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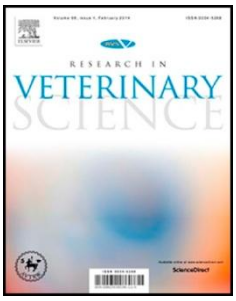

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Doppler blood pressure measurement in pigs during anaesthesia.

SHORT COMMUNICATION

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Abstract

To determine the accuracy of Doppler blood pressure measurement in anaesthetised pigs 8 Large White pigs (*Sus scrofa*) were anaesthetised with zolazepam and tiletamine as Zoletil 100 (4 mg/kg) and xylazine (2 mg/kg) by intramuscular injection followed by isoflurane in 100% oxygen. Blood pressure measurements were recorded using a Doppler probe on the radial artery and a catheter in the femoral artery connected to a transducer. The sample mean of the Doppler measurements were compared to the sample mean of the invasive systolic arterial blood pressure while accounting for the heart rate, end-tidal CO_2 and temperature. The predicted error of the Doppler was greatest when pigs were hypotensive and normothermic: 11 (CI: 6 to 15) mmHg. Doppler measurements should be interpreted with caution in anaesthetised pigs that are hypotensive and normothermic.

Keywords: pig, anaesthesia, blood pressure.

Non-invasive measurement of blood pressure in pigs during anaesthesia is notoriously unreliable because of their short limbs, thick skin and subcutaneous fat (Thurmon and Smith 2007, Swindle et al. 2012). While there are few studies investigating the accuracy of non-invasive blood pressure measurement techniques in pigs (Caulkett et al. 1994) there are a number of studies investigating this issue in other species including cats (Grandy et al. 1992, Caulkett et al. 1998, Acierno et al. 2010), dogs (Bosiack et al. 2010) and horses (Parry et al. 1982, Bailey et al. 1994). However, the unique anatomy of the pig means these results should not be extrapolated across species.

The gold standard of monitoring blood pressure is direct arterial blood pressure measurement. It is the technique against which other methods are compared for accuracy and consistency and is less prone to human and equipment error than non-invasive measurement methods (Caulkett et al. 1994). The Doppler technique is a form of non-invasive blood pressure measurement that is often utilised, but the accuracy of this technique varies. Grandy et al (1992) reported in cats that the systolic arterial blood pressure (SABP) was equivalent to the Doppler reading + 14 mmHg while Caulkett et al (1998) concluded the Doppler was a reliable predictor of mean arterial blood pressure in cats. In dogs the Doppler over estimated SABP during hypotension and underestimated it if the dog was normotensive (Bosiack et al. 2010). An unacceptably large error with 5% of Doppler readings in horses having an error of +/- 20 mmHg has also been reported (Bailey et al. 1994).

The aim of this study is to determine whether or not Doppler blood pressure measurements are accurate in pigs during general anaesthesia. We hypothesised that the Doppler technique would yield measurements for systolic blood pressure that were accurate based upon comparison with invasive SABP.

This study was approved by the Animal Ethics Committee of Murdoch University according to the guidelines of the National Health and Medical Research Council of Australia code of

practice for the care and use of animals for scientific purposes (AustralianGovernment 2004). Eight Large White pigs (*Sus scrofa*) utilised in surgery and anaesthesia teaching for veterinary students were weighed and anaesthetised with a combination of zolazepam and tiletamine as Zoletil 100 (4 mg/kg, Virbac Australia Pty. Ltd., Milperra, NSW, Australia) and xylazine (2 mg/kg, Ilium Xylazil 100 mg/mL, Troy Laboratories Australia Pty. Ltd., Glendenning, NSW, Australia) by intramuscular injection in the neck. An auricular vein was cannulated and propofol (1-2 mg/kg, 1%, Norbrook Laboratories Ltd., Victoria, Australia) was administered intravenously if required to achieve an adequate depth of anaesthesia for orotracheal intubation. Anaesthesia was maintained with isoflurane (Attane Isoflurane 1mL/mL, Bayer Australia Ltd, NSW, Australia) delivered in 100% oxygen via a Bain breathing system (for pigs < 10 kg) or a circle breathing system (for pigs > 10kg). The pigs breathed spontaneously unless the end tidal CO_2 ($ETCO_2$) exceeded 55 mmHg in which case manual intermittent positive pressure ventilation was commenced.

A veterinary student under supervision of an experienced veterinary anaesthetist assessed the depth of anaesthesia subjectively throughout the procedure, and the delivery of isoflurane was adjusted accordingly (vaporiser setting: 0.5-2.5%). A 20 or 22 gauge catheter was placed percutaneously in the femoral artery for continuous measurement of invasive blood pressure via a transducer positioned approximately at the level of the right atrium. The transducer was calibrated against a column of water and zeroed to atmospheric pressure prior to use. Oxyhaemoglobin saturation, pulse rate, heart rate (HR), respiratory rate, $ETCO_2$, direct arterial blood pressure, oesophageal temperature and an electrocardiogram (ECG) were monitored continuously and recorded every 5 minutes. All variables were measured with a Surgivet V9203 multivariable monitor (Polymount GCX® Corporation, Petaluma, CA, USA). A Doppler probe was secured with tape over the radial artery and a size 3 or 4 non-invasive blood pressure cuff (the width of which was approximately 40% of the

74 circumference of the limb) (Critikon Neonatal Soft-cuff, GE Healthcare, Milkwaukee,
75 U.S.A.) was positioned proximal to the probe for Doppler blood pressure measurements
76 (Ultrasonic Doppler Flow Detector, Model 811-B, Parks Medical Electronics, Aloha, Oregon,
77 U.S.A.). The pigs were in dorsal recumbency for the duration of anaesthesia and for all
78 measurements.

79 This study was performed in the context of student practical classes so at convenient time
80 points direct blood pressure measurements for systolic, mean and diastolic blood pressure
81 were recorded in triplicate. Simultaneous measurements of Doppler blood pressure were
82 made by inflating the cuff with the sphygmomanometer to a pressure that occluded the radial
83 artery, slowly deflating the cuff, and recording the pressure at which flow through the vessel
84 was audible on three consecutive occasions. The HR, $ETCO_2$ and temperature were recorded
85 at the same time. GM and RC collected data for each set of blood pressure measurements
86 within one minute. The pigs underwent an exploratory laparotomy and were euthanased at the
87 end of surgery with intravenous pentobarbitone.

88 Data for analysis was the mean of the triplicate measurements for comparison. The SABP,
89 HR, $ETCO_2$ and temperature data were categorised into low, normal and high measurements.
90 These categories were determined on an empirical basis for SABP (< 90, 90-130, > 130
91 mmHg), $ETCO_2$ (< 35, 35-45, > 45 mmHg) and temperature (< 37, 37-40, > 40 °C) and by
92 dividing the distribution of recorded HR into 3 groups with half the animals in the middle
93 group and a quarter of the animals in both the low and high HR groups (< 81, 81-92, > 92
94 beats per minute (bpm)). The expected error for Doppler blood pressure was calculated as the
95 difference between SABP and Doppler blood pressure.

96 All data was analysed in R (R Core team 2013, R Foundation Statistical Computing, Vienna,
97 Australia). For each triplicate measurement the sample mean was calculated. The error was
98 then defined as the observed difference in mean Doppler measurement and mean SABP. A

linear regression model was fitted with error as the response variable and main effects of mean observed SABP, $ETCO_2$, heart rate and temperature. Each of the main effects was treated as categorical variables. Second-order interaction terms between the mean observed SABP and the other main effects were also included. Model selection using a step down approach with a P-value > 0.05 as the cut-off was used to select the terms in the final model. The final model included the main effects mean observed SABP, HR and temperature; and the second order terms of HR and temperature with mean observed SABP. The final model was use to give predicted mean error rates and 95% confidence intervals for the mean error rate. Data is expressed as mean (SD).

Data was collected from 8 pigs that weighed 16.2 (4.2) kg and were approximately 6 weeks of age. The number of time points for comparison of Doppler blood pressure to SABP was 101. The HR, $ETCO_2$ and temperature at the blood pressure measurement time points was 88 (11) bpm, 49 (8) mmHg and 37 (0.5) °C respectively. The number of observations within each category of SABP, HR, $ETCO_2$ and temperature are reported in Table 1. The expected error of Doppler blood pressure measurement was greatest (11 (CI: 6 to 15) mmHg) when the pig was hypotensive with a normal temperature. Doppler blood pressure measurement underestimates SABP to the greatest extent (0 (CI: -7 to 6 mmHg) when a pig is hypotensive and hypothermic (Table 2). There was no effect of $ETCO_2$ or HR on the error of Doppler blood pressure measurement.

The incidence of hypotension is higher in young animals (Pettifer and Grubb 2007) and as the pigs in this study were young it may not be appropriate to apply these results to older pigs. Furthermore, there is incredible variation in the biological measurements from pigs of different breeds and ages so it remains that the results of this study pertain to approximately 6 week old Large White pigs (Thurmon and Smith 2007).

Isolated values for blood pressure should always be interpreted with caution, as they may not represent the perfusion status of a patient. A pattern or trend in blood pressure measurement should be identified and will enable a more accurate evaluation of a patient during anaesthesia (MacFarlane et al. 2010). Appropriate therapy can then be instituted to optimise blood pressure and increase the confidence of the anaesthetist that perfusion to important organs is adequate to maintain oxygen delivery. Furthermore, these trends can aid in assessing the response to treatment of hypotension or hypovolaemia. Isolated data points were used for comparison in this study, as our aim was to determine if Doppler blood pressure measurements accurately reflected SABP. We have not reported trends in blood pressure in these pigs, as it was not our intention to comment upon the physiological response of pigs to the anaesthetic protocol utilised.

The data in this study was categorised to determine the influence of abnormalities in the HR, $ETCO_2$ and body temperature on the accuracy of Doppler blood pressure measurements. Systolic arterial blood pressure, $ETCO_2$ and body temperature were categorised empirically but given the variation in HR in this species and the potential influence of anaesthetic drugs on the HR, the entire set of HR data was divided into three groups as described above. While this approach has its limitations we felt that in the context of this study it was appropriate as there is no reliable data about the normal HR of pigs of this age receiving this combination of drugs. The normal HR category was, however, very narrow so this parameter warrants further description in this species, age and breed of animal receiving the combination of drugs administered for general anaesthesia in this study.

The Doppler may over estimate SABP by up to 15 mmHg during anaesthesia of Large White pigs (mean weight 16.2 kg) when the body temperature is normal and the blood pressure is low. This degree of error is potentially clinically significant so measurements should be interpreted with caution if hypotension is suspected.

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Conflicts of Interest

The authors have no conflicts of interest to declare.

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Table 1:

The number of observations within each category (hypo-, normo- and hyper-) of each variable (blood pressure, heart rate, end tidal CO_2 and temperature).

	Category		
Variable	**Hypo-**	**Normo-**	**Hyper-**
Systolic arterial blood pressure (mmHg)	49	46	0
Heart rate (bpm)	25	38	21
End tidal CO_2 (mmHg)	8	23	53
Temperature (°C)	35	49	0

Table 2:

Predicted error rate of Doppler blood pressure for each category of systolic arterial blood pressure (SABP) and temperature. End tidal CO_2 and HR were excluded as there was no effect of alterations in these parameters on the error of Doppler blood pressure measurement.

SABP (mmHg)	Temperature (°C)	Error (mmHg)	95% confidence interval
Normotension	Hypothermia	2	-3 to 7
Normotension	Normothermia	1	-5 to 6
Hypotension	Hypothermia	0	-7 to 6
Hypotension	Normothermia	11	6 to 15