Evaluation of Doppler Ultrasonic and Oscillometric Methods of Indirect Blood Pressure Measurement in Cats

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ABSTRACT

Reliability of 804 indirect measurements of systemic arterial blood pressure (BP) was assessed in 13 cats by comparing results obtained indirectly by oscillometry (BP_o) and Doppler ultrasonography (BP_{ud}) with those obtained simultaneously by a reference method, direct radiotelemetry (BP_{rt}). The reliability varied considerably among sites of cuff placement and method of indirect measurement in conscious cats. The highest correlations in conscious cats occurred when indirect estimates were obtained as the average of five consecutive values. Indirect and reference measurements were better correlated in anesthetized cats. The indirect devices underestimated all BP parameters, and the magnitude of difference varied among cuff placement sites and device type. Results obtained by these indirect techniques in cats should be interpreted with caution. Either device provided a reliable estimate of BP in anesthetized cats; however, the Doppler device applied over the median artery provided the most reliable measurements in conscious cats.

INTRODUCTION

Several diseases have been associated with elevations of systemic arterial blood pressure (BP) in cats.[1–5] In particular, systemic hypertension has been associated with feline chronic kidney disease and hyperthyroidism.[2,6,7] End-organ damage in the eyes, kidneys, central nervous system, and cardiovascular system has been causally attributed to systemic hypertension.[5–13]

Direct measurement of BP by intra-arterial catheterization or needle puncture provides an accurate and precise measurement of this vital sign. Direct methods are not always practical in the clinical setting because currently available direct devices may require anesthesia or sedation and a high degree of technical skill. These methods also create opportunities for infection and hemorrhage, and their invasiveness may produce an anxiety-induced artifactual increment in BP.

Several devices are commercially available that estimate BP indirectly by utilizing

an external, inflatable cuff. Studies evaluating the reliability of indirect devices have demonstrated that oscillometry and/or Doppler ultrasonography can produce results that are strongly correlated with directly obtained BP measurements in anesthetized cats.[14–16] However, establishing a diagnosis systemic hypertension with indirect BP measurements requires a device with proven reliability in conscious cats. Movement, increased skeletal muscle tone, and lability of measured parameters may interfere with the reliability of these devices in conscious cats.

A radiotelemetric system validated for direct measurement of BP, pulse rate (PR), and movement in experimental studies has been adapted for use in cats.[17–23] This method involves surgical placement of a small implant into the subcutaneous fat of the abdomen. The implant body contains a pressure transducer connected to the intra-arterial catheter and a radio transmitter. Information from the radiotelemetric implant is relayed to a receiver and stored by a computer. The radiotelemetric system allows for simultaneous comparisons between directly obtained measurement of BP and indirect BP measurements obtained in conscious, minimally restrained cats.

The purpose of the present study was to evaluate the accuracy and precision of estimates of BP provided by ultrasonic Doppler flowmetry and oscillometry by comparison with direct BP measurements obtained simultaneously by radiotelemetry.

MATERIALS AND METHODS

Animals

Thirteen adult mixed-breed cats (four sexually intact males, three neutered males, and six sexually intact females) with a mean weight of 3.55 ± 0.73 kg were procured from the University of Georgia College of Veterinary Medicine Laboratory Animal Facility. All animals were vaccinated against common viral diseases and treated for ectoparasites and endoparasites. Cats were antibody-negative for feline leukemia virus and feline immunodeficiency virus. All studies were conducted in accord with the NIH Guidelines for Care and Use of Laboratory Animals were approved by the Institutional Animal Care Committee.

Radiotelemetry System

The use of the radiotelemetry system in cats has been previously described.[19] Briefly, the implant catheter was placed intra-arterially in the femoral artery with the implant body being secured in the subcutaneous space of the flank. A radio signal transmits pressure waveform data via a receiver (RLA-2000, Data Sciences) located at a BP measurement station to a computer (Prolinea 4/66, Compaq Computer). The temporal pattern of BP was then reconstructed from the modulations in the radio signal, and the telemetric systolic BP (SBP_{rt}), diastolic BP (DBP_{rt}), and mean BP (MBP_{rt}) were determined by computer-assisted analysis (Dataquest IV, v2.2, Data Sciences) of these data, as previously described.[17] The receiver was located at a BP measurement station, and direct measurements were obtained as a 5-second mean every 30 seconds; the direct BP reading was taken as the average of all direct measurements. The calibration of each implant was validated prior to implantation and after removal by comparison with a mercury manometer with the aid of a dynamic pressure chamber.

Surgical Placement of Implants

Surgical procedures were performed aseptically in a surgical suite dedicated to this purpose as previously described.[19] For placement of radiotelemetric implants (TA11PA-C40, Data Sciences), anesthesia was induced with sodium thiopental at 5 mg/kg IV, the trachea was intubated, and a stable plane of anesthesia was maintained by delivery of halothane at concentrations of 1% to 3% in oxygen. The femoral artery was ligated distally, and the catheter was placed in the proximal femoral artery and advanced approximately 5 cm. The cats were allowed to recover at least 2 weeks following implant placement before BP studies were

performed. To study elevated BP in the cats, renoprival hypertension was induced by partial nephrectomy in six cats, using a previously described procedure.[22]

Indirect Blood Pressure Estimates

All indirect estimates of BP used either a device that employed the oscillometric principle (Dinamap Model 8300, Critikon.) or a device utilizing the ultrasonic Doppler principle (Model 811, Parks Electronics) and results for indirect estimates were compared with values obtained simultaneously via the direct radiotelemetric system. The oscillometric method provided estimates of mean BP (MBP_o), heart rate (HR_o), systolic BP (SBP_o), and diastolic BP (DBP_o), whereas the ultrasonic Doppler method was used to provide estimates of systolic BP (SBP_{ud}).

Cats were held quietly on the BP measurement station for at least 5 minutes before any indirect measurements were taken. Because initial studies demonstrated that movement interfered with the reliability of both indirect methods, measurements obtained while a subject was moving were discarded. Cuff sizes for the indirect devices were selected so that the cuff width represented approximately 30% to 50% of the limb circumference.[24,25] Limb circumferences ranged from 4 to 7 cm, so all indirect estimations used a No. 2 neonatal cuff (Disposa-Cuf, Critikon).

The occluding cuff for the oscillometric device was attached to three sites on the cats. Occlusion of the coccygeal artery was achieved by placing the cuff 1 cm distal to the base of the tail, with the artery arrow positioned along the ventral midline. Occlusion of the median artery was achieved by placing the cuff on the proximal portion of the thoracic limb between the elbow and carpal pad, with the artery arrow over the medial surface of the limb. Occlusion of the cranial tibial artery was achieved by placing the cuff on the pelvic limb proximal to the hock, with the artery arrow facing cranially. If the oscillometric device failed to display a complete set of estimated values for three consecutive measurements, the cuff was repositioned and the measurements repeated. A measurement failure was defined as the failure of the oscillometric device to provide a complete set of BP estimates (i.e., failure of a measurement cycle to provide a value for SBP_o, MBP_o, and/or DBP_o).

Placement of the Doppler probe was palmar in the thoracic limb (median artery) and plantar in the pelvic limb (tarsal artery). For estimates using the ultrasonic Doppler device, the appropriate surface of the limb was shaven, and an aqueous ultrasonic transmission gel (Aquasonic 100, Parker Laboratories) was applied between the probe and the skin. Position of the flow probe was adjusted until a clear signal was obtained from the amplified loudspeaker, and the probe was fixed into position with white adhesive tape. The occluding cuff, with sphygmomanometer (Sphygmomanometer, Tomac) attached, was secured proximally to the Doppler flow detector. To estimate systolic BP, the cuff pressure was increased until the flow signal disappeared or 200 mm Hg, whichever was greater. Pressure in the cuff was gradually deflated at a rate of approximately 2 mm Hg/second. Earphones were used, and the manometer pressure coinciding with the first audible flow signals was taken as systolic BP_{ud}.

Preliminary Cuff Site Selection Studies in Conscious Cats

Preliminary studies were performed in four cats (three normal cats and one with reduced renal mass) to determine the site providing the strongest correlation between the radiotelemetry reference method and each indirect BP device. Three sites (coccygeal, tibial, and median arteries) were evaluated using the oscillometric device. Two sites (median and tarsal arteries) were evaluated using the Doppler device. On the basis of these initial studies, two sites were chosen for further evaluation with the oscillometric device and one site for the Doppler device.

Comparative Studies in Conscious Cats

For these studies, the median and coccygeal artery sites were evaluated with the oscillometric device, and the median artery site was evaluated with the ultrasonic Doppler device. To produce a broad range of BP values, 13 cats (eight normal and five with reduced renal mass) with varying values for BP were studied. These cats provided normal and elevated values for BP. To reduce BP, four normal cats received 12.5 to 25 mg of atenolol (Atenolol, Lederle Laboratories) and 5 to 10 mg hydralazine (Hydralazine, UDL Laboratories.) orally twice daily for 2 days, with dosage adjusted to produce a drop of approximately 20 mm Hg in mean BP, as measured by radiotelemetry. A minimum of five oscillometric and Doppler ultrasonographic measurements were taken before and after administration of the pharmacologic agents in each cat.

Comparative Studies in Anesthetized Cats

Because of difficulty in obtaining reliable BP measurements in conscious cats with the oscillometric device, simultaneous indirect and direct BP measurements were performed in four normal anesthetized male cats. For these studies, the median and coccygeal arteries were selected for evaluation by the oscillometric device and the median artery was used for the Doppler device. Measurements were obtained as BP was lowered by increasing the concentration of inspired halothane from 1.5% to 4%. At each 10 mm Hg decrement in MBP_{rt}, three to five indirect estimates were performed at each site during simultaneous direct measurements by radiotelemetry. This procedure was continued until MBP_{rt} declined to approximately 50 mm Hg. The BP was then allowed to return to baseline values during inhalation of 1.5% halothane. Subsequently, to increase BP, lactated ringer's solution containing 0.03 mg phenylephrine/ml (Phenylephrine, Schein Pharmaceutical) was infused slowly IV, while maintaining halothane concentrations at 1.5%. Each cat received a total of approximately 0.30 mg of phenylephrine. At each 10 mm Hg increment in MBP_{rt}, three to five indirect estimates were performed at each site during simultaneous direct measurements. The infusion was continued until a total increase in MBP_{rt} of approximately 30 mm Hg above baseline values was achieved.

Statistical Analyses

All values are expressed as mean ± standard deviation. Simple linear regression analysis was used to evaluate the relationships between the indirect and direct values. Mean differences were determined by comparing the values simultaneously obtained for a parameter by the direct and indirect method, with positive values indicative of underestimation by an indirect device. The percentages of measurements within 5 and 10 mm Hg of the radiotelemetric reference method for both indirect devices were calculated. Limits of agreement plots were performed for each comparison.[26] A commercial software package (Statview 4.5, Abacus Concepts) was used to for statistical comparisons. A *P* value less than .05 was considered indicative of a statistically significant difference.

RESULTS

Preliminary Cuff Site Selection Studies

Preliminary studies for the ultrasonic Doppler method were obtained from two cuff placement sites, with a total of 80 simultaneous measurements in four conscious cats at spontaneous BP. The median artery site provided the strongest correlation between SBP_{ud} and SBP_{rt}, and this site was selected for further evaluation in comparative studies. Preliminary studies for the oscillometric method were obtained from three cuff placement sites, with 96 simultaneous direct and indirect determinations in four conscious cats at spontaneous BP. On the basis of these studies, the coccygeal and median artery cuff sites were chosen for further evaluation.

Comparative Studies in Conscious Cats

Comparative studies for the ultrasonic Doppler method were obtained from the

Table 1. Correlation of Simultaneous Indirect and Direct Blood Pressure Measurements in 13 Conscious Cats

Method/ Arterial Site	No. of Measurements	Parameter	Systolic	Mean	Diastolic
Oscillometry/	127	R^2	0.324*	0.349*	0.346*
Coccygeal		Difference†	17.1 ± 29.8	25.6 ± 29.8	25.6 ± 22.5
		<5 mm Hg‡	11.0%	6.3%	7.1%
		<10 mm Hg‡	26.8%	12.6%	12.6%
		Mean ± SD§	134.5 ± 21.7	113.7 ± 20.2	98.5 ± 18.7
		Range§	107–186	80–162	71–147
Oscillometry/	123	R^2	0.258*	0.315*	0.295*
Median		Difference†	15.2 ± 28.2	16.2 ± 28.4	11.5 ± 28.3
		<5 mm Hg‡	14.6%	8.1%	9.8%
		<10 mm Hg‡	27.6%	16.3%	25.2%
		Mean ± SD§	131.5 ± 23.8	111.2 ± 23.8	95.4 ± 22.4
		Range§	104–209	80–184	59–159
Doppler/					
Median	130	R^2	0.824*	ND	ND
		Difference†	23.1±19.4	ND	ND
		<5 mm Hg‡	7.7%	ND	ND
		<10 mm Hg‡	19.2%	ND	ND
		Mean ± SD§	166.1 ± 46.3	ND	ND
		Range§	76–254	ND	ND

*Significant linear relationship ($P < .0001$).
†Difference = direct – indirect measurement.
‡Percentage of indirectly obtained values within 5 or 10 mm Hg of the direct value.
§Measurements obtained by the direct radiotelemetric method (mm Hg).
ND = not determined.

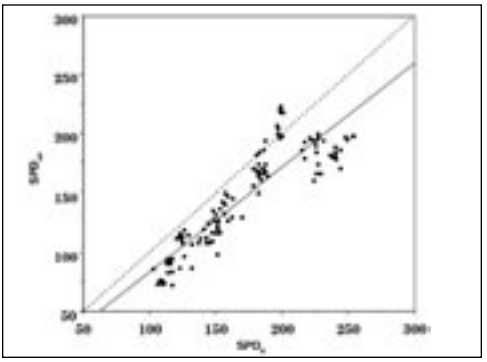

Figure 1. Results of linear regression analysis (R^2=0.824; $P < .0001$) for systolic arterial pressure by Doppler ultrasonography (SBP_{ud}) at the median artery site in comparative studies in 13 conscious cats (130 comparisons). Each data point corresponds to values simultaneously obtained by direct measurement by radiotelemetry (SBP_{rt}) and SBP_{ud}.

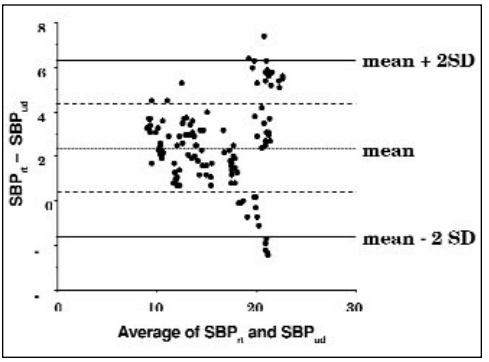

Figure 2. Results of Bland and Altman limits of agreement plot[26] for systolic arterial pressure by Doppler ultrasonography (SBP_{ud}) at the median artery in conscious cats. Each data point corresponds to the difference between the direct measurement by radiotelemetry (SBP_{rt}) and SBP_{ud} (SBP_{rt}–SBP_{ud}), plotted against the average of the two simultaneously obtained results. Also depicted is the mean overall difference is depicted (dotted line), the mean ± one standard deviation (dashed line), and mean ± two standard deviations (solid line) of the difference. There was no significant linear regression relation, although the difference between SBP_{ud} and the reference method appeared to increase at higher BP.

median artery site (Table 1), with a total of 130 simultaneous measurements in 13 conscious cats. These studies demonstrated a strong correlation between SBP_{rt} and SBP_{ud} (Figure 1) at the median artery site. The

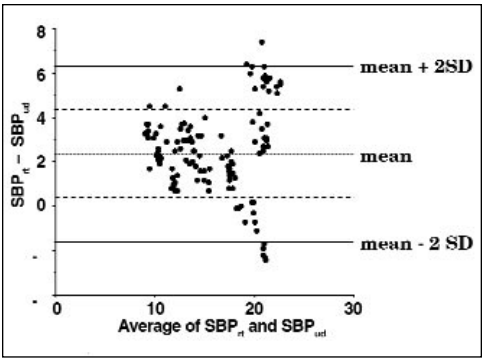

Figure 3. Results of linear regression analysis of systolic arterial pressure by oscillometry (SBP_o) at the median artery site (R^2=0.258; $P < .0001$) in comparative studies in 13 conscious cats (123 comparisons). Each data point corresponds to values simultaneously obtained by direct measurement by radiotelemetry (SBP_{rt}) and SBP_o.

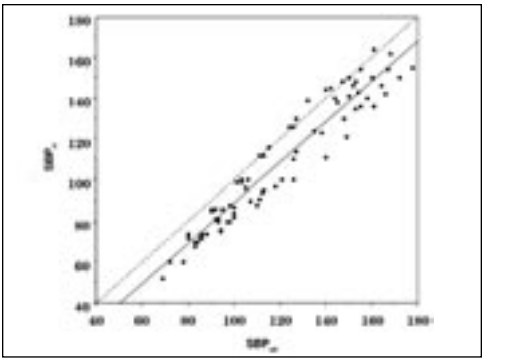

Figure 4. Results of linear regression analysis of values for systolic arterial pressure by Doppler ultrasonography (SBP_{ud}) at the median artery site (R^2=0.928; $P < .0001$) in comparative studies in 13 anesthetized cats (82 comparisons). Each data point corresponds to values simultaneously obtained by direct measurement by radiotelemetry (SBP_{rt}) and SBP_{ud}.

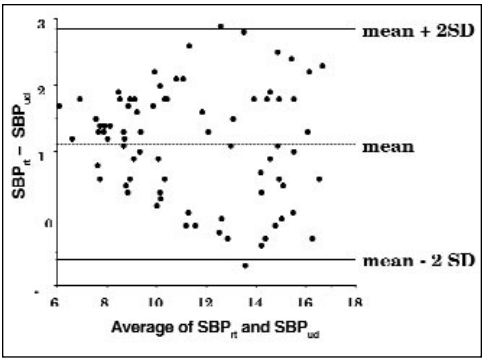

Figure 5. Results of Bland and Altman limits of agreement plot[26] for systolic arterial blood pressure by Doppler ultrasonography (SBP_{ud}) at the median artery in anesthetized cats. Each data point corresponds to the difference between the direct (SBP_{rt}) and SBP_{ud} (SBP_{rt}–SBP_{ud}), plotted against the average of the two simultaneously obtained results. Also depicted is the mean overall difference (dotted line), the mean ± one standard deviation of the difference (dashed line), and mean ± two standard deviations (solid line). There was no significant linear regression relation present, although the difference between SBP_{ud} and the reference method appeared to increase at higher BP.

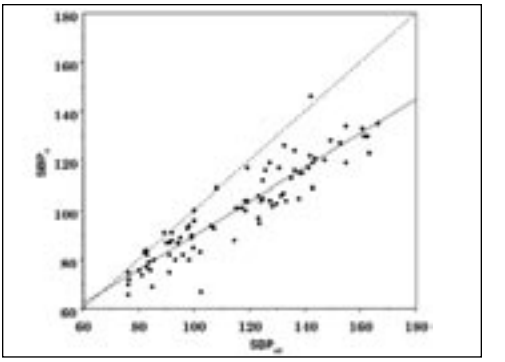

Figure 6. Results of linear regression analysis of values for systolic arterial pressure by oscillometry (SBP_o) at the median artery site (R^2=0.853; $P < .0001$) in comparative studies in four anesthetized cats (85 comparisons). Each data point corresponds to values simultaneously obtained by direct measurement by radiotelemetry (SBP_{rt}) and SBP_o.

Doppler device underestimated direct values for BP (Table 1), and the degree of error with this device increased ($P < .0001$) at higher BP (Figure 2). A minority of values were within 10 mm Hg of the directly obtained values (Table 1).

Comparative studies for the oscillometric method were conducted at two sites for cuff placement (Table 1), with a total of 250 estimates in 13 conscious cats. These studies indicated poorer correlations between BP_o and the directly obtained measurements (Figure 3). The oscillometric device underestimated all BP parameters in conscious cats (Table 1). The differences between direct and indirect measurement methods at the coccygeal artery cuff site were similar to the corresponding values for the median

Table 2. Correlation of Indirect and Direct Blood Pressure Measurements in 13 Conscious Cats Using the Averages of Five Consecutive Simultaneous Determinations

Method/ Arterial Site	No. of Measurements	Parameter	Systolic	Mean	Diastolic
Oscillometry/ Coccygeal	16	R^2	0.522*	0.552*	0.642*
		Difference†	9.4 ± 24.2	22.0 ± 19.3	22.7 ± 15.9
		Mean ± SD‡	131.7 ± 20.1	111.4 ± 20.4	96.7 ± 20.6
		Range‡	111–175	91–157	72–147
Oscillometry/ Median	16	R^2	0.677**	0.677**	0.713**
		Difference†	17.1 ± 16.9	16.3 ± 16.7	12.0 ± 15.4
		Mean ± SD‡	133.4 ± 28.3	112.4 ± 26.9	95.7 ± 23.8
		Range‡	105–197	80–172	72–146
Doppler/ Median	18	R^2	0.855**	ND	ND
		Difference†	22.4 ± 17.1	ND	ND
		Mean ± SD‡	145.5 ± 50.2	ND	ND
		Range‡	76–218	ND	ND

All linear regression relationships were significant; *P < .01; **P < .0001.
†Difference = direct – indirect measurement.
‡Measurements obtained by the direct radiotelemetric method (mm Hg).
ND = not determined.

Table 3. Correlation of Simultaneous Indirect and Direct Blood Pressure Measurements in Four Anesthetized Cats

Method/ Arterial Site	No. of Measurements	Parameter	Systolic	Mean	Diastolic
Oscillometry/ Coccygeal	81	R^2	0.800*	0.700*	0.602*
		Difference†	14.7 ± 11.8	27.0 ± 10.6	23.3 ± 9.1
		<5 mm Hg‡	24.7%	0.0%	1.2%
		<10 mm Hg‡	37.0%	4.9%	9.9%
		Mean ± SD§	113.7 ± 24.7	93.5 ± 19.3	74.5 ± 14.4
		Range§	77–166	62–135	49–110
Oscillometry/ Median	85	R^2	853*	0.809*	0.711*
		Difference†	15.2 ± 10.6	21.8 ± 9.0	19.3 ± 9.5
		<5 mm Hg‡	22.4%	2.4%	8.2%
		<10 mm Hg‡	38.8%	12.9%	15.3%
		Mean ± SD§	115.5 ± 25.1	94.4 ± 19.6	76.1 ± 14.3
		Range§	76–166	62–134	49–107
Doppler/ Median	82	R^2	928*	ND	ND
		Difference†	11.5 ± 8.3	ND	ND
		<5 mm Hg‡	23.2%	ND	ND
		<10 mm Hg‡	41.5%	ND	ND
		Mean ± SD§	119.0±30.1	ND	ND
		Range§	69–178	ND	ND

*Significant linear relationship (P < .0001).
†Difference = direct – indirect measurement.
‡Percentage of indirectly obtained values within 5 or 10 mm Hg of the direct value.
§Measurements obtained by the indirect radiotelemetric method (mm Hg).
ND = not determined.

artery site. A minority of values obtained by oscillometry were within 10 mm Hg of the directly obtained values

Averaging of five consecutive simultaneous measurements strengthened correlations, especially for the oscillometric device and tended to decrease the mean difference between indirect and direct methods (Table 2).

Comparative Studies in Anesthetized Cats

Comparative studies were obtained from the median artery site in four anesthetized cats, with a total of 248 simultaneous measurements (Table 3). These studies demonstrated a strong correlation between SBP_{ud} and SBP_{rt} at the median artery site (Figure 4). The Doppler device tended to underestimate BP, and the difference between indirect and

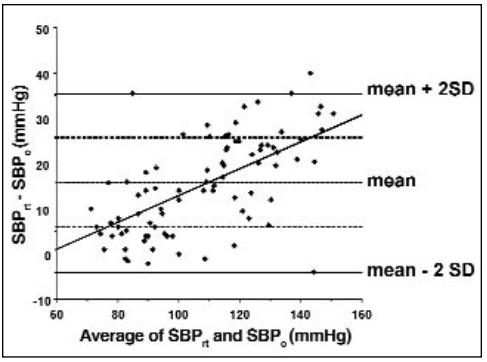

Figure 7. Results of Bland and Altman limits of agreement plot[26] for systolic arterial pressure by oscillometry (SBP_o) at the median artery. Each data point corresponds to the difference between the direct (SBP_{rt}) and SBP_o (SBP_{rt}–SBP_o), plotted against the average of the two simultaneously obtained results. Also depicted is the mean overall difference (dotted line), mean ± one standard deviation of the difference (dashed line), mean ± two standard deviations (solid line), and the simple liner regression relation (R^2=0.379; P < .001) between the differences and averages of the 2 methods (dark solid line).

direct values tended to increase at higher BP, although there was no significant regression pattern to the increase (Figure 5). The correlations for BP estimates with the oscillometric device in anesthetized cats (Table 3; Figure 6) were substantially increased from the corresponding values obtained in conscious cats. The range of differences for SBP_o; MBP_o; DBP_o at the coccygeal artery cuff site were similar to the corresponding values for the median artery site (Table 3). A minority of values for both devices fell within 10 mm Hg of the corresponding direct values. The oscillometric device underestimated all BP parameters in anesthetized cats, with the degree of underestimation increasing (R^2 = 0.379; P < .001) at higher BP for the oscillometric device (Figure 7).

Failure Rate for Indirect Devices

The percentage of attempted measurements that failed to provide a complete set of values (failure rate) for the oscillometric method (22 ± 18%) was similar at the coccygeal and median artery sites, although failure rates varied from 0 to 100% for individual cats. Failure rate for the ultrasonic Doppler device was 0%.

DISCUSSION

The measurement of BP is a valuable clinical tool. While direct measurements of BP are accurate and precise, their utility is limited by their invasiveness. Some studies have compared results of indirect devices to direct measurements but they have relied upon anesthesia or sedation.[14–16] To be relevant to measurement of BP in awake patients, the reliability of indirect devices should be evaluated in conscious animals. This is confirmed by the dramatic differences in reliability of the indirect devices in conscious verses anesthetized cats in this study.

The Doppler device was well correlated with direct BP measurements in both conscious and anesthetized cats. Furthermore, although it was occasionally difficult to perform the technique, operators were able to obtain a BP with this device from each cat on each attempt. The oscillometric device was poorly correlated with the direct BP in these same cats under similar circumstances, although averaging five consecutive determinations improved the reliability of this device somewhat in conscious cats. Failure to obtain a reading occurred in approximately 20% of measurement attempts with the oscillometric device. This problem of measurement failures has been reported previously in a study of anesthetized cats.[15]

Several studies have addressed the relationship between simultaneously obtained direct and indirect values for BP in cats. In one study,[15] three indirect devices were evaluated in anesthetized cats. Indirect BP estimates from these devices were compared with simultaneous direct measurements obtained by intra-arterial catheterization. Regression analysis demonstrated that the ultrasonic Doppler measurement device had the strongest correlation at the hind limb site for all BP parameters, whereas the oscillometric device had the strongest correlations at the tail site for all BP parameters.

It was concluded that the Doppler device had the highest overall accuracy and lowest failure rate in anesthetized cats. In the present study, similar results were obtained in anesthetized cats, and the Doppler device had the greatest utility in conscious cats.

Another study evaluated the reliability of an ultrasonic Doppler device in anesthetized cats at the median artery site.[14] Indirect BP estimations were compared with simultaneously obtained direct measurements. The estimates obtained by the Doppler device were strongly correlated with the direct measurements. Systolic BP measured by this technique was consistently underestimated and a correction factor of +14 mm Hg was recommended to account for this underestimation. A similar degree of underestimation by the ultrasonic Doppler device in anesthetized cats was obtained in the present study (11.5 mm Hg). Since data collected in the anesthetized and conscious cat in the present study demonstrated that errors of both indirect devices were variable, use of a correction factor does not seem to present a valid approach.

Both indirect BP devices underestimated BP in anesthetized and conscious cats. The range of these underestimations varied from 11 to 26 mm Hg in conscious cats and from 11 to 27mm Hg in anesthetized cats. The Association for the Advancement of Medical Instrumentation (AAMI) specifies criteria for validation of indirect BP devices intended for use in humans.[27] The AAMI's criteria specify the mean difference between the test and reference method should not exceed 5 ± 8 mm Hg. In the present study, both indirect devices failed to meet these criteria. Failure to meet AAMI criteria would lead to the rejection of the corresponding indirect device for use in humans. Many indirect devices meet the AAMI criteria for accuracy and precision in human beings, including devices that use methods of BP estimation that are similar to those used in the present study.[28] Although a recent report describes validation of an oscillometric device in anesthetized cats,[16] measurement of BP in cats, especially in the awake state, is substantially more difficult than in humans. Until devices are developed and validated by comparison with a reference method in conscious cats, the Doppler device used in the present study would seem to provide a reliable approach to estimation of BP in conscious cats in the clinical setting.

The radiotelemetric system used in the present studies provided values for MBP, SBP, and DBP for comparison with simultaneously obtained indirect BP estimation devices. Studies have verified the precision and accuracy of this direct BP measurement method.17,29–31 In a study conducted in the authors' laboratory, direct radiotelemetric measurements correlated strongly with the simultaneously obtained direct intra-arterial pressure values in three cats (R^2: MBP = 0.999, SBP = 0.997, DBP = 0.998; $P < .0001$) with bias values less than 2 mm Hg at 3 months after implantation.[19]

Inaccuracies from oscillometric BP estimation devices might arise from shivering or other movement by the cats that could interfere with the ability of the device to detect oscillations from pulsatile blood flow. In the present studies, this problem was addressed by familiarizing the cats with the measurement room prior to studies, limiting noise and activity in the measurement room, and having the cats gently restrained by familiar personnel. If an animal moved during a BP_o determination sequence, the values were discarded. Three sites were evaluated for cuff placement with the oscillometric device. Although it is possible that oscillations are more easily detected other sites, such as the brachial artery, the utility of other cuff sites for the oscillometric device were not evaluated. A second potential source of inaccuracy in determining BP_o is BP lability. The oscillometric BP determination sequence ranges from approximately 30 to 150 seconds in duration. If BP changes during the determination sequence, BP_o and BP_{rt} could disagree substantially. This source of error was addressed through minimizing patient disturbance and by fre-

quent BP_{rt} determination throughout the indirect device's cycle.

The ultrasonic Doppler was more reliable in the present studies. The average determination sequence for the ultrasonic Doppler method is approximately 30 seconds, and this method could be affected similarly to the oscillometric method by a sudden change in BP. Because estimates were discarded if the cat moved during the determination sequence, the present studies should have minimized this known source of error with the ultrasonic Doppler method.

In the present study, the Doppler device provided an approximation of BP in conscious cats that was strongly correlated with directly measured BP. In contrast, the oscillometric device provided estimates for BP that were less well correlated in conscious cats. Results obtained with both devices were well correlated to the reference method in measurements obtained under anesthesia. Although neither indirect device met the AAMI criteria for accuracy or precision, these correlations would support the use of the ultrasonic Doppler with the cuff at the median artery site, either as a single measurement or as the average of five consecutive values for evaluating BP in conscious cats. The ultrasonic Doppler device at the median artery and the oscillometric device at the median or coccygeal artery site provided results that were well correlated to BP in anesthetized cats.

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