Evaluation of noninvasive oscillometric blood pressure monitoring in anesthetized boid snakes

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Objective—To determine the accuracy of a noninvasive oscillometric monitor in the measurement of arterial blood pressure in anesthetized boid snakes.

Design—Evaluation study.

Animals—4 boa constrictors (Boa constrictor), 2 carpet pythons (Morelia spilota), and 2 reticulated pythons (Python reticulatus).

Procedures—After induction of anesthesia with isoflurane, each snake was instrumented with an arterial catheter connected to a pressure transducer and oscilloscope to obtain invasive measurements of systolic (SAP), diastolic (DAP), and mean (MAP) arterial blood pressure as well as a pressure waveform. A cuff connected to an oscillometric device was placed on the tail immediately distal to the vent for noninvasive measurements. Heart rate, respiratory rate, and invasive and noninvasive measurements of SAP, DAP, and MAP were obtained every 5 minutes for 45 minutes. Delivered isoflurane concentration was increased in 15-minute increments to induce hypotension. Repeatability of each device and fixed and proportional biases between devices were calculated.

Results—Throughout most of the measured ranges of blood pressures, the oscillometric unit overestimated the SAP and underestimated the DAP and MAP, compared with respective direct measurements. When the invasively determined SAP was > 100 mm Hg, the oscillometric unit underestimated all 3 variables. Fixed bias was significant for SAP and DAP, and proportional bias was significant for SAP and MAP.

Conclusions and Clinical Relevance—When using an oscillometric blood pressure monitor on anesthetized boid snakes, veterinarians can potentially monitor changes in blood pressure, although the displayed readings may underestimate DAP and MAP and overestimate SAP. Indirect measurements of blood pressure made with the oscillometric device cannot substitute for direct measurements. (J Am Vet Med Assoc 2009;234:625-630)

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>CI</td>
<td>Confidence interval</td>
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<tr>
<td>DAP</td>
<td>Diastolic arterial blood pressure</td>
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<tr>
<td>IMBP</td>
<td>Invasively measured blood pressure</td>
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<tr>
<td>MAP</td>
<td>Mean arterial blood pressure</td>
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<tr>
<td>NMBP</td>
<td>Noninvasively measured blood pressure</td>
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<tr>
<td>SAP</td>
<td>Systolic arterial blood pressure</td>
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Arterial blood pressure during anesthesia can be monitored several ways. Invasive blood pressure monitoring is widely considered the gold standard and involves surgical or percutaneous placement of an intraarterial catheter and measurement through a pressure transducer.1,4 This type of blood pressure monitoring is not routinely used in domestic animal anesthesia because of the risk of arterial damage and thrombosis, the technical skill required for catheter placement, and the cost of monitoring equipment. In reptiles, the IMBP procedure is additionally complicated by the lack of superficial vessels, which necessitates a surgical approach to access an artery.3

Noninvasive blood pressure monitoring does not involve the risk of arterial damage and closely approximates IMBP in many species, making it practical for most anesthetized patients.1 Whereas oscillometric devices have been evaluated for use in multiple species, including dogs,13-17 cats,8,10 horses,20 and nonhuman

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The nuances of cardiovascular physiology in snakes may contribute to unique challenges to accurate blood pressure measurement. Noncrocodilian reptiles have a 3-chambered heart with 2 atria and a single-chambered ventricle. This anatomy of a snake heart allows for flow and pressure separation between chambers and intracardiac shunting. The evolutionary adaptations for and the advantages of intracardiac shunting have been reviewed. The extent to which shunting occurs when snakes are anesthetized and the effects of shunting on NMBP are unknown.

Many laboratory studies have involved IMBP monitoring in snakes, but noninvasive methods are less well accepted. Oscillometric devices are growing in popularity in reptile medicine, but these devices have not been validated by comparison to simultaneous readings obtained with an invasive blood pressure monitor. Researchers in another study asserted that a veterinary oscillometric device most closely approximated invasively measured SAP, DAP, and MAP when dogs were hypotensive, whereas the device underestimated SAP, DAP, and MAP when dogs were normotensive and hypertensive. The goal of the study reported here was to determine the accuracy (in relation to IMBP) and precision of NMBP values obtained with an oscillometric device in anesthetized boid snakes over a range of arterial blood pressure values.

Materials and Methods

Snakes—Eight snakes (4 boa constrictors [Boa constrictor], 2 carpet pythons [Morelia spilota], and 2 reticulated pythons [Python reticulatus]) weighing between 4 and 16 kg (8.8 to 35.2 lb) were used. All snakes were acquired on loan from private collections with the informed consent of the owners. Each was housed separately and was healthy on the basis of results from a physical examination. Snakes were fed thawed mice or rats, and food was withheld for 1 week prior to and following surgery. Water was provided ad libitum. The experimental protocol was approved by the North Carolina Zoological Park Animal Care and Use Committee. All snakes were returned to their owners at the end of the project.

Study design and procedures—During the surgery and monitoring periods, snakes were maintained in a 21°C (70°F) room with a supplemental heat lamp and recirculating warm water blanket. Anesthesia was induced in each snake with 5% isoflurane in 100% oxygen (1 L/min), which was delivered through a nonrebreathing system via an endotracheal tube. Once the righting reflex was no longer evident, snakes were maintained with isoflurane and manually ventilated 1 to 2 times/min for the duration of the procedure. Each snake was positioned in dorsal recumbency, and the skin was aseptically prepared. A right ventrolateral incision was made between the first and second rows of lateral scales, 2 to 3 cm craniolateral to the heart base. The right aortic arch was identified and isolated. A sterile, 22-gauge, 1-inch, over-the-needle catheter placed and threaded into the right aortic arch and capped with an injection port. The catheter was sutured to the body musculature with 1 simple interrupted suture. The surgical site was covered with a gauze sponge moistened with warm, sterile saline (0.9% NaCl) solution.

The arterial catheter was connected to a saline solution-filled tube and pressure transducer (for direct measurements) connected to a precalibrated and zeroed oscilloscope that provided values for SAP, DAP, and MAP as well as a pressure waveform. A blood pressure cuff (for indirect measurements) was placed on the tail immediately distal to the vent. Appropriate cuff width was determined by calculating 40% of the circumference of the tail at the point of measurement, which is the standard convention in domestic animal blood pressure measurement and is recommended by the manufacturer. The arterial pressure waveform was continuously monitored to detect catheter failure. Heart rate, respiratory rate, and invasive measurements of SAP, DAP, and MAP were obtained at 5-minute intervals (0, 5, 10, 15, 20, 25, 30, 35, 40, and 45 minutes). Three attempts to acquire NMBP measurements were also made at each interval. Delivered isoflurane concentration was set at 1.3% and then subsequently increased to 3.0% and 5.0% in 5-minute increments to induce hypotension. After 45 minutes, the arterial catheter was removed and hemostasis was achieved by manual pressure. The incision was closed in 2 layers. Each snake received butorphanol (2.0 mg/kg [0.91 mg/lb], IM) and enrofloxacin (15 mg/kg [6.8 mg/lb], SC) in lactated Ringer’s solution (10 mL/kg [4.5 mL/lb], SC) at the conclusion of the procedure.

Statistical analysis—Three attempts were made at each 5-minute time point to acquire a reading with the oscillometric device. Each instance that the oscillometric device provided a reading for each variable (SAP,
MAP, and DAP) was considered a successful attempt, and each instance a time-out message, weak signal, or motion error was generated was considered a failed attempt. Results for devices are reported as mean ± SD. To evaluate repeatability of NIBP and IMBP values, all time points for which 3 independent sets of successful readings were achieved (n = 32) were examined by means of the Friedman test, with the Dunn post hoc comparison. A value of P < 0.01 was considered significant. Repeatability comparisons were made separately for SAP, MAP, and DAP for each monitoring device.

Time points at which the successful attempts did not differ by > 10% between IMBP and NMBP (n = 62) were used to calculate mean values of each variable for data analysis. Time points at which 1 or more NMBP variables differed by > 10% (n = 7) between successive attempts were eliminated from data analysis because many clinicians, when given a large discrepancy between 2 successive readings, would believe either 1 reading or neither. Thus, averaging 2 discordant readings in 1 time period could not be justified.

A commercial statistical package was used for data analyses. The D’Agostino and Pearson omnibus normality test was used to assess distribution of the data. Proportional and fixed biases comparing measuring devices were determined by means of reduced major axis regression (ordinary least products regression). Fixed bias was defined as a 95% CI for the regression equation intercept that did not include 0, and proportional bias was defined as a 95% CI for the slope that did not include 1.

The overall mean difference between NMBP and IMBP values, SD of the mean difference, and limits of agreement (95% CI) were calculated for SAP, DAP, and MAP. Bland-Altman plots comparing IMBP and NMBP values for each variable were constructed with commercial software. For variables with significant proportional bias, the mean difference between devices was displayed as a regression of the individual differences and the limits of agreement were calculated from the regression of the absolute residuals.

**Results**

For each snake, a total of 30 attempts were made to measure arterial blood pressure with the oscillometric unit. Mean ± SD number of attempts per snake that failed to provide a reading was 5.4 ± 4.4, resulting in a failure rate of 18.2 ± 14.4%. Data from 1 male carpet python were excluded from data analysis because the oscillometric device gave no readings; this was the only snake that maintained a heart rate < 30 beats/min. Heart rates determined by the invasive and noninvasive units were within 1 beat/min for all readings. Six snakes produced at least 1 successful attempt/time point. In

![Figure 2](image1.png)

**Figure 2**—Values for MAP in 7 anesthetized boid snakes measured at several points during a 45-minute period with a noninvasive oscillometric monitor and an invasive monitor.

![Figure 3](image2.png)

**Figure 3**—Values for DAP in 7 anesthetized boid snakes measured at several points during a 45-minute period with a noninvasive oscillometric monitor and an invasive monitor.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intercept</th>
<th>95% CI</th>
<th>Slope</th>
<th>95% CI</th>
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<tbody>
<tr>
<td>SAP</td>
<td>33.33</td>
<td>25.44 to 41.22</td>
<td>0.67</td>
<td>0.59 to 0.76</td>
</tr>
<tr>
<td>MAP</td>
<td>3.70</td>
<td>–3.34 to 10.72</td>
<td>0.76</td>
<td>0.68 to 0.85</td>
</tr>
<tr>
<td>DAP</td>
<td>–24.51</td>
<td>–31.76 to –17.25</td>
<td>0.97</td>
<td>0.88 to 1.07</td>
</tr>
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</table>

Table 1—Summary of intercepts and slopes for results of reduced major axis regression analyses to test differences between NMBP and IMBP values for 7 anesthetized boid snakes at several points during a 45-minute period (n = 62 readings).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean difference</th>
<th>SD</th>
<th>Limits of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP</td>
<td>3.71</td>
<td>15.29</td>
<td>–26.28 to 33.69</td>
</tr>
<tr>
<td>MAP</td>
<td>–14.75</td>
<td>10.37</td>
<td>–35.08 to 5.59</td>
</tr>
<tr>
<td>DAP</td>
<td>–26.46</td>
<td>7.70</td>
<td>–41.56 to –11.37</td>
</tr>
</tbody>
</table>

Table 2—Summary of NMBP and IMBP values for 7 anesthetized boid snakes at several points during a 45-minute period (n = 62 readings).
the remaining snake, the device failed during all 3 attempts at the first time point (0 minutes), resulting in 69 time points with data from 7 snakes. Matched IMBP and NMBP values for SAP, MAP, and DAP were graphically displayed (Figures 1–3).

The Friedman test failed to reveal a significant difference between the 3 attempts for each NMBP and IMBP variable, indicating that both devices produced repeatable results. Results of the reduced major axis regression for determination of proportional and fixed bias were summarized (Table 1). Proportional bias between the IMBP and NMBP values was identified for MAP and SAP but not for DAP. Fixed bias between the IMBP and NMBP values was evident for DAP and SAP but not for MAP. All blood pressures measured in the study were within the detectable range indicated by the manufacturer.27

The overall mean difference between NMBP and IMBP values, SD of the mean difference, and limits of agreement (95% CI) were also summarized (Table 2). Visual examination of Bland-Altman plots revealed that the oscillometric unit overestimated the SAP and underestimated the DAP and MAP for most of the measured range. For data points in which invasively determined SAP was >100 mm Hg, the oscillometric device underestimated all 3 variables. Bland-Altman plots were generated for each variable (Figures 4–6); the mean difference and limits of agreement lines for the SAP and MAP plots were generated by use of regressions of the data to address the proportional bias.30

**Discussion**

An oscillometric noninvasive blood pressure device was used to monitor anesthetized, medium to large boid snakes; in most pressure ranges, the unit generally underestimated MAP and DAP. Only MAP was associated with no fixed bias between devices, allowing the closest approximation of IMBP by NMBP. Diastolic arterial blood pressure was the only variable with no proportional bias, indicating that DAP may be the most useful value for monitoring changes in blood pressure. In the lower half of the measured range, the oscillometric unit overestimated SAP, whereas it underestimated SAP at higher pressures; this pattern indicated the existence of proportional bias in measuring SAP. When using an oscillometric blood pressure monitor on anesthetized boid snakes, clinicians can monitor general changes in blood pressure with time. The varying agreement and significant bias between the devices in the present study indicated that the oscillometric device cannot substitute for direct IMBP measurements. Consequently, this device should not be used in a research or critical care setting in which a high degree of accuracy and precision is required.
The results of this study also highlighted the difficulty of adapting technology designed for humans or companion mammals for use in ectotherms. Briefly, with an oscillometric device, the pressure in the inflated cuff is slowly released and the point at which the first arterial pressure oscillation is detected is reported as the SAP. The displayed MAP is the pressure at which the peak amplitude of the arterial pressure wave is detected.\textsuperscript{15,31} The displayed NMBP values are calculated on the basis of a device-specific algorithm that has been optimized for use in companion mammals and could introduce error when used in other species.\textsuperscript{31}

Other sources of error include cuff size, artery choice, and low heart rate (as is characteristic of most snakes). Cuff size was standardized to a cuff-tail ratio of 40\%, according to the manufacturer’s recommendations for dog limbs. Choosing a cuff that is too large can cause the oscillometric device to underestimate blood pressure, whereas choosing a cuff that is too small will result in the opposite.\textsuperscript{32} Inappropriate cuff size represents a fixed bias, and it is unlikely to have affected the results of the present study because 1 variable (SAP) was overestimated for most measurements, whereas DAP and MAP were underestimated. The cuff was placed over the ventral coccygeal artery, which is surrounded by the musculature of the tail and fairly noncompliant snake skin. These factors could have resulted in greater resistance to the compression by the blood pressure cuff. A second likely contributor to the variability in our study was artery choice; invasive measurements were obtained in the aortic arch, close to the heart, but noninvasive measurements were measured at the tail. Differences in vessel size and distance from the heart may result in discrepancies in blood pressure measurements at distant sites.\textsuperscript{3} Catheterization of the aortic arch was chosen over catheterization of the abdominal aorta to prevent arterial damage and a decrease in perfusion to the tail, which is the only feasible location for NMBP measurement.

Use of a monitor designed for mammals on reptiles with comparatively low heart rates can also compromise accuracy because automated oscillometric devices can be inaccurate in bradycardic animals.\textsuperscript{3} Although the manufacturer reports that the machine has a detectable pulse range of 20 to 300 beats/min, we were unable to record blood pressure readings from 1 snake with a heart rate persistently < 30 beats/min.

General anesthesia in all animals carries an important risk, including cardiovascular depression and hypotension. In domestic mammals and humans, the effects of hypotension include decreases in renal, cerebral, and cardiac perfusion, leading to organ damage.\textsuperscript{32} The effects of perianesthetic hypotension may not become evident for a long period after an anesthetic episode.\textsuperscript{32,33} For these reasons, blood pressure monitoring is considered standard of care for these species. At the moment, the effects of prolonged hypotension are unknown in reptiles. As the degree of care increases for reptiles in companion animal and zoo practice, a greater number of reptiles with underlying disease will be treated and anesthetized for surgery or diagnostics. These reptiles may be less tolerant of prolonged hypotension than a healthy reptile, and an anesthetic episode may precipitate organ dysfunction. To optimize the care of exotic animal patients in the perioperative period, it is important to evaluate advanced monitoring techniques, such as blood pressure measurement. The device used in the study reported here is a simple, noninvasive way to monitor changes in blood pressure in anesthetized boid snakes but cannot be used as a replacement for direct blood pressure measurement when accurate monitoring is a priority.

References

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