periods of time possible, studies that would be almost impossible to carry out using only manual measurements.

We also identified a number of problems during the measurement period, the main ones being:

- The implants are not as user-friendly as they could be. During calibration and tuning, a period of 60 seconds between measurements is much too long. However, during measurement, 16 seconds is (mostly) too short. Since the broadcast interval cannot be changed after encapsulation, 60 seconds had to be selected with unpleasant consequences for the calibration and tuning work.

- The implants were sensitive to external disturbances. Because the communication implant-antenna-receiver is carried by an electromagnetic (EM) field, it has to compete with all other surrounding EM radiation to be detected by the receiver. The two ways of ensuring this is to 1) select a frequency far away from other frequencies and 2) broadcast a strong signal. As for point 1, there's no free choice, use of the EM spectrum is closely regulated. So the only way open for improvements is to transmit a stronger signal.

Based on these and other observations, it was decided to develop a new generation of the implant. The core of the implant, i.e. where the temperature is measured, will remain unchanged but several changes related to signal strength and practical handling will be made. Here is a summary of planned improvements:

- Redesigned electronics will result in a much higher signal output.
- The broadcast interval will be selectable from the list 15, 30, 60, 120 and 240 seconds and can be set externally with a 'remote control'.
- The implant can be made to 'go to sleep' during which it consumes current in the order of 1 µA. In 'sleep', the implant has a life span measured in years. The sleep mode is also controlled from the 'remote'.
- It will be possible to set the current used for transmission to be one of the following values: 0.5 mA, 1mA, 2mA, 4mA, 8mA. The lower value can be used where distances are small and/or external disturbances are low. In situation where there is much noise or where antennas cannot be mounted close to the animals, the higher current values may be selected, thereby increasing the signal strength and range. The flip side of the stronger signal is shorter battery life: a higher current will drain the battery sooner.

Ethical statement

All studies were performed in accordance with the Council of Europe Convention (ETS123)/ Directive (86/609/EEC) for the protection of vertebrate animals used for experimental and other scientific purposes, and with approval of the Animal Care Committee of MSD Animal Health.

Literature study

In animal research various systems are used to measure body temperature, and literature on comparisons of methods of body temperature measurement is extensive. However, almost none of these systems are suitable for continuous core body temperature measurement in pigs. Several studies [1,2,3] using infrared thermography to predict rectal temperature concluded that there is not a strong relationship between rectal and skin temperature and that infrared thermometry is not a good alternative to rectal temperature. Subcutaneously injectable transponders are widely used to measure body temperature [4,5,6]. However, this is not a continuous measurement and transponders need to be scanned with a handheld reader at a distance of 2-5 cm from the transponder to measure temperature. In ruminants [7] and horses [8] it is possible to use transponders that are administered orally and stay in the rumen or gastrointestinal tract. Although these 'pills' measure temperature continuously, from a distance, in unsedated freely moving animals, these orally administered transponders are not suitable for long term measurements in swine, because these transponders will pass through the gastrointestinal tract in about 48 hours before being pooped out [9]. Therefore, to our knowledge the telemetry implants used in this study are the best option for long term continuous core body temperature measurements in freely moving swine.

References

1. Sikoski, P., Banks, M.L., Young, R.W., Wallace, J.M., Nader, M.A. (2007). Comparison of rectal and infrared thermometry for obtaining body temperature in cynomolgus macaques (Macaca fascicularis). *Journal of Medical Primatology* **36**, 381-384.
2. Stephens Devalle, J.M. (2005). Comparison of Tympanic, Transponder, and Noncontact Infrared Laser Thermometry with Rectal Thermometry in Strain 13 Guinea Pigs (Cavia porcellus). *American Association for Laboratory Animal Science* **44**, 35-38.

3. Dewulf, J., Koenen, F., Laevens, H., de Kruif, A. (2003). Infrared thermometry is not suitable for the detection of fever in pigs. *Vlaams Diergeneeskindig tijdschrift* **72**, 373-379.

4. Torrao, N.A., Hetem, R.S., Meyer, L.C.R., Fick, L.G. (2011). Assessment of the use of temperature-sensitive microchips to determine core body temperature in goats. *Veterinary Record* **168**, 328.

5. Chen, P.H., White, C.E. (2006). Comparison of rectal, microchip transponder, and infrared thermometry techniques for obtaining body temperature in the laboratory rabbit (Oryctolagus cuniculus). *Journal of the American Association for Laboratory Animal Science* **45**, 57-63.

6. Quéva, C., Bremner-Danielsen, M., Edlund, A., Ekstrand, J., Elg, S., Erickson, S., Johansson, T., Lehmann, A., Mattsson, J.P. (2003). Effects of GABA agonists on body temperature regulation in GABA B(1) mice. *British Journal of Pharmacology* **140**, 315–322.

7. Signer, C., Ruf, T., Schober, F., Fluch, G., Paumann, T., Arnold, W. (2010). A versatile telemetry system for continuous measurement of heart rate, body temperature and locomotor activity in free-ranging ruminants. *Methods in Ecology and Evolution* **1**, 75-85.

8. Green, A.R., Gates, R.S., Lawrence, L.M. (2005). Measurement of horse core body temperature. *Journal of Thermal Biology* **30**, 370-377.

9. Brown-Brandl, T.M., Yanagi, T. Jr., Xin, H., Gates, R. S., Bucklin, R.A., Ross, G.S. (2003). A new telemetry system for measuring core body temperature in livestock and poultry. *Applied Engineering in Agriculture* **19**, 583-589.