Evaluation of oscillometric and vascular access port arterial blood pressure measurement techniques versus implanted telemetry in anesthetized cats

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Objective—To compare the use of a semi-invasive vascular access port (VAP) device or noninvasive oscillometry versus invasive telemetry for blood pressure measurements in cats.

Animals—6 healthy cats.

Procedures—30 days before the study, all cats received an implanted telemeter and a VAP device. During normotension and experimentally induced hypertension, blood pressure was measured with the implanted devices and with noninvasive oscillometry at 4 time points.

Results—Compared with invasive telemetry, VAP had a correlation coefficient from 0.8487 to 0.9972, and noninvasive oscillometry had a correlation coefficient from 0.7478 to 0.9689.

Conclusions and Clinical Relevance—Use of the VAP device and noninvasive oscillometry had a high degree of correlation with invasive telemetry as the gold standard for blood pressure measurement. Use of a VAP device resulted in a slightly higher degree of correlation, compared with noninvasive oscillometry. (*Am J Vet Res* 2011;72:1015–1021)

Multiple methods and techniques have been developed to measure blood pressure in animals. Direct or invasive (arterial catheterization) methods and indirect or noninvasive methods are presently used in experimental and clinical trials. Radiotelemetry was developed as a reliable method to monitor physiologic functions, including arterial blood pressure, in awake and free-moving laboratory animals such as rats, dogs, and cats.[1–5] Implantable radiotelemetry transmitters are surgically connected to subcutaneously tunneled arterial catheters, are calibrated before and after implantation, and accurately and reproducibly detect changes in arterial blood pressure for extended periods of time, although bias of the zero reference value is a concern. Alternatively, subcutaneously tunneled arterial catheters can be connected to a VAP and a completely external and calibrated pressure sensing device used to continuously or intermittently record arterial blood pressure. Noninvasive (Doppler, oscillometric, and plethymographic) methods use a cuff placed around the distal portion of the limb or tail, a sphygmomanometer, and procedures for detection of blood flow (Doppler) or arterial pulsations. Most oscillometric methods have been validated against radiotelemetry as a gold standard in rats.[6] Validation of less-invasive and noninvasive techniques for measuring blood pressure is critical when performing clinical trials in client-owned animals such as cats and has benefits in everyday clinical veterinary practice. The purpose of the study reported here was to compare use of a semi-invasive VAP device or noninvasive oscillometry with invasive telemetry for blood pressure measurements in anesthetized cats.

Abbreviations

DAP	Diastolic arterial blood pressure
MAC	Minimum alveolar concentration
MAP	Mean arterial blood pressure
SAP	Systolic arterial blood pressure
VAP	Vascular access port

Materials and Methods

Animal care and instrumentation—This study was approved by the institutional animal care and use committee of the study facility. Six healthy sexually intact domestic shorthair cats (3 males and 3 females), ranging in age from 12 to 17 months and weighing 2.8 to 4.6 kg, were the subjects of this study. Thirty days before beginning the study, a radiotelemetry device[a,b] as well as a VAP[c] with a 3F atraumatic rounded tip[d] (length, 20 to 25 cm) had been surgically implanted in each cat. For the telemetry device, under general anesthesia with isoflurane at 1% to 3% and strict asep-

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tic conditions, a small-animal radiotransmitter[a] with a weight of 11 g and a volume of 6 mL was implanted in the cats, providing telemetry signals for body temperature, arterial blood pressure through an antithrombotic gel-filled catheter, and a 2-electrode lead ECG. The device was subcutaneously secured to the superficial abdominal musculature of the left flank via a ventral skin incision. The arterial pressure catheter was tunneled to the left hind limb and introduced and placed in the abdominal aorta via the left femoral artery. The 2 ECG electrodes were tunneled subcutaneously and secured to the superficial muscles of the left and right sides of

Table 1—Mean ± SD values for SAP, DAP, and MAP simultaneously derived via invasive radiotelemetry, noninvasive oscillometry, and VAP technology at baseline (awake) and during steady-state isoflurane anesthesia in a study in 6 healthy cats.

		Invasive radiotelemetry			Noninvasive oscillometry			VAP		
Variable	**Time point**	**SAP**	**DAP**	**MAP**	**SAP**	**DAP**	**MAP**	**SAP**	**DAP**	**MAP**
Baseline	4 wk	160 ± 12	116 ± 8	138 ±11	NA	NA	NA	NA	NA	NA
	14 wk	159 ± 20	120 ± 16	138 ± 18	NA	NA	NA	NA	NA	NA
2.2% isoflurane	4 wk	76 ± 10	47 ± 12	59 ± 12	86 ± 9	28 ± 2	46 ± 2	76 ± 6	45 ± 5	57 ± 4
	14 wk	65 ± 7	44 ± 9	53 ± 8	63 ± 4	42 ± 8	51 ± 6	83 ± 10	25 ± 4	45 ± 6
	12 wk	64 ± 7	42 ± 7	51 ±7	77 ± 7	26 ± 5	46 ± 6	60 ± 13	39 ± 11	49 ± 11
	13 wk	71 ± 12	48 ± 14	58 ±13	77 ± 4	29 ± 4	48 ± 4	63 ± 8	42 ± 6	51 ± 7
1.8% isoflurane	4 wk	79 ±10	48 ± 12	60 ± 11	85 ± 9	29 ± 3	48 ± 4	80 ± 6	47 ± 5	59 ± 5
and phenylephrine*		151 ± 18	101 ± 25	124 ± 23	162 ± 23	87 ± 24	117 ± 24	162 ± 22	107 ± 26	128 ± 21
1.8% isoflurane	14 wk	72 ± 13	47 ± 12	57 ± 12	71 ± 4	45 ± 8	56 ± 5	85 ± 9	27 ± 4	46 ± 4
and phenylephrine*		140 ± 17	95 ± 16	116 ± 16	146 ± 16	95 ± 20	118 ± 18	154 ± 18	73 ± 10	107 ± 21
MAC†	12 wk	112 ± 25	84 ± 22	96 ± 23	109 ± 25	53 ± 20	76 ± 25	99 ± 33	80 ± 32	89 ± 33
	13 wk	109 ± 34	80 ± 30	93 ± 33	111 ± 26	51 ± 22	75 ± 28	100 ± 11	77 ± 33	88 ± 32

Recordings were made at 4 time points: 4 and 14 weeks after implantation of a radiotelemetry device as well as during MAC determinations performed 12 and 13 weeks after implantation.

*Phenylephrine administered IV as a bolus after 15 minutes of anesthesia; data in upper row were obtained before administration of phenylephrine, and data in the lower row were obtained during administration of phenylephrine. †MAC values were 1.1 ± 0.5% and 1.2 ± 0.5% for 12 and 13 weeks, respectively.

NA = Not applicable.

Table 2—Mean ± SD coefficients of variability (%) at 2 steady-state end-tidal isoflurane concentrations for 5 consecutive MAP readings as derived via invasive telemetry, noninvasive oscillometry, and VAP technology in the same cats as in Table 1.

Variable	**Invasive telemetry**	**Noninvasive oscillometry**	**VAP**
2.2% isoflurane	2.7 ± 2.4	8.4 ± 2.2	4.0 ± 3.7
1.8% isoflurane	2.9 ± 2.8	5.5 ± 4.3	3.9 ± 3.3
Mean ± SD (range)	2.8 ± 2.5 (0.5–10.5)	6.9 ± 3.6 (2.8–16.7)	4.0 ± 3.4 (0.5–11.6)
P value*	—	< 0.001	0.2

Aggregate data were obtained at 4 and 14 weeks. Values reported are mean ± SD.

*Comparison of noninvasive oscillometry and VAP with invasive telemetry.

— = Not applicable.

Table 3—Overall bias (ie, absolute pressure difference), precision (Pearson correlation coefficient), concordance, and accuracy (bias correction factor) obtained when comparing noninvasive oscillometry and VAP values with invasive telemetry readings for all SAP, DAP, and MAP values recorded in 6 anesthetized cats throughout the study (ie, 4 to 13 weeks).

Variable	**Pressure**	**Oscillometry vs invasive telemetry**	**VAP vs invasive telemetry**
Bias (mm Hg)	SAP	–10.1 ± 16.7	–2.5 ± 10.1
	DAP	20.2 ± 12.7	–2.5 ± 7.2
	MAP	10.0 ± 13.3	–2.5 ± 6.5
	P value*	< 0.001	> 0.05
Pearson coefficient (precision)	SAP	0.8960 (0.87–0.92)	0.9681 (0.96–0.98)
	DAP	0.8981 (0.87–0.92)	0.9740 (0.97–0.98)
	MAP	0.9170 (0.90–0.93)	0.9823 (0.98–0.99)
Concordance coefficient	SAP	0.8632 (0.83–0.89)	0.9624 (0.95–0.97)
	DAP	0.7060 (0.66–0.75)	0.9677 (0.96–0.98)
	MAP	0.8756 (0.85–0.90)	0.9788 (0.97–0.98)
Bias correction factor (accuracy)	SAP	0.9634	0.9941
	DAP	0.7862	0.9935
	MAP	0.9548	0.9964

Bias data are mean ± SD. Coefficients are presented with 95% confidence intervals (in parentheses). Values for each comparison of noninvasive oscillometry with VAP for Pearson and concordance coefficients are significantly ($P < 0.05$) different.

*Comparisons among SAP, DAP, and MAP.

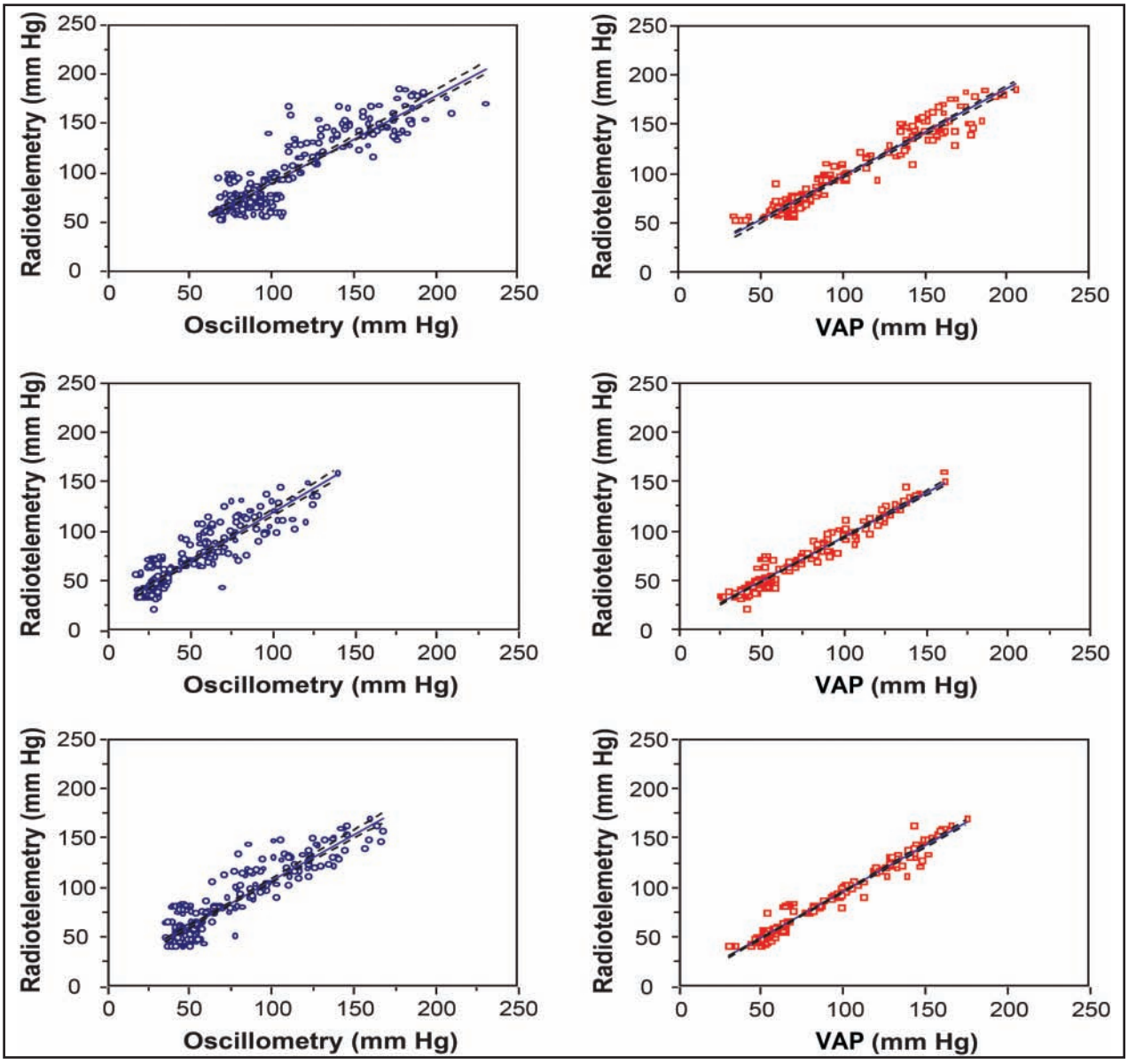

Figure 1—Linear regression plots comparing noninvasive oscillometry-derived (left column; blue circles) and VAP-derived (right column; red squares) pressures against invasive radiotelemetry readings for SAP (top row), DAP (middle row), and MAP (bottom row) values recorded in a study in 6 healthy cats. Solid blue lines represent regression lines, and dashed lines represent 95% confidence intervals.

the thoracic wall by use of a lead II configuration. The surgical incisions were closed in 2 layers: the underlying musculature was closed with absorbable sutures, and the skin was closed with staples. During the same procedure, a VAP was implanted by use of a femoral artery indwelling catheter. This 20- to 25-cm catheter (made of soft compliant material) was implanted under strict aseptic conditions by performing an incision over the right femoral artery and introducing a 3F catheter,[e] designed for chronic use, into the abdominal aorta. This catheter was subcutaneously tunneled to a subcutaneous pocket on the animal's right hip region, where it was attached to the VAP and secured to the underlying fascia. The catheter and port were flushed with 2 to 3 mL of a locking solution of taurolidine citrate[e] to prevent clotting and bacterial growth, and the incision was closed in layers with absorbable sutures and staples. The VAP was used in conjunction with a wearable telemetry transmitter[c] to provide a less-invasive telemetric arterial pressure signal. Throughout the duration of the study, the VAP and catheter were flushed with saline (0.9% NaCl) solution and locked periodically (approx every 7 days) to ensure chronic patency. No major body cavity was opened or accessed during the VAP implantation procedures. After surgery, animals were allowed to recover for ≥ 30 days, during which they were observed daily for signs of distress and the wound sites were monitored for signs of infections. A prophylactic antimicrobial (cephalexin) was administered at the time of surgery (30 mg/kg, IV) and for 3 days (30 mg/kg, PO, q 12 h) after surgery. The skin incision staples were removed approximately 12 days after surgery. No signs of infection, pain, or distress related to the surgery were observed at any time. The invasive telem-

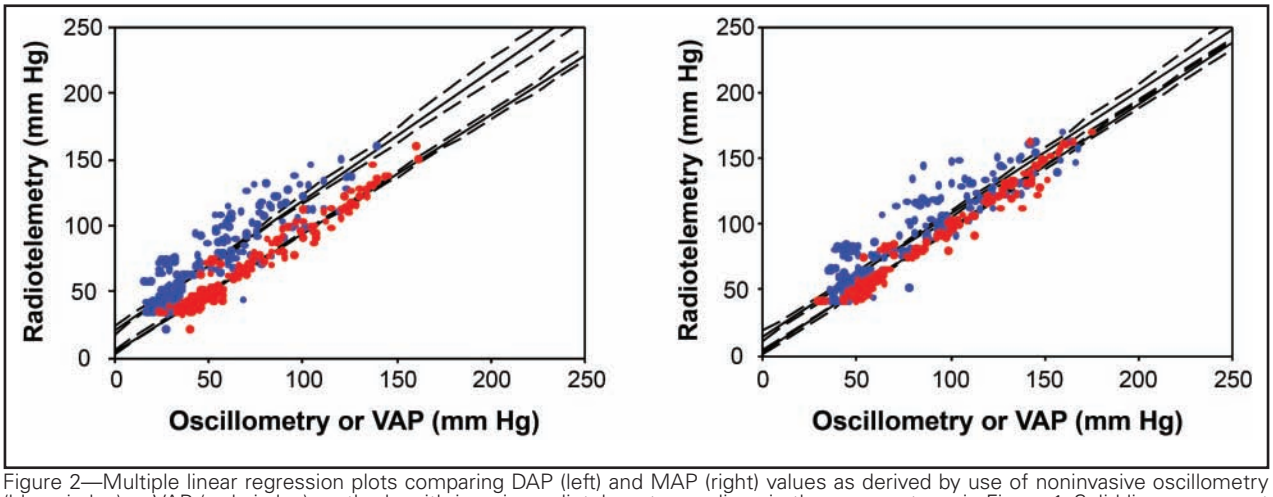

Figure 2—Multiple linear regression plots comparing DAP (left) and MAP (right) values as derived by use of noninvasive oscillometry (blue circles) or VAP (red circles) methods with invasive radiotelemetry readings in the same cats as in Figure 1. Solid lines represent regression lines, and dashed lines represent 95% confidence intervals.

etry and VAP techniques permitted the simultaneous and continuous monitoring of ECG, arterial (femoral artery) blood pressure, and body temperature. During the study, a volume-pressure recording tail cuff[f] to measure blood pressure via noninvasive oscillometry was also used. The cuff was placed around the base of the tail, and the hair was not clipped over the measurement site. During this study, cuff sizes with a width from 2 to 2.5 cm and a length ranging from 3 to 8 cm were used.

Experimental design—Six cats were anesthetized with isoflurane at 4 and 14 weeks. Recordings of arterial blood pressure were made by use of all 3 techniques at normotension (MAP < 85 mm Hg) after stabilization for 15 minutes at 2 end-tidal isoflurane concentrations (2.2% and 1.8%) and at hypertension (MAP > 85 mm Hg) 5 seconds following administration of a phenylephrine bolus (80 µg, IV) at 1.8% isoflurane. Additional measurements were performed at (mean ± SD) 84.5 ± 0.7 days (12 weeks) and 91.5 ± 0.7 days (13 weeks) after implantation, during determination of the MAC of isoflurane.[7] Recordings were made at 2.2% and at the mean ± SD MAC of isoflurane (1.1 ± 0.5% and 1.2 ± 0.5%, respectively). At each time point, 5 concurrent determinations of arterial blood pressure were obtained and the mean was calculated for each method.

Hemodynamic monitoring—Arterial blood pressures were simultaneously recorded via invasive telemetry, VAP, and noninvasive oscillometry techniques. Telemetry signals were captured by use of a telemetry receiver[a] and relayed along with an atmospheric pressure reference[a] to a personal computer via a data-exchange model.[a] Arterial blood pressure signals were obtained from the implanted VAP via noncoring Huber needles and a manometer through a calibrated fluid-filled telemetered transducer.[b] Radio signals from the wearable transmitters were captured and converted back to an analog signal by use of a telemetry receiver. Simultaneously, noninvasive oscillometry measurements were derived via appropriately sized tail cuffs[f] (15 to 20 mm) connected to a calibrated stand-alone monitor.[g] Telemetry measurements were collected immediately prior to inflation of the tail cuff.

Data collection—Throughout the studies, the analog telemetered blood pressure signals were digitally sampled (1,000 Hz), recorded, viewed, and analyzed by use of a common software platform.[h] For all measurements, recorded values included SAP, DAP, and MAP.

Statistical analysis—Data are presented as mean ± SD. At each time point, the mean and SD for the 5 repeated measurements of DAP, MAP, and SAP were calculated. To evaluate measurement repeatability at steady state, coefficients of variability (mean ± SD) were also determined for data collected under anesthesia (2.2% and 1.8% isoflurane) at 4 and 14 weeks; differences in repeatability (ie, between mean coefficients of variation) were evaluated by use of a 2-way ANOVA for invasive telemetry, noninvasive oscillometry, VAP, and Tukey post hoc tests. For all time points, intermethodology comparisons were made by use of simple and multiple linear regression analyses over the aggregate of all collected data points (ie, all measurements and all time points); slope and intersect differences were evaluated by use of multiple linear regression. In addition, bias, precision, and accuracy of noninvasive oscillometry and VAP-derived blood pressure values (compared with invasive telemetry readings) were evaluated via Bland-Altman analysis[8,9] as well as Pearson and concordance correlations, respectively. In all comparisons, values of $P < 0.05$ were considered significant and invasive telemetry values were used as a reference (ie, as the gold standard).

Results

A first analysis was made comparing the VAP and noninvasive oscillometry techniques with the often used and referenced invasive telemetry technique (gold standard). Recordings at 4 and 14 weeks revealed a high degree of similarity: the 95% confidence interval for the 2 measurements overlapped in 29 of 32 time points (**Table 1**). Mean ± SD coefficients of variability were lowest for invasive telemetry, intermediate for VAP, and highest for noninvasive oscillometry (**Table 2**). Overall bias, precision (Pearson coefficient), concordance coefficient, and accuracy (bias correction factor) calcula-

tions revealed consistently higher values for the VAP versus invasive telemetry comparison, compared with the noninvasive oscillometry versus invasive telemetry comparison (**Table 3**). The correlation coefficient (R^2) for 4 to 13 weeks between invasive telemetry and VAP was 0.9649 for MAP, 0.9372 for SAP, and 0.9488 for DAP (**Figure 1**). The R^2 for 4 to 13 weeks between invasive telemetry and noninvasive oscillometry was 0.8409 for MAP, 0.8029 for SAP, and 0.8066 for invasive telemetry. In comparison with MAP and invasive telemetry in multiple linear regression plots, the regression lines representing noninvasive oscillometry and VAP were clearly farther apart at DAP (**Figure 2**). The 95% confidence intervals for noninvasive oscillometry

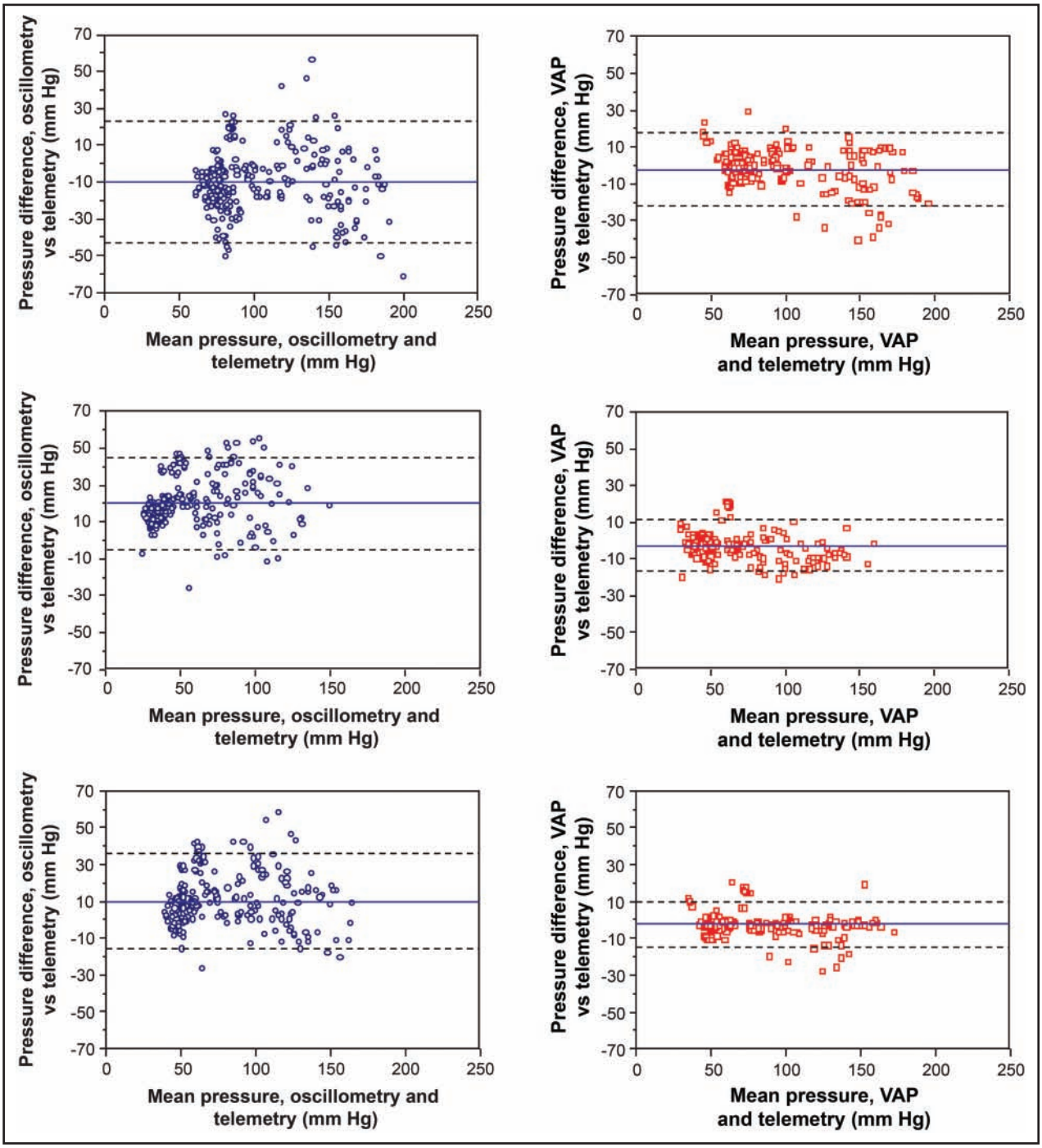

Figure 3—Bland-Altman plots comparing noninvasive oscillometry-derived (left; blue circles) and VAP-derived (right; red squares) pressures with invasive telemetry readings for SAP (top row), DAP (middle row), and MAP (bottom row) in the same cats as in Figure 1. Bias (blue lines) and limits of agreement (± 1.96 SD; dashed lines) are indicated. For the figures in the left column, values on the y-axis indicate the difference between pressures measured via oscillometry and radiotelemetry; values on the x-axis indicate the mean of those pressures. For the figures in the right column, values on y-axis indicate the difference between pressures derived via VAP and radiotelemetry; values on the x-axis indicate the mean of those pressures.

were consistently wider. The Bland-Altman plots also revealed consistently reduced bias and limits of agreement for VAP versus invasive telemetry, compared with noninvasive oscillometry versus invasive telemetry (**Figure 3**).

Discussion

The use of tail cuffs in dogs for indirect measurement of blood pressure and the use of VAP blood pressure measurement are clinically acceptable and precise.[10] There was good correlation and no significant differences among the 3 methods examined in the present study in cats. Certain differences between direct (radiotelemetry and VAP technology) and indirect measurements are to be expected.[11] These differences can be explained because of the different artery used in the measurement[12] (femoral vs coccygeal artery) and because the indirect method measures blood pressure as the movement of the arterial wall as a consequence of a pressure wave (noninvasive oscillometry) and the direct methods measure this pressure wave directly (VAP and invasive telemetry). Also, the attachment of the VAP catheter to a telemetry device could add some bias, although because of constant calibration to atmospheric conditions, the authors believe this source of bias to be minimal.

Despite the expected differences, the overall correlation of both systems with invasive telemetry was high. As expected, the R^2 of the tail cuff system (noninvasive oscillometry) was slightly lower, compared with the VAP. In this design, we chose not to clip the hair from the tail where the cuff was placed. When certain drug trials need to involve client-owned animals to achieve registration, it is often undesirable to clip the hair from the tail at the site where a monitoring cuff is placed. Furthermore, a previous study[13] failed to detect important differences between limbs with hair clipped and those with unclipped hair.

Previous studies often evaluated oscillometric blood pressure monitoring in cats by use of a direct method as a comparison. One study[13] did not find a good correlation between oscillometric and direct measurement, and another study[14] found that apart from a minor underestimation of SAP during normo- and hypertension, the oscillometric monitor yielded accurate measurements for DAP and MAP throughout the entire pressure range. An evaluation of Doppler ultrasonic and oscillometric methods of indirect blood pressure measurement in cats found that in anesthetized cats, oscillometric methods underestimated all blood pressure variables.[15] The American Heart Association has recommended tail-cuffed blood pressure measurement for high-throughput experimental designs. However, some tail-cuff methods have good agreement with radiotelemetry and others do not, indicating that each tail-cuff method requires independent validation.[6]

The Pearson and concordance correlation coefficients were lower in the noninvasive oscillometry and invasive telemetry comparison, compared with the VAP and invasive telemetry comparison. Especially for the measurement of DAP, the bias correction factor seemed to confirm less alignment. This could mean that noninvasive oscillometry might be slightly less accurate with lower blood pressures. These findings seem to be at odds with those of a study[16] in anesthetized dogs in which a noninvasive oscillometry monitor lacked accuracy at high pressures.

Noninvasive oscillometry and invasive telemetry systems are subject to a certain bias. It is expected that this bias is possibly lower in the VAP system of measuring blood pressure because of constant calibration to atmospheric conditions. However, the overlap of part of the regression lines combined with high correlation coefficients clearly indicated the validity of noninvasive oscillometry and invasive telemetry, although the wider limits of agreement when the noninvasive oscillometry device was used should warrant a certain degree of caution.

Overall, results of the study reported here indicated the high accuracy of the VAP and noninvasive oscillometry system and also confirmed the accuracy of the invasive telemetry system. Use of VAP and noninvasive oscillometry may provide reliable alternatives for invasive telemetry in future animal studies. Noninvasive oscillometry is presently widely used in clinical veterinary practice. Results of the present study indicated that noninvasive oscillometry is an accurate and reliable way to measure blood pressure in anesthetized cats.

a. DSI Physio Tel C50-PXT transmitter, Data Sciences International, Saint Paul, Minn.
b. emkaPACK radiotransmitter, EMKA Technologies, Falls Church, Va.
c. MTI/CP6 titanium port, Access Technologies, Skokie, Ill.
d. IntiSilf medical grade silicone rubber, Silastic, Dow Corning Corp, Midland, Mich.
e. Access Technologies, Skokie, Ill.
f. IOX-2, EMKA Technologies, Falls Church, Va.
g. Cardell veterinary monitor, model 9403, Midmark Corp, Versailles, Ohio.
h. Microsoft Office Excel, Microsoft Corp, Redmond, Wash.

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