Arterial blood gas measurements are different for brachycephalic and nonbrachycephalic dogs acclimatized to an altitude of 1,535 meters

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OBJECTIVE
To define reference intervals (RIs) for arterial blood gas (aBG) measurements in healthy, nonsedated, dolichocephalic, and mesocephalic (nonbrachycephalic) dogs at approximately 1,535 m above sea level and compare these findings with healthy, nonsedated, brachycephalic dogs living at the same altitude.

ANIMALS
120 adult nonbrachycephalic dogs and 20 adult brachycephalic dogs.

METHODS
Cases were prospectively enrolled from October 2021 to June 2022. Dogs were enrolled from the community or after presentation for wellness examinations or minor injuries including lacerations, nail injuries, and lameness. Physical examinations and systolic blood pressure (sBP) measurements were obtained before blood sample collection. Arterial blood was collected from the dorsal pedal artery or femoral artery. After data collection, brachycephalic dogs underwent pre- and postexercise tolerance assessments.

RESULTS
The mean and RI values for arterial pH (7.442; 7.375 to 7.515), partial pressure of oxygen in arterial blood (PaO₂; 78.3; 59.2 to 92.7 mm Hg), partial pressure of carbon dioxide in arterial blood (PaCO₂; 28.0; 21.5 to 34.4 mm Hg), saturation of arterial oxygen (SaO₂; 98.4; 84.3% to 101.4%), HCO₃ (18.9; 14.9 to 22.4 mmol/L), concentration of total hemoglobin (ctHb; 17.5; 13.4 to 21.1 g/dL), and sBP (133; 94 to 180 mm Hg) were established for healthy nonbrachycephalic dogs at 1,535-m altitude. All aBG measurements were statistically and clinically different from those previously reported for dogs at sea level. Brachycephalic dogs had significantly lower PaO₂ and SaO₂ (P = .0150 and P = .0237, respectively) and significantly higher ctHb (P = .0396) compared to nonbrachycephalic dogs acclimatized to the same altitude; the nonbrachycephalic RIs were not transferable to the brachycephalic dogs for PaO₂.

CLINICAL RELEVANCE
This study represents the first collation of aBG measurements for healthy nonbrachycephalic dogs acclimatized to an altitude of 1,535 m. Additionally, this study identified differences in arterial oxygenation measurements between brachycephalic and nonbrachycephalic dogs. RIs in brachycephalic dogs need to be established.

Keywords: altitude, blood gas, arterial, oxygenation, ventilation

Arterial blood gas (aBG) evaluation is a point-of-care diagnostic test used to evaluate oxygenation, ventilation, and acid-base balance in critically ill patients, particularly dogs. The partial pressure of oxygen in arterial blood (Pao₂) is dependent on the dog’s pulmonary physiology and the partial pressure of oxygen in the atmospheric air (Pao₂). With an increase in altitude and concurrent drop in barometric pressure, the number of gas molecules in the atmosphere decreases; therefore, each gas within the air mixture has a lower partial pressure. Pao₂ ultimately dictates the partial pressure of oxygen in the alveoli (PaO₂), the driving force for gas exchange. The PAO₂ is lower than Pao₂ due to humidification in the airways and the presence of carbon dioxide in the alveoli. Because the
partial pressure of carbon dioxide in arterial blood (Paco\textsubscript{o}) and water vapor are constant, the percent reduction in PA\textsubscript{o} relative to P\textsubscript{b} becomes greater with an increase in altitude. A low PA\textsubscript{o} secondary to altitude is termed hypobaric hypoxemia. Hypobaric hypoxemia results in systemic hypoxemia, stimulating erythropoietin release to increase the oxygen-carrying capacity of the blood. This results in a physiologic increase in RBC mass, which might be considered to be polychemorexia. Peripheral chemoreceptors will also respond to hypoxemia, triggering sympathetic vasoconstriction and increasing blood pressure. In people living at various altitudes, studies\textsuperscript{1–10} have identified an inverse relationship between altitude and PA\textsubscript{o}, saturation of arterial oxygen (Sa\textsubscript{o}), and Paco\textsubscript{o} due to adaption to hypobaric hypoxemia. Hypoxemia leads to hyperventilation and respiratory alkalosis, which in turn triggers a compensatory increase in renal bicarbonate (HCO\textsubscript{3}) secretion to restore acid-base balance. At higher altitudes, however, the metabolic compensation remains incomplete.\textsuperscript{11} Evaluating an aBG from a healthy person acclimatized to altitude using reference intervals (RI) appropriate for sea level would lead the clinician to an inappropriate diagnosis of hypoxemia and respiratory alkalosis with metabolic compensation.

Several veterinary studies\textsuperscript{12–14} investigating the effects of chronic hypoxemia on the cardiopulmonary system document mean or median PA\textsubscript{o} values for a small group of dogs acclimated to various altitudes. Each of these studies were not intended to determine RIs for aBG values. Additionally, a few studies\textsuperscript{15,16} that report a pH value did not report the metabolic compensation with HCO\textsubscript{3} values. A 1982 study\textsuperscript{16} reported aBG parameters from dogs with gastric dilation and volvulus, and from 37 healthy dogs at an altitude of 1,535 m. The study did not address whether these dogs were acclimatized to this altitude or the ages and breeds of the control subjects. Two additional publications\textsuperscript{17,18} present aBG values from a group of 10 healthy dogs breathing room air at an altitude of 1,535 m. The aBG values presented for healthy dogs at a 1,535-m altitude differ from the RIs for dogs living near sea level.\textsuperscript{19–21} These studies support the need to determine RIs for dogs living at a 1,535-m altitude to allow clinicians to determine the clinical relevance of deviations from accepted sea-level RIs. Both previous studies enrolled 10 dogs, while the Clinical and Laboratory Standards Institute\textsuperscript{22} recommends at least 120 subjects to generate RIs with 95% CIs.

Brachycephalic breeds have anatomic abnormalities that result in changes in oxygenation and ventilation.\textsuperscript{22} The most prominent anatomic change is increased upper airway resistance secondary to narrowed nostrils, elongated and thickened soft palate, everted laryngeal saccules, and a hypoplastic trachea. In addition, they may have functional abnormalities in both the larynx and pharynx.\textsuperscript{24,25} A recent study\textsuperscript{23} at sea level has shown that the anatomic changes in brachycephalic breeds result in significantly lower Paco\textsubscript{o} and higher Paco\textsubscript{o}.

The primary purpose of this study was to define the RIs for aBG measurements (pHa, Pa\textsubscript{o}, Paco\textsubscript{o}, Sa\textsubscript{o}, and HCO\textsubscript{3}), concentration of total hemoglobin (ctHb), and systolic blood pressure (SBP) for healthy, dolichocephalic and mesocephalic (nonbrachycephalic), nonsedated dogs acclimated to an altitude of approximately 1,535 m. We hypothesized that healthy nonbrachycephalic dogs living at altitude will have a lower Paco\textsubscript{o}, Sa\textsubscript{o}, Paco\textsubscript{o}, and HCO\textsubscript{3}, with a higher pHa, ctHb, and SBP compared to sea level RIs reported in published work. The secondary purpose was to evaluate aBG values from a group of nonse-dated brachycephalic dogs to determine if there were differences in aBG values for brachycephalic dogs compared to nonbrachycephalic dogs acclimatized to altitude. We hypothesized that brachycephalic dogs acclimatized to living at altitude will have lower Paco\textsubscript{o} and Sa\textsubscript{o}, and higher Paco\textsubscript{o} compared to nonbrachycephalic dogs acclimatized to altitude.

**Methods**

**Case selection**

Cases were prospectively enrolled from October 2021 to June 2022 at the Colorado State University James L. Voss Veterinary Teaching Hospital. Dogs were enrolled from the community, or after presentation for wellness examinations, or for minor injuries including lacerations, nail injuries, and lameness. All dogs were client-owned, and owner consent was obtained before enrolment. All procedures performed were approved by the IACUC at Colorado State University. Nonbrachycephalic and brachycephalic dogs were evaluated for enrollment. All dogs were required to be at least 1 year of age, have lived at their current home address for at least 6 months within Fort Collins or the immediate surrounding area (approx 1,535-m altitude), and have an appropriate demeanor to facilitate blood sample collection without sedation. The dogs were free of overt systemic disease as determined by physical examination, CBC, and serum biochemistry. Dogs were not receiving any medications or supplements, aside from flea and heartworm prevention. Brachycephalic breeds were excluded if they had any upper airway surgical correction.

**Data collection**

Physical examinations and SBP measurements were obtained before blood sample collection. SBP was obtained by placing the patient in lateral recumbency, using a noninvasive blood pressure monitor (Doppler; Parks Medical Electronics, Inc) on the dorsal pedal artery.\textsuperscript{26} A blood pressure cuff was placed proximally, which was approximately 30% to 40% of the circumference of the proximal extremity.\textsuperscript{26} All dogs were breathing room air (F\textsubscript{O}\textsubscript{2}, 21%) and were not sedated when blood samples were collected. Arterial blood samples were collected by either a diplomate of the American College of Veterinary Emergency and Critical Care (DACVECC) or an ACVECC-accredited small animal resident. Venous blood was collected for CBC and serum biochemistry. Lidocaine 2% (lidocaine hydrochloride; VetOne) was instilled SQ and superficial to the dorsal pedal artery 5 minutes before arterial blood sampling.
Arterial blood was collected in a PICO dry heparin-coated syringe (PICO syringe; Radiometer America) from the dorsal pedal artery or femoral artery for aBG analysis. Arterial blood samples were analyzed using the ABL800 Flex (ABL800 Flex Blood Gas Analyzer; Radiometer America) within 3 minutes of sample collection. After data collection, brachycephalic dogs underwent pre- and postexercise tolerance assessment to identify the severity of brachycephalic obstructive airway syndrome using a clinical grading scheme as described by Riggs et al.27

**Statistical methods**

Descriptive statistics were calculated using commercially available software (Excel version 15.35; Microsoft Corporation). RIs were calculated for aBG measurements from the nonbrachycephalic breed patients according to current American Society for Veterinary Clinical Pathology recommendations.28 Testing for normality was performed via the Anderson-Darling test with $P = .05$ set as the cutoff, and outliers were determined with the Tukey and Dixon-Reed tests, and evaluation of the histograms (Prism 9, version 9.5.1; GraphPad Software). The nonbrachycephalic breed RIs were evaluated for transferability to brachycephalic breeds using the approach outlined by Lahti et al.29 Normally distributed data are presented with mean ± SD, and non-normally distributed data are presented as median (IQR). A Welch $t$ test was used to compare the means of dogs at altitude to dogs at sea level.30 Continuously distributed data are represented as mean ± SD. A $t$ test or the Mann-Whitney-Wilcoxon test as appropriate. The Student’s $t$ test or the nonparametric Mann-Whitney-Wilcoxon test as appropriate.

**Results**

One hundred twenty healthy adult nonbrachycephalic dogs, and 20 adult brachycephalic dogs without evidence of systemic disease were enrolled. One healthy nonbrachycephalic dog was excluded from pHa, PaCO$_2$, PaO$_2$, SaO$_2$, and HCO$_3$ analysis due to an erroneously high PaO$_2$ value. The mean age of dogs in the nonbrachycephalic group was 5.07 ± 2.68 years, the mean weight was 24.96 ± 10.87 kg, and the mean sBP was 132.6 ± 20.2 mm Hg. The mean age of dogs in the brachycephalic group was 4.78 ± 2.69 years.

**Table 1**—Mean, SD, median, and range for select arterial blood gas measurements and systolic blood pressure in 120 healthy, nonsedated nonbrachycephalic dogs acclimatized to an altitude of 1,535 m above sea level.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>Median</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P value of normality test</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHa</td>
<td>119</td>
<td>7.442</td>
<td>0.031</td>
<td>7.44</td>
<td>7.350</td>
<td>7.520</td>
<td>.110</td>
</tr>
<tr>
<td>PaCO$_2$ (mm Hg)</td>
<td>119</td>
<td>28.0 ± 3.1</td>
<td>28.2</td>
<td>78.3</td>
<td>17.6</td>
<td>37.0</td>
<td>.798</td>
</tr>
<tr>
<td>PaO$_2$ (mm Hg)</td>
<td>119</td>
<td>98.4 ± 4.0</td>
<td>99.4</td>
<td>79.3</td>
<td>11.4</td>
<td>101.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>SaO$_2$ (%)</td>
<td>117</td>
<td>89.8</td>
<td>4.0</td>
<td>78.6</td>
<td>73.4</td>
<td>101.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>cHb (g/dL)</td>
<td>120</td>
<td>17.5</td>
<td>1.8</td>
<td>14.9</td>
<td>11.4</td>
<td>21.5</td>
<td>.251</td>
</tr>
<tr>
<td>HCO$_3$ (mmol/L)</td>
<td>119</td>
<td>18.9 ± 1.8</td>
<td>18.1</td>
<td>28.0</td>
<td>13.1</td>
<td>23.8</td>
<td>.798</td>
</tr>
<tr>
<td>sBP (mm Hg)</td>
<td>120</td>
<td>133</td>
<td>20.2</td>
<td>130</td>
<td>90</td>
<td>210</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SD. cHb = Total hemoglobin. HCO$_3$ = Bicarbonate. PaCO$_2$ = Partial pressure of arterial carbon dioxide. PaO$_2$ = Partial pressure of arterial oxygen. pHa = pH of arterial blood. SaO$_2$ = Saturation of arterial oxygen. sBP = Systolic blood pressure.

Bold font denotes statistical significance with a $P$ value of less than .05.

**Table 2**—Upper and lower reference intervals, and CI reference limits, for select arterial blood gas measurements and systolic blood pressure in 120 healthy, nonsedated nonbrachycephalic dogs acclimatized to an altitude of 1,535 m above sea level.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>n</th>
<th>LRL of RI</th>
<th>URL of RI</th>
<th>CI 90% of LRL</th>
<th>CI 90% of URL</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaCO$_2$ (mm Hg)</td>
<td>119</td>
<td>21.5</td>
<td>34.4</td>
<td>17.6–22.7</td>
<td>33.1–37.0</td>
</tr>
<tr>
<td>PaO$_2$ (mm Hg)</td>
<td>119</td>
<td>59.2</td>
<td>92.7</td>
<td>55.20–63.40</td>
<td>91.9–108.0</td>
</tr>
<tr>
<td>SaO$_2$ (%)</td>
<td>117</td>
<td>84.4</td>
<td>101.4</td>
<td>73.4–92.8</td>
<td>101.0–101.8</td>
</tr>
<tr>
<td>cHb (g/dL)</td>
<td>120</td>
<td>13.4</td>
<td>21.1</td>
<td>13.5</td>
<td>20.6</td>
</tr>
<tr>
<td>HCO$_3$ (mmol/L)</td>
<td>119</td>
<td>14.9</td>
<td>22.4</td>
<td>13.1–16.2</td>
<td>21.9–23.8</td>
</tr>
<tr>
<td>sBP (mm Hg)</td>
<td>120</td>
<td>94</td>
<td>180</td>
<td>97</td>
<td>179</td>
</tr>
</tbody>
</table>

the mean weight was 12.76 ± 7.96 kg, and the mean sBP was 144.5 ± 27.9 mm Hg. The median pre-exercise tolerance test score was 1 (0.75), and the postexercise tolerance test score was 2 (1).27

The mean, SD, median, range (Table 1), 90% CI of the reference limits, RIs (Table 2) for each aBG measurement (pH, PaCO₂, PaO₂, SaO₂, ctHb, and HCO₃⁻) and sBP for nonbrachycephalic dogs have been established, as well as a statistical comparison between the dogs at a 1,535-m altitude and sea level30 with significant differences identified in all measurements (Table 3). Statistical comparison between nonbrachycephalic and brachycephalic dogs identified differences in weight, SaO₂, PaO₂, and ctHb (Table 4). This indicates that RIs developed for nonbrachycephalic dogs were not transferrable for brachycephalic breeds for these measurements.

Scatter plots comparing nonbrachycephalic dogs to brachycephalic dogs with RI guidance lines of nonbrachycephalic dogs have been established (Figure 1).

Table 4—Arterial blood gas measurements and systolic blood pressure for healthy, nonsedated nonbrachycephalic and brachycephalic dogs acclimatized to an altitude of 1,535 m above sea level.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Nonbrachycephalic</th>
<th>Brachycephalic</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>4.5 (3.8)</td>
<td>4.8 (3.5)</td>
<td>.6308</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>26 (15.1)</td>
<td>10.2 (4.9)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>pH</td>
<td>7.442 ± 0.031</td>
<td>7.432 ± 0.046</td>
<td>.2019</td>
</tr>
<tr>
<td>PaCO₂ (mm Hg)</td>
<td>28.0 ± 3.2</td>
<td>29.5 ± 3.5</td>
<td>.0638</td>
</tr>
<tr>
<td>PaO₂ (mm Hg)</td>
<td>78.6 (7.5)</td>
<td>73.6 (17.1)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>SaO₂ (%)</td>
<td>99.4 (1.8)</td>
<td>97.9 (6.2)</td>
<td>.0237</td>
</tr>
<tr>
<td>ctHb (g/dL)</td>
<td>17.5 ± 1.8</td>
<td>18.4 ± 1.7</td>
<td>.0396</td>
</tr>
<tr>
<td>HCO₃⁻ (mmol/L)</td>
<td>19.1 (2.1)</td>
<td>19.3 (2.0)</td>
<td>.3778</td>
</tr>
<tr>
<td>sBP (mm Hg)</td>
<td>132 ± 20</td>
<td>146 ± 28</td>
<td>.0782</td>
</tr>
</tbody>
</table>

Data are reported as mean ± SE and as median (IQR).


Bold font denotes statistical significance with a P value of less than .05.

Figure 1—Scatter plots of nonbrachycephalic and brachycephalic dogs of pH (A), PaO₂ (mm Hg; B), PaCO₂ (mm Hg; C), HCO₃⁻ (mmol/L; D), SaO₂ (%) E), ctHb (g/dL; F), systolic blood pressure (mm Hg; G), and weight (kg; H) with reference intervals of nonbrachycephalic dogs as established in this study. P values are noted above the comparison line; red horizontal line, median. BC = Brachycephalic. HCO₃⁻ = Bicarbonate. non-BC = Nonbrachycephalic. PaCO₂ = Partial pressure of arterial carbon dioxide. PaO₂ = Partial pressure of arterial oxygen. SaO₂ = Saturation of arterial oxygen.
Discussion

The current study established aBG RIs for healthy nonbrachycephalic dogs acclimatized to an altitude of 1,535 m. There were significant increases in pH, SaO₂, and ctHb and significant decreases in PaO₂, Paco₂, and HCO₃⁻ in dogs at altitude compared to RIs at sea level. In addition, there were significant decreases in PaO₂ and SaO₂, as well as an increase in ctHb in brachycephalic dogs compared to nonbrachycephalic dogs.

In the current study, the mean pH in nonbrachycephalic dogs was 7.442, which is higher than the mean pH reported in a smaller population of dogs at a similar altitude (mean pH, 7.390). The primary reason for an increase in pH at altitude is due to compensatory hyperventilation. The difference between these two studies is likely due to the fact that the dogs in the previous study had their blood samples taken during anesthetic recovery. General anesthesia depresses the respiratory system, causing hypoventilation, an increase in Paco₂, and a lower pH. When compared to established RIs for dogs at sea level, the mean pH in this study was significantly higher, which is similar to the relationship documented in humans at altitude.8,30

The mean PaO₂ in nonbrachycephalic dogs in this study was 78.3 ± 8.0 mm Hg, which is similar to previous studies performed in dogs at altitude but significantly lower than the established RIs for dogs at sea level. As previously discussed, PaO₂ ultimately determines the PAO₂, which is the driving force for gas exchange. A low PAO₂ secondary to altitude is termed hypobaric hypoxia, which ultimately results in a low PaO₂.

The mean PaCO₂ in nonbrachycephalic dogs in this study was 28.0 ± 3.2 mm Hg, which was significantly lower than the established RIs for dogs at sea level and comparable to previous veterinary and human studies evaluating PaCO₂ at altitude. With acclimatization to altitude, hypoxic stimulation of peripheral arterial chemoreceptors increases ventilation. Hyperventilation results in a lower PaCO₂ and the development of respiratory alkalosis. Additionally, the PaCO₂ values in this study were lower than those studies performed in a smaller population of dogs at a similar altitude. As previously mentioned, the arterial blood samples in the previous studies were obtained during recovery from general anesthesia, which may have impacted the PaCO₂ due to the respiratory depressant effects of the anesthetic drugs.

The mean SaO₂ in nonbrachycephalic dogs in this study was 98.4 ± 4.0%, which was significantly higher than the established RIs for dogs at sea level but is comparable to findings in human studies at altitude. In people, SaO₂ has been shown to remain stable or increase with an increase in altitude, which is likely due to the characteristics of the oxygen-hemoglobin dissociation curve and the effects of a decrease in Paco₂ due to respiratory acclimatization.

The mean HCO₃⁻ in nonbrachycephalic dogs in this study was 18.9 ± 1.8 mmol/L, which supports the findings of previous veterinary and human studies that demonstrated decreases in HCO₃⁻ at higher altitudes. As seen in this study, the development of respiratory alkalosis triggers compensatory renal HCO₃⁻ secretion to restore the acid-base balance. In people at higher altitudes, metabolic compensation remains incomplete and the patients remain alkalotic.2

The mean ctHb in nonbrachycephalic dogs in this study was 17.5 ± 1.8 g/dL, which is significantly higher than the established RIs for dogs at sea level. In people, it has been shown that hypoxemia stimulates erythropoietin release resulting in polycythemia, which increases the oxygen-carrying capacity of blood. The mean sBP in nonbrachycephalic dogs was significantly lower (mean, 132 ± 20 mm Hg) than the sea level population (mean, 147 ± 25 mm Hg). In people, there is a progressive increase in blood pressure associated with increases in altitude. This is due to the peripheral chemoreceptor response initiated by hypoxia, triggering sympathetic vasoconstriction and subsequent increase in blood pressure. Doppler blood pressure measurements have previously been shown in veterinary medicine to consistently underestimate direct systolic arterial blood pressure from the dorsal pedal artery, which may have been the cause of the lower mean blood pressure in this study. It has been shown to have an acceptable mean bias of 2.8 mm Hg, of which the 95% limits of agreement were −46.4 to 51.6 mm Hg, demonstrating poor precision. The location of the blood pressure reading and body position of the animal can also have an impact on the overall Doppler systolic blood pressure reading. Doppler blood pressure measurement is one of the more commonly used methods in veterinary practice as it is the least invasive method to measure sBP, therefore limiting iatrogenic stress and falsely elevated measurements.

When comparing the nonbrachycephalic dogs to the brachycephalic dogs, there were no significant differences in pH, PaO₂, HCO₃⁻, or sBP. However, there were significant differences in SaO₂, Paco₂, and ctHb. Brachycephalic dogs at sea level have a decreased PaO₂ and SaO₂ compared to nonbrachycephalic dogs. This may be due to several predisposing conformational factors impacting oxygenation, such as an increased upper airway resistance due to a narrowed nasal passage, an elongated and thickened soft palate, everted laryngeal sacculles, and hypoplastic trachea, in addition to prominent nasopharyngeal turbinates. Brachycephalic breeds, in particular English bulldogs, have been used in translational research to assess people with obstructive sleep apnea, who similarly have narrowed airway passages, increase in body condition score, and nasal congestion, sustaining chronic hypoxemia during the rapid-eye movement cycle of sleeping. Brachycephalic breeds have been shown to have a higher packed cell volume compared to nonbrachycephalics that is directly correlated to a chronic, mild, decrease in PaO₂. In addition to being located at altitude and therefore
resulting in more erythropoietin release, obstructive sleep apnea in brachycephalic dogs may contribute to additional erythropoietin release as described in people.\textsuperscript{2,41} People who have some level of upper airway impingement, such as obstructive sleep apnea, have an activation of their renin-angiotensin-aldosterone system in which renin will enhance RBC production.\textsuperscript{42,43} Although the HCO\textsubscript{3} concentration of the brachycephalic system in which renin will enhance RBC production, this was not statistically significant (\(P = .3778\)). \(\text{Paco}_2\) was significantly increased in a previous sea level brachycephalic study, likely due to upper airway obstruction.\textsuperscript{23} \(\text{Paco}_2\) was not significantly different between brachycephalic and nonbrachycephalic dogs in this study; however, there was a larger difference between the means of both groups. The sBP was not significantly different between brachycephalic and nonbrachycephalic dogs. Previous research\textsuperscript{44-46} has shown increases in \(\text{Paco}_2\) in people with obstructive sleep apnea, likely due to activation of the renin-angiotensin-aldosterone system, arterial wall thickening, endothelial dysfunction, and systemic inflammation.

There are a few important limitations to this study. There was a large variation in weight in the nonbrachycephalic dog group, and body condition score was not evaluated as a variable affecting aBG measurements. In addition, erythropoietin concentration was not evaluated in this study, so its role in contributing to the changes seen at altitude cannot be assessed. Future studies may consider evaluating influences of weight, body condition score, breed, and erythropoietin concentrations to further understand their contributions to the changes seen at altitude. Due to machine and/or sampling errors, repeat arterial blood sampling was required in a few dogs, which may have contributed to an increase in stress and panting, which may affect ventilation measurements.

In conclusion, we report the RIs of aBG measurements for nonbrachycephalic dogs that have acclimatized to an altitude of 1,535 m above sea level. These values can be used clinically to ensure the appropriate diagnosis of oxygenation, ventilation, and acid-base abnormalities and ultimately the implementation of appropriate treatment interventions for dogs at altitude. As brachycephalic dogs had significantly lower \(\text{Pa}_2\) and \(\text{Sa}_2\), and significantly higher ctHb values compared to nonbrachycephalic dogs, further research is required to establish appropriate RIs for brachycephalic dogs at an altitude of 1,535 m.

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### Disclosures

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