Accuracy of an oscillometric blood pressure monitor during phenylephrine-induced hypertension in dogs

Rose M. McMurphy, DVM; Melissa R. Stoll, DVM; Raymond McCubrey, MS

Objective—To examine the agreement between direct arterial blood pressure measurements obtained from 2 arteries and indirect blood pressure measurements obtained with an oscillometric blood pressure monitor (OBPM) during normotension and phenylephrine-induced hypertension in dogs.

Animals—16 male Beagles.

Procedures—In anesthetized dogs, arterial catheters were placed in the lingual and dorsal pedal arteries for measurement of arterial blood pressure. A blood pressure cuff was placed on either the dog’s fore- or hind limb and connected to an OBPM. Systolic, diastolic, and mean arterial blood pressures (SAP, DAP, and MAP, respectively) were recorded from both arteries and the OBPM every 5 minutes for 30 minutes (baseline), during a 30-minute period in which dogs received a phenylephrine infusion IV to induce hypertension, and for 30 minutes after discontinuation of the infusion. Mean differences in blood pressure values and confidence intervals were calculated to compare the indirect and direct measurement techniques.

Results—In dogs, oscillometry underestimated SAP during normotension, and the difference between oscillometric and direct measurements increased during hypertension. Oscillometry underestimated DAP, but the difference between oscillometric and direct measurements decreased during hypertension. There was close agreement among techniques for MAP determination. Biases between direct measurements and OBPM blood pressure values measured from dogs’ forelimbs or hind limbs were not significantly different.

Conclusions and Clinical Relevance—In normotensive dogs, oscillometric measurements of MAP and SAP agreed more closely with direct arterial pressure measurements than oscillometric estimates of DAP. Oscillometric measurement of MAP was accurate during both normotension and hypertension in dogs. (Am J Vet Res 2006;67:1541–1545)

Hypertension in dogs is increasingly recognized as a complication of several diseases such as renal dysfunction,1 hyper- and hypothyroidism,1 hyperadrenocorticism,1 diabetes mellitus,4 and pheochromocytoma,1 hepatic disease,5 and intracranial neoplasia.6 Consequences of untreated hypertension can include retinopathy and choroidopathy, encephalopathy, and renal tubular or glomerular damage.17 Therefore, it is important to be able to screen for and diagnose systemic hypertension in dogs. Accurate diagnosis of hypertension depends on several factors, including the environment in which the dog is evaluated,4 stress or procedure-associated restraint, blood pressure cuff size,9 position and site of cuff placement,10 operator experience, repeatability of results,11 and accuracy of the blood pressure monitor used.

There are 2 noninvasive methods for the measurement of arterial blood pressure in dogs, namely the use of Doppler ultrasonography or OBPMs. Oscillometric blood pressure assessments have been compared with direct arterial pressure measurements in normotensive, hypotensive, and hypertensive dogs.10,12–16 However, it is important to validate the monitor used because the microprocessors and algorithms for establishing systolic and diastolic arterial pressure are not the same among all units and the reliability of different monitors varies.13,17 Agreement between the oscillometric and direct arterial blood pressure measurements from the cranial tibial artery has been evaluated in anesthetized dogs in which blood pressure was varied by altering the depth of anesthesia17; however, hypertension was not induced in that study.15 The use of an OBPM has been assessed in anesthetized foals during hypotension, normotension, and phenylephrine-induced hypertension.18

The purpose of the study reported here was to examine the agreement between direct arterial blood pressure measurements obtained from 2 arteries and indirect blood pressure measurements obtained with an OBPM during normotension and phenylephrine-induced hypertension in dogs and examine the effect of cuff placement on the fore- or hind limb.

Materials and Methods

Animals—Sixteen healthy adult purpose-bred intact male Beagles (weight range, 6.8 to 11.4 kg) were used for the study. An institutional animal care and use committee approval was granted prior to the start of this study.
Anesthesia and instrumentation—For each dog, atropine (0.54 mg/mL) was administered SC (0.04 mg/kg) 30 minutes prior to anesthesia; this treatment was given to prevent development of bradycardia secondary to the baroreceptor response to phenylephrine-induced hypertension. Anesthesia was induced with a 2.5% solution of thiopental sodium administered IV to effect (dose, 10 to 13 mg/kg). The trachea was intubated, and the endotracheal tube was connected to a circle anesthetic breathing circuit. Anesthesia was maintained with halothane in oxygen delivered from an out-of-circuit precision vaporizer with an oxygen flow of 30 mL/min. End-tidal halothane concentration was monitored with a halogenated agent monitor that was calibrated with known gas standards.e The anesthetic vaporizer was adjusted to maintain an end-tidal halothane concentration of 1.0% of 1 atmosphere. End-tidal carbon dioxide concentration was monitored with a previously calibrated capnograph.f Esophageal temperature was maintained at 37.5° to 38.3°C by use of warm water circulating pads. The dogs were positioned in right lateral recumbency. A 20-gauge, 5.1-cm catheter was placed in the lingual artery and attached to an identical transducer that was positioned at the midsternum level. Another 20-gauge, 5.1-cm catheter was placed in the dorsal pedal artery and attached to an identical transducer. Each of the 2 transducers was connected to a multichannel recorder and oscilloscope. 

Experimental design—Dogs were assigned to 1 of 2 groups. In group I, a disposable, 3.5-cm blood pressure cuff was secured on the left forelimb of 8 dogs, midway between the carpus and the radiohumeral joint. In group II, a 3.5-cm blood pressure cuff was placed just proximal to the tarsus of the left hind limb of 8 dogs. The height of the 3.5-cm cuff was within the recommended range of 40% to 60% of limb circumference for all of the dogs in the study. Blood pressure cuffs were calibrated to read pressure values on an OBPM. 

In phase 1, values of DAPL, DAPP, and OMP were recorded simultaneously every 5 minutes for 30 minutes; systolic, diastolic, and mean arterial blood pressures were recorded via each method. Pulse rate was assessed via 3 methods—from the direct arterial pressure waveform display, by use of the OBPM, and via palpation and counting of pulses during a 30-second period. A constant rate infusion of phenylephrine (60 μg/mL) was then started at a rate of 1 μg/kg/min and increased to 3 μg/kg/min to attain a mean arterial blood pressure value of approximately 140 mm Hg and a systolic arterial blood pressure > 200 mm Hg. Blood pressure and pulse rate measurements were recorded every 5 minutes for 30 minutes during this infusion (phase 2). The infusion of phenylephrine was discontinued, and data were recorded for an additional 30 minutes (phase 3). End-tidal halothane and end-tidal carbon dioxide concentrations and esophageal temperature were recorded at 5-minute intervals throughout the study.

Statistical analysis—Agreement between indirect and direct blood pressure measurements and between DAPL and DAPP values was determined by use of the method reported by Bland and Altman.g Mean differences between values determined via each direct arterial blood pressure measurement method and OMP values (ie, DAPL-OMP and DAPP-OMP) and mean differences between DAPL and DAPP values (ie, DAPL-DAPP) during phases 1, 2, and 3 for each group were calculated to derive an estimate of the difference between methods (bias) and limits of agreement (confidence intervals). For the comparisons between direct and indirect methods, a positive bias represented an underestimation of blood pressure by the OBPM, and a negative bias represented an overestimation of blood pressure by the OBPM. The nearer a bias value was to zero, the greater the agreement between the 2 measurement methods being compared. An ANOVA for repeated measures was used to compare the estimates for each phase within a group to determine whether hypertension had an effect on agreement. Comparisons were also made between groups to detect any effect of blood pressure cuff location on agreement. A value of P < 0.05 was considered significant. The mean difference between pulse rate measurements during each phase was calculated for each method and analyzed in a manner similar to that used for the blood pressure values.

Results

During each phase of the study, the mean differences (bias) in blood pressure along with the 95% confidence intervals were calculated (Tables 1–3). For comparisons of direct arterial pressure values with oscillometric values, a positive number indicated that the OBPM underestimated blood pressure, and a negative number indicated that the OBPM overestimated blood pressure. For comparisons between the direct arterial pressure values obtained from the lingual and dorsal pedal arteries, a positive number indicated that the lingual artery pressure was higher, and a negative number indicated that the dorsal pedal artery pressure was higher.

The comparisons between the 2 direct arterial pressures revealed that the systolic arterial blood pressure determined from the dorsal pedal artery was higher than that determined from the lingual artery. There

| Table 1—Mean differences (bias) ± SEM and 95% confidence intervals for systolic arterial blood pressure values (mm Hg) obtained via an indirect oscillometric (OMP) and 2 direct (DAPL and DAPP) arterial blood pressure measurement methods before (phase 1), during (phase 2), and after (phase 3) IV infusion of phenylephrine in dogs. |
|---|---|---|---|
| Group | DAPL-OMP comparison | DAPP-OMP comparison | DAPL-DAPP comparison |
| | Bias | 95% CI | Bias | 95% CI | Bias | 95% CI |
| I (blood pressure cuff on forelimb; n = 8) | | | | | | |
| Phase 1 | 0.88 ± 1.92 | -2.01 to 4.76 | 7.75 ± 2.00 | 3.71 to 13.79 | -6.88 ± 1.50 | -8.97 to 3.84 |
| Phase 2 | 7.28 ± 2.00 | 3.23 to 11.34 | 22.95 ± 2.24* | 18.28 to 27.67 | -14.29 ± 1.14 | -16.64 to -11.93 |
| Phase 3 | 10.96 ± 2.00* | 6.90 to 15.01 | 15.64 ± 2.34 | 10.95 to 20.37 | -6.29 ± 1.14 | -8.65 to -3.93 |
| II (blood pressure cuff on hind limb; 8) | | | | | | |
| Phase 1 | 2.79 ± 1.93 | -1.10 to 6.68 | 5.4 ± 2.00 | 1.37 to 9.45 | -2.62 ± 1.50 | -5.66 to 0.41 |
| Phase 2 | -1.85 ± 2.00 | -5.90 to 2.20 | 9.42 ± 2.24 | 4.72 to 14.11 | -10.69 ± 1.14 | -13.05 to -8.33 |
| Phase 3 | 1.79 ± 2.00 | -2.26 to 5.85 | 6.15 ± 2.23 | 1.46 to 10.84 | -4.86 ± 1.14 | -7.21 to -2.50 |

*Value significantly (P < 0.05) different from the phase 1 value for this comparison in this group. CI = Confidence interval.
were no significant differences in systolic arterial blood pressure values among phases within groups or between groups I and II. Diastolic and mean arterial pressure measurements determined via DAPL were only slightly higher than the values determined via DAPP, and there was no significant difference among phases within groups or between groups I and II.

With regard to systolic arterial blood pressure, there was good agreement between the direct arterial pressure measurements (DAPL or DAPP) and OMP values during phase 1 in both groups, and the OBPM modestly underestimated (positive bias number) systolic arterial blood pressure (Table 1). In group I, the bias (mean difference in systolic arterial blood pressure) for DAPP-OMP was significantly greater during phase 2 than phase 1, and the bias for DAPL-OMP was greater during phase 3 than phase 1. These differences were greater for the comparisons of DAPP-OMP than DAPL-OMP.

Oscillometric measurements underestimated diastolic arterial blood pressure during phase 1 in both groups (Table 2). The bias (mean difference in diastolic arterial blood pressure) for DAPL-OMP was greater during phase 3 than phase 1. These differences were greater for the comparisons of DAPL-OMP than DAPP-OMP.
was significantly less during phases 2 and 3, compared with findings in phase 1. The bias for DAPP-OMP was less during phase 2 than phase 1 in group II only.

Oscillometric measurements slightly underestimated mean arterial blood pressure during phase 1 in both groups (Table 3). The differences between measurements obtained via each direct arterial method and the OBPM were less during phase 2 in the group II dogs.

There was close agreement among all methods of pulse rate measurement, with no differences among phases within groups or between groups I and II (Table 4). There were no differences between groups or within groups at any measurement time for end-tidal halothane concentration, end-tidal carbon dioxide concentration, or body temperature. Body weight between groups was not different.

Discussion

By use of the oscillometric technique, systolic arterial blood pressure measurements in dogs during normotension agreed closely with DAPL values, particularly when the blood pressure cuff was placed on the forelimb (bias, 0.88 ± 1.92 mm Hg). Oscillometry slightly underestimated systolic arterial blood pressure in comparison with the DAPL values; in this instance, the bias was less when the blood pressure cuff was placed on the hind limb (bias, 5.4 ± 2.00 mm Hg). It is well known that direct arterial pressure measurements vary depending on the artery that is cannulated. Arteries that are more distally located, such as the dorsal pedal artery, will have amplification of the systolic wave and exaggeration of the diastolic wave, and the systolic arterial blood pressure measurement will be higher than that derived from an artery that is close to the aorta. During phase 1, the mean difference in systolic arterial blood pressure measurements obtained from the 2 arteries (DAPL-DAPP) was -6.88 ± 1.50 mm Hg in group I and -2.62 ± 1.50 mm Hg in group II, indicating that the value derived from the dorsal pedal artery was higher than that derived from the lingual artery.

When hypertension was induced (phase 2), bias in all systolic arterial blood pressure comparisons increased except for DAPL-OMP in group II. In all other comparisons between direct and indirect blood pressure measurement methods, the OBPM underestimated systolic arterial blood pressure, and the bias was greatest for DAPP-OMP in group I (bias, 22.95 ± 2.24 mm Hg). The difference between lingual and dorsal pedal arterial pressure values also increased during infusion of phenylephrine, and DAPP values were 10 to 14 mm Hg greater than DAPL values. Underestimation of systolic arterial blood pressure via oscillometry during phenylephrine-induced hypertension in dogs has been reported previously.

During oscillometry, the pulse impinges on the inflated cuff proximal to the occluded artery and causes oscillations within the cuff and, subsequently in the tubing into the monitor with the transducer. As the cuff is deflated, a marked increase in the amplitude of the oscillations identifies the point when blood first flows through the artery and is estimated to be systolic arterial blood pressure. The amplitude of the oscillations continues to increase and reaches a peak that coincides with mean arterial blood pressure. Phenylephrine induces hypertension by increasing vascular resistance. In addition, phenylephrine infusions may result in decreased systolic ejection time secondary to increases of afterload. Because peak systole is such a brief period, it is possible that as the blood pressure cuff is gradually but continuously deflating, the oscillometric monitor does not detect the initial marked increase in amplitude of the oscillations and thus underestimates the blood pressure. Phenylephrine also changes the pulse contour and impedance within the more distally located vessels, which may affect accuracy of a monitor. It is notable that for oscillometric estimates of systolic arterial blood pressure within a specific artery, the agreement was better when the cuff placement was closer to that artery. This may account for some of the reports of underestimations of systolic arterial blood pressure by oscillometric monitors. However, whether the cuff was placed on the forelimb or the hind limb of the dogs in the present study, the agreement between direct and indirect blood pressure measurements was better for DAPL-OMP than DAPP-OMP.

Diastolic arterial blood pressure was underestimated by the OBPM; mean differences ranged from approximately 14 to 24 mm Hg, and the bias was greater for DAPL-OMP than DAPP-OMP in both groups. Results of studies involving other oscillometric monitors are similar. Unlike systolic arterial blood pressure, mean diastolic arterial blood pressure in normotensive and hypertensive dogs was approximately 6 mm Hg higher in the lingual artery, compared with the value derived from the dorsal pedal artery. The bias between direct and indirect arterial pressure monitoring methods decreased during hypertension (in both groups, the bias was reduced to approx 5 mm Hg and approx 10 mm Hg for DAPP-OMP and DAPL-OMP respectively). For diastolic arterial blood pressure, agreement was better between the oscillometric measurement and DAPP. Similar to findings for systolic arterial blood pressure, if the mean difference for DAPL-DAPP (now a positive number) is added to the bias for DAPP-OMP, it approximates the bias for DAPL-OMP.

Mean arterial blood pressure measurements were also underestimated by the OBPM, but as with diastolic arterial blood pressure, the bias decreased during phase 2; there was excellent agreement during phase 2 in the dogs in which the blood pressure cuff was placed on the hind limb (group II). The DAPL-DAPP difference in mean arterial blood pressure was quite small (approx 4 mm Hg), and as with diastolic arterial blood pressure, the bias for DAPP-OMP was better than that for DAPL-OMP. Other studies have also revealed closest agreement between indirect and direct blood pressure measurement methods during assessment of mean arterial blood pressure.

The present study was limited because of the choice of study dogs. All of the dogs were Beagles of similar size and conformation. Clinically, we and others have noted that adequate occlusion of arterial flow with a blood pressure cuff may not always occur, and consequently, there is an overestimation of blood pressure values. Dogs with thin legs and little muscle mass to contribute to arterial occlusion during cuff inflation.
may have erroneously high pressure readings, and limbs of chondrodystrophic breeds can represent a challenge for the appropriate positioning and size selection of the blood pressure cuff. In chondrodystrophic dogs, the tail is possibly a better site for blood pressure cuff placement than the limbs. Choice of cuff size has been evaluated, and the cuff height should be within 40% to 60% of the limb circumference in dogs. Blood pressure values derived by use of a cuff that is too large may be erroneously low, and those derived by use of a cuff that is too small may be erroneously high.

Guidelines for diagnosis of hypertension in dogs are generally the reference values for systolic or mean arterial blood pressure. It would appear from the results of the study reported here that in normotensive dogs, values of systolic arterial blood pressure and mean arterial blood pressure derived via direct arterial pressure measurement and oscillometry are in better agreement than values of diastolic arterial pressure derived via those methods; furthermore, values of mean arterial blood pressure derived via direct arterial pressure measurement and oscillometry are in good agreement during both normotension and hypertension in dogs. Because the OBPM underestimated systolic arterial blood pressure during hypertension in dogs, a diagnosis of hypertension in a dog would be supported if oscillometric systolic arterial blood pressure values were repeatedly within or on the cusp of the hypertensive range, particularly if the mean arterial blood pressure value was also high.

### References