# NEW APPROACHES TO THE MEASUREMENT OF ENERGY EXPENDITURE IN PIGS

L.R. GILES and J.M. GOODEN

## SUMMARY

New procedures have been developed for the continuous measurement of energy expenditure in finisher pigs. Energy expenditure is measured from oxygen consumption calculated as the product of cardiac output and the difference in blood oxygen content between arterial and mixed venous blood (Fick principle). Key features of this approach have been the use of new technology to measure cardiac output using transit-time ultrasound and fibre-optic oximetry to measure mixed venous oxygen saturation. The results are presented for the oxygen consumption of finisher pigs at raised ambient temperatures using these new procedures.

## INTRODUCTION

Most systems for the continuous measurement of energy expenditure in farm animals are based on the measurement of gaseous exchange using automated open-circuit respiration chambers (McClean and Tobin, 1987). Whilst these systems are very precise, the physical resources required are expensive and measurements are unsuitable for the short-term study of changes in oxygen ($O_2$) consumption because of the inevitable lag time within the chamber. Face-masks allow short-term measurements but require lengthy training periods with pigs. Alternatively, a ventilated hood (or head-box) is essentially a thermoneutral technique because of the difficulty in controlling the climatic environment within the hood when examining the effect of raised or lowered ambient temperature on energy expenditure. Of the indirect tracer techniques, carbon dioxide ($CO_2$) entry rate, which requires a continuous infusion of $^{14}C$-labelled substrate, has been widely used in ruminants (Corbett *et al.* 1971), but has received little attention with pigs. The doubly-labelled water technique requires some assumptions about the unidirectional losses of deuterium and $^{18}O$ in body tissues and methane production from the alimentary tract of fast-growing animals (Midwood *et al.* 1989). In addition, doubly-labelled water is expensive, particularly when administered to large domestic animals. Both tracer techniques are unsuitable for short-term measurements of energy expenditure and both measure $CO_2$ production which is inherently less accurate then $O_2$ consumption as a measure of energy expenditure.

An alternative approach which we have examined in this laboratory is to calculate $O_2$ consumption as the product of cardiac output and the difference in $O_2$ concentration between arterial and mixed venous blood (Fick principle). This concept is obviously not new. Other studies have measured cardiac output using dye and thermal dilution, radioactive microspheres and

---

Department of Animal Science, University of Sydney, Camden NSW 2570

doppler ultrasound, and many laboratories routinely sample arterial and mixed venous blood using implanted polyvinyl catheters. Our interest results from the availability of new technology which allows the continuous and simultaneous measurement of cardiac output and blood oxygen saturation.

## CONTINUOUS MEASUREMENT OF CARDIAC OUTPUT

Cardiac output is measured as the volume-rate of blood flow through the pulmonary artery using new technology based on transit-time ultrasound, patented by Cornell University (Transonic Systems Inc., Ithaca, New York). This approach has advantages over the doppler ultrasound system used by Sawyer and Stone (1966) as blood flow is sensed independently of blood vessel size, vessel alignment and flow profile as described by Drost (1978). The blood flow probe is placed surgically around the pulmonary artery and the tissue which grows around the probe body provides acoustic coupling between the probe and the blood vessel. The probe is connected to a bench-top meter which provides a direct read-out of cardiac output. The voltage output signals from the blood flow meter are recorded on a micropower data-logger and stored using a memory cartridge for later computer analysis.

The pigs return to pre-surgery, voluntary food intake within 3 to 7 days after implanting the blood flow probe and acoustic coupling is complete within the same period. This method of measuring cardiac output has been maintained, trouble-free in finisher pigs (60-90kg live weight ) for up to two months by which time the pigs have outgrown their metabolism crates. In a recent study (Giles *et al.* 1990), mean (sd) cardiac output recorded over 24h was 9.3 (2.53) l/min for four female pigs (average 89 kg live weight), fed ***ad libitum*** a diet estimated to contain 14 MJ digestible energy per kg and housed at 22°C (Table 1). This variation in cardiac output between pigs has been consistently observed in our studies to date and could partly explain the variation in energetic efficiency between pigs of the same genotype.

The Transonic procedure for the measurement of blood flow has been compared in this laboratory with the dye-dilution method using the jugular vein (Lush *et al.* 1989); and with the flow rate of heparinized blood pumped through the portal vein of sheep (Neutze *et al.* 1989). In both studies their was no significant difference in blood flow between techniques and it can be confidently expected that the Transonic approach will accurately monitor blood flow in a range of blood vessels in other surgically-prepared domestic animals.

## CONTINUOUS MEASUREMENT OF BLOOD OXYGEN SATURATION

Fibre-optic catheter technology was first developed for use in human medicine to continuously monitor mixed venous 02 saturation (Gamble *et al.* 1965). A fibre-optic light beam of specific wave lengths is delivered to the tip of a specially-designed catheter and a second fibre-optic bundle within the catheter transfers the light reflected from the blood to a bench-top meter. The approach essentially measures blood colour which is directly related to blood $O_2$ saturation. Current available technology (Oximetrix: Abbott Laboratories, North Chicago) has been shown in this laboratory to be suitable for use in pigs and sheep housed in metabolism crates.

Blood samples can be withdrawn from the tip of the catheter, at least daily to allow calibration of $O_2$ saturation with photometric measurements (Hemoximeter: Radiometer, Copenhagen). In addition to the blood sampling facility, the Oximetrix catheters also provide the continuous recording of blood temperature and blood flow can be recorded by thermal dilution. This latter facility, though not a continuous measure of blood flow, provides an alternative blood flow measure if it is not possible to surgically implant the Transonic probe.

In our experience the Oximetrix catheter has remained patent for up to two weeks in finisher pigs. If the fibre-optic bundles become damaged or the catheter tip becomes covered with a blood clot, it is possible to withdraw the catheter and replace with a new catheter. In a recent study (Giles ***et al.*** 1990), mean (sd) mixed venous $O_2$ saturation recorded over 24h was 55.5(2.31)% for four female finisher pigs fed ***ad libitum*** and housed at 22°C (Table 1). Our studies indicate that a greater proportion of the variation in $O_2$ consumption between pigs is due to variation in cardiac output rather than variation in mixed venous $O_2$ saturation.

## MEASUREMENT OF OXYGEN CONSUMPTION IN PIGS

Oxygen consumption has now been measured in finisher pigs (60-100 kg live weight ) by applying the Transonic blood flow and Oximetrix 02 saturation techniques to the Fick equation as follows:-

$$QO_2 = CO \times (SaO_2 - SvO_2) \times Hb \times 1.34 / 10 \quad \text{where}$$

$QO_2$ = oxygen consumption (ml/min)
CO = cardiac output (l/min)
$SaO_2$ = arterial oxygen saturation (%)
$SvO_2$ = mixed venous oxygen saturation (%)
Hb = haemoglobin concentration (g/100ml blood)

Early in our studies we found that Sa02 and Hb of finisher pigs remained constant over time irrespective of changes in ambient temperature and respiration rate (see Fig. 1).This meant that $SaO_2$ and Hb could be measured photometrically from blood sampled at 6-8h intervals during the day and $QO_2$ could then be recorded continuously by monitoring CO and $SvO_2$.

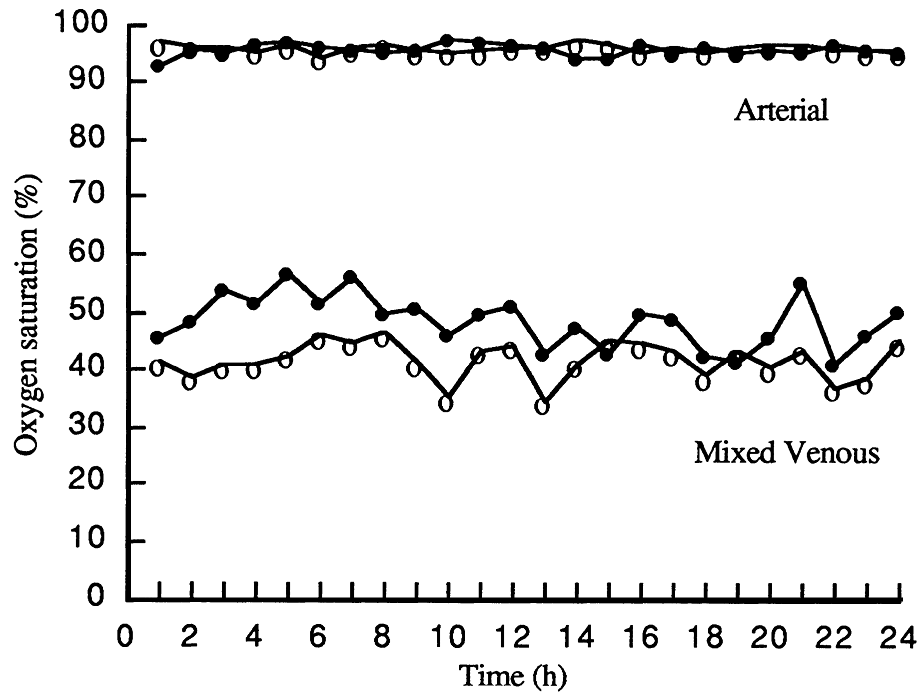


Fig. 1. Effect of ambient temperature on blood oxygen saturation of a finisher pig (84kg live weight) fed ***ad libitum:*** (o) 22°C; (●) 30°C

Cardiac output of finisher pigs is measured with a Transonic blood flow probe placed surgically around the pulmonary artery at 60 kg live weight. During surgery a polyvinyl catheter is placed in the saphenous branch of the femoral artery using the Seldinger technique to sample Sa02 and Hb. Complete recovery is indicated by return to ***ad libitum*** food intake in 3-7 days. The Oximetrix catheter is placed in the pulmonary artery approximately 10 days after surgery and 2 days before measuring $QO_2$. The pig is placed under light anaesthesia and a catheter 'introducer' is placed in the jugular vein using the Seldinger technique to allow entry of the Oximetrix catheter. Once clear of the introducer, a latex balloon is inflated at the tip of the catheter and the catheter is advanced through the heart and into the pulmonary artery. The air in the balloon interferes with the acoustic signal to the Transonic blood flow probe allowing accurate placement of the Oximetrix catheter in the pulmonary artery. The Transonic and Oximetrix devices are ideally compatable as both provide similar voltage output signals which are recorded on a miropower data logger. Data is stored on a memory cartridge to allow retrieval and computer analysis of $QO_2$ using the Fick equation.

During early studies with finisher pigs $QO_2$ was measured in a head box and compared with the new procedures. Mean $QO_2$ was similar for both techniques when measured over the same 2h period (Giles ***et al.*** '1989). In later studies we have used the new procedures to measure $QO_2$ of female finisher pigs fed ***ad libitum*** a diet, estimated to contain 14 MJ digestible energy per kg, and exposed to ambient temperatures above 22°C (Giles ***et al.*** 1990). Ambient temperature was increased to 25, 28 and 31°C for 48h, with four days at 22°C between each raised temperature treatment . By day 2, $QO_2$ continued to fall at each raised temperature treatment in association with a decline in voluntary food intake and a rise in rectal temperature and respiration rate (RR) (Table 1). By day 2, RR and CO had declined at 31°C compared to day 1 (RR=159 respirations/min and CO=8.7 l/min). $SvO_2$ increased from 22°C to 25°C, reflecting reduced activity of pigs at raised ambient temperatures.

Table 1 Effect of raised ambient temperature for 48h on the mean 24h results (day 2) of four female pigs (average 89kg live weight)

| Ambient temperature | (°C) | 22.7 | 25.9 | 28.5 | 31.4 | SEM |
|---|---|---|---|---|---|---|
| Voluntary food intake | (g/day) | 2846 | 2340 | 1888 | 900 | 391.0 |
| Cardiac output | (l/min) | 9.3 | 9.5 | 8.4 | 7.5 | 0.41 |
| Mixed venous $O_2$ saturation | (%) | 55.5 | 60.0 | 60.1 | 59.5 | 1.10 |
| $O_2$ consumption | (ml/min) | 511 | 464 | 433 | 371 | 18.2 |
| Respiration rate | (/min) | 27 | 51 | 85 | 112 | 28.5 |
| Rectal temperature | (°C) | 39.3 | 39.5 | 39.9 | 40.9 | 0.36 |

Recent studies have been completed with finisher pigs maintained at 31°C for up to 12 days (Giles, unpublished) and the decline in $QO_2$, RR and CO over time have been confirmed. Voluntary food intake remained constant after day 2 in association with body temperature which remained above 40°C throughout the study.

## CONCLUSIONS

The continuous measurement of cardiac output for at least two months, the maintenance of fibre-optic catheters for up to two weeks and the agreement with head box, dye-dilution and photometric measurements has demonstrated the success of these new procedures with finisher pigs maintained in metabolism crates. This same approach has now been transferred to sheep (Gooden, unpublished). Because of the ability to monitor minute by minute changes in oxygen consumption, the full potential of this approach will be realized when used to assess the effects of exercise, the amelioration of stress and the effects of drugs/hormones on energy expenditure. The extention of this technology to the measurement of blood flow and blood oxygen content in the portal, uterine and mammary blood vessels will allow study into the effects of nutrient supply on the energy expenditure of digestion , pregnancy and lactation.

ACKNOWLEDGEMENTS

This work was partly funded by the Pig Research and Development Corporation (PRDC). Surgical facilities and technical support were provided by the Department of Animal Science, Camden and climate-controlled rooms were provided by CSIRO, Department of Animal Production, Badgerys Creek. Mr L.R. Giles was in receipt of a postgraduate scholarship from PRDC with salary support from NSW Agriculture & Fisheries.

REFERENCES

CORBETT, J.L., FARRELL, D.J., LENG, R.A., McCLYMONT, G.L., YOUNG, B.A. (1971). ***Brit. J. Nutr. 36*** **: *277.***

DROST, C.J. (1978). ***Proc. San Diego Biomed. Symp.*** **17 : 299.**

GAMBLE, W.J., HUGENHOLTZ, P.G., MONROE, R.G., POLANYI, M. and NADAS, A.S. (1965). *Circulation.* **41 : 328.**

GILES, L.R., GOODEN, J.M., BLACK, J.L., ANNISON, E.F. and TUCKER, R.G. (1989). ***Proc. Nutr. Soc. Aust.*** **14 :** 121.

GILES, L.R., GOODEN, J.M., LORSCHY, M.L., ANNISON, E.F. and BLACK, J.L. (1990). ***Proc. Nutr. Soc. Aust.*** **15 : 41.**

LUSH, J.M., GOODEN, J.M. and ANNISON, E.F. (1989). ***Proc. Nutr. Soc. Aust.*** **14** : 147.

McCLEAN, J.A. and TOBIN, G. (1987). “Animal and Human Calorimetry”. Cambridge University Press, Cambridge.

MIDWOOD, A.J., HAGGARTY, P., McGAW, J., ROBINSON, J. and FULLER, M.F. (1989). In ‘Proceedings of the Eleventh Symposium on the Energy Metabolism of Farm Animals”, p. 341, editors Y. Honing and W.H. Close. (Lunteren, Netherlands).

NEUTZE, S.A., ODDY, V.H., GOODEN, J.M., EDWARDS, S.R. and NANDRA, KS. (1989). ***Proc. Nutr. Soc. Aust.*** **14** : 146.

SAWYER, D.C. and STONE, H.L. (1966). In “Swine in Biomedical Research”, p.405, editors L.K. Bustad, R.O. McClellan and M.P. Bums. (Pacific Northwest Laboratory, Richland, Washington, USA).