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Systolic Arterial Pressure in Dogs Pharmacologically Induced to Vasoconstriction and Vasodilation: Accuracy of Measurement by Photoplethysmography

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ABSTRACT

***Background*:** Systolic arterial pressure (SAP) monitoring is an essential parameter in veterinary anesthesiology, enabling early detection of hemodynamic instability. Arterial catheterization is considered the gold standard; however, non-invasive methods such as Doppler (DOP) and photoplethysmography (PPG) have emerged as relevant alternatives when arterial catheterization is not feasible. While PPG is well established in human medicine, its application in animals remains scarcely explored. The aim of this study was to assess the accuracy of PPG in measuring SAP in dogs anesthetized with propofol, comparing it with DOP under vasoconstriction and vasodilation induced by norepinephrine and sodium nitroprusside, respectively.

***Materials, Methods & Results*:** Eleven healthy male dogs (1-6 years-old; 7-15 kg) were enrolled in the study. Following fasting and pre-anesthetic evaluation, anesthesia was induced with propofol (7.53 ± 2.13 mg/kg) and maintained with continuous infusion of the same agent (0.55-0.59 mg/kg/min), with no significant differences between treatments. Baseline SAP was recorded during infusion of 0.9% saline solution (5 mL/kg/h). Subsequently, each dog received, in randomized order, norepinephrine (NOR; 0.3-0.7 µg/kg/min) or sodium nitroprusside (NIT; 1-7 µg/kg/min), interspersed with saline until hemodynamic recovery. Each phase was evaluated at 3 time points (T1, T2, and T3 at 5-min intervals), with SAP measured by DOP (ulnar artery) and PPG (interdigital sensor). Data were analyzed using ANOVA or Friedman tests, followed by post hoc comparisons, and correlations were estimated by Spearman's rank test ($P < 0.05$). SAP increased significantly with NOR and decreased with NIT compared to SAL. In DOP, the SAP reduction with NIT was significant at T2 and T3 versus SAL, whereas PPG detected differences as early as T1. Correlations between PPG and DOP were very strong under NOR (r = 1.00; $P = 0.0028$), strong under NIT (r = 0.82), and weak to moderate under SAL (r = 0.50).

***Discussion*:** PPG demonstrated performance equivalent to that of DOP under pharmacologically induced vasoconstriction, suggesting that it may reliably estimate SAP in this scenario. During vasodilation, although the correlation remained strong, a reduction in sensitivity was observed, possibly attributable to lower peripheral pulse amplitude and reduced pulsatile contrast, as previously described in humans under the effect of vasodilators. At baseline normotension, the correlation was only moderate, indicating greater variability between methods when no marked hemodynamic changes are present. Furthermore, the similarity in propofol infusion rates among groups suggests that blood pressure variations were primarily due to the action of vasoactive drugs rather than fluctuations in anesthetic depth. In conclusion, PPG represents a promising tool for estimating SAP in anesthetized dogs, showing greater reliability under vasoconstrictive conditions. However, its clinical application should be approached with caution in states of normotension or hypoperfusion, and further studies with larger sample sizes and validation against invasive methods are required to confirm its accuracy and broaden its applicability.

Keywords: pulse oximetry, SAP, Doppler, norepinephrine, sodium nitroprusside, PPG, total intravenous anesthesia, propofol, canine.

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INTRODUCTION

Systolic arterial pressure (SAP) is an essential parameter in anesthetic monitoring, enabling the early detection of hypotension and hypertension in dogs [10]. The invasive method, through arterial catheterization, is considered the gold standard; however, it presents technical limitations and inherent risks, being primarily indicated in critical situations that require continuous and highly accurate monitoring, such as in unstable patients or during procedures of greater complexity [1,14,20].

In this context, non-invasive methods for blood pressure measurement, such as photoplethysmography (PPG), represent relevant alternatives to invasive monitoring [21]. In human medicine, PPG is widely applied, particularly in pulse oximetry [15], but also in more complex applications, including non-invasive blood pressure estimation [8], assessment of arterial stiffness and peripheral perfusion [16], as well as sleep and respiratory disorder monitoring [22]. In contrast, its application in veterinary medicine remains limited, being used almost exclusively for pulse oximetry, with few studies investigating its accuracy in blood pressure measurement [3,7,21,23,24]. These studies indicate that PPG may correlate with established methods, such as vascular Doppler and oscillometry, although evaluations have predominantly been conducted under stable physiological conditions. Considering that changes in vascular tone - frequent in anesthetic settings, shock, or under the influence of vasoactive agents - may compromise the reliability of indirect methods, it becomes essential to investigate PPG performance in hemodynamically challenging scenarios [19].

The aim of the present study was to assess the influence of norepinephrine and sodium nitroprusside on SAP measurement obtained by Doppler and PPG in dogs anesthetized with propofol, testing the hypothesis that both methods would show good correlation even under pharmacologically induced changes in peripheral vascular resistance.

MATERIALS AND METHODS

Animal selection

Eleven healthy male mixed-breed dogs with docile temperaments, aged between 1 and 6 years-old and weighing 7 to 15 kg, were enrolled in the study. The health status of the animals was confirmed prior to inclusion through physical examination, laboratory testing (complete blood count, leukogram, albumin, aspartate aminotransferase, creatinine, alkaline phosphatase, gamma-glutamyltransferase, total proteins, phosphorus, urea, and urinalysis by cystocentesis), as well as imaging studies (echocardiography and abdominal ultrasonography). All dogs were client-owned, domiciled, and their participation in the study was formally authorized by their owners.

Anesthetic protocol

Prior to the anesthetic procedure, dogs were fasted for solids for 8 h with no restriction of water intake. The animals were hospitalized on the day before the experiment, during which preoperative preparation was performed, including acclimatization, trichotomy, and venous catheterization, without administration of premedication.

Anesthetic induction was carried out with propofol[1] [Hyfol® - IV], administered at a dose sufficient to abolish the swallowing reflex and allow orotracheal intubation with a Murphy tube of appropriate diameter for each patient. Anesthesia was maintained with total intravenous anesthesia (TIVA) with propofol, with the infusion rate adjusted to maintain the patient at stage III, planes 1-2 (absence of laryngeal and palpebral reflexes, rotation of the eyeball, preservation of the corneal reflex, and adequate muscle relaxation). Supplemental oxygen (100%) was provided throughout the procedure. Physiological parameters were continuously monitored during anesthesia, with immediate interruption of the protocol in case of complications.

Experimental treatments

Dogs were positioned in dorsal recumbency for SAP monitoring. Initially, all animals received the saline treatment (SAL), consisting of 0.9% sodium chloride (NaCl)[2] [administered at 5 mL/kg/h] in order to establish baseline values. Subsequently, in randomized order, each animal received one of the vasoactive treatments: nitroprusside treatment (NIT), with sodium nitroprusside[3] [Nitroprus® - 1-7 µg/kg/min, IV, diluted in 5% dextrose solution], or norepinephrine treatment (NOR), with norepinephrine bitartrate[4] [0.3-0.7 µg/kg/min, diluted in 0.9% NaCl]. Infusions were delivered using a syringe pump[5] [Medrena® SP50 Syringe Pump], with volume adjustment to maintain

the total fluid therapy rate at 5 mL/kg/h. Between treatments, a new SAL infusion was administered until hemodynamic parameters returned to baseline values for at least 5 min.

For each treatment, non-invasive SAP data were obtained using 2 methods: vascular Doppler[6] (DOP) and PPG[7]. The Doppler sensor was positioned over the ulnar artery of the thoracic limb, while the pulse oximeter sensor for photoplethysmography was placed in the interdigital region of the same limb. Blood pressure measurements followed a procedure analogous to that described by Vaccarin *et al*. [21], adapted to the instruments employed in this study. Two different investigators, blinded to the treatment and each assigned to 1 method, performed the measurements, with the use of headphones standardized for the Doppler investigator.

Three evaluation time points (T1, T2, and T3) were recorded in a spreadsheet, at 5-min intervals. Baseline data collection began during the SAL phase. In the subsequent phases, data acquisition was initiated once a 20% variation in mean arterial pressure (MAP) relative to baseline was observed. In cases where such variation was not achieved, recordings were performed upon reaching the maximum infusion rate established for the drug. MAP limits were defined (maximum of 140 mmHg and minimum of 45 mmHg); infusion rates were adjusted as necessary to maintain MAP within these parameters before initiating experimental data collection.

Surgical procedure

At the end of data collection, the animals underwent elective orchiectomy. Scrotal trichotomy, aseptic preparation, and intratesticular blockade with 2% lidocaine[3] [Xylestesin® - 2 mg/kg] were performed. The surgery was carried out by a trained and properly attired surgical team. In patients showing a 20% increase in baseline values of heart rate (HR), SAP, and respiratory rate (RR) during the intraoperative period, fentanyl[3] [Fentanest® - 2.5 µg/kg, IV] was administered. All dogs received sodium cephalothin[8] [Keflin® - 30 mg/kg, IV] prior to the surgical incision. At the end of surgery, dipyrone[9] [D-500® - 25 mg/kg, IV] was administered. In addition, tramadol[4] [tramadol hydrochloride - 2 mg/kg] and meloxicam[10] [Maxicam® - 0.1 mg/kg] were administered subcutaneously.

Patients were clinically monitored in the anesthetic recovery room and discharged once they had regained consciousness and their vital parameters were within the normal range for the species. Postoperative home medication consisted of meloxicam [0.1 mg/kg, PO, once daily for 3 days] and dipyrone [25 mg/kg, PO, every 8 h for 5 days]. Follow-up for suture removal was scheduled 10 days after surgery.

Statistical analysis

Data were initially tested for normality using the Shapiro-Wilk test. Parametric data (normal distribution) are presented as mean ± standard deviation and were analyzed by repeated-measures analysis of variance (ANOVA), followed by Tukey's test for comparisons between treatments and among time points within the same treatment. Non-parametric data (non-normal distribution) are presented as median (minimum–maximum) and were analyzed using the Friedman test followed by Dunn's *post hoc* test. All analyses were performed using commercial software[11] (GraphPad Prism), and differences were considered statistically significant when $P < 0.05$.

RESULTS

The mean ± standard deviation of age and body weight were 3.3 ± 1.1 years and 10.4 ± 2.6 kg, respectively. For anesthetic induction, 7.53 ± 2.13 mg/kg of propofol was required. The maintenance infusion rate (mg/kg/min) of propofol was 0.55 ± 0.05 for the SAL treatment, 0.59 ± 0.09 for the NIT treatment, and 0.57 ± 0.08 for the NOR treatment, with no significant differences among treatments ($P > 0.05$).

As shown in Table 1, SAP evaluation in the NOR treatment demonstrated differences compared with NIT at all time points, by both measurement methods (DOP and PPG), showing higher values for NOR. In the NIT treatment, a difference compared with SAL was observed at T2 and T3 using the DOP method. Finally, with the PPG method, NIT differed from SAL as early as T1. In Figure 1, SAP demonstrated a very strong correlation (r = 1.0) between methods only for NOR. During NIT treatment, the correlation was strong (r = 0.82). During SAL, however, correlation between methods proved weak (r = 0.50).

Table 1. Mean ± standard deviation (normal distribution) or median (range; nonparametric data) of cardiovascular variables of 11 healthy propofol-anesthetized dogs subjected to pharmacologically induced vasoconstriction with norepinephrine (NOR), vasodilation with nitroprusside (NIT) or control treament of normotension with saline (SAL).

Variable	Treatment	Time point		
		T1	T2	T3
$SAP_{Doppler}$ (mmHg)	SAL	152 ± 25	156 ± 19	155 ± 18
	NIT	133 ± 23	132 ± 21*	133 ± 20*
	NOR	171 ± 27†	176 ± 26†	178 ± 32†
SAP_{PPG} (mmHg)	SAL	160 ± 26	155 ± 22	150 ± 17
	NIT	132 ± 21*	134 ± 21	134 ± 21
	NOR	173 ± 24†	178 ± 30†	177 ± 31†

*Significantly different from SAL at a given time point according to Tukey test ($P < 0.05$). †Significantly different from NIT at a given time point according to Tukey test ($P < 0.05$) or Fisher's Least Significant Difference ($P < 0.05$). Times do not differ in any treament ($P > 0.05$). $SAP_{Doppler}$, systolic arterial pressure obtained using Doppler; SAP_{PPG}, systolic arterial pressure obtained using photopletysmography.

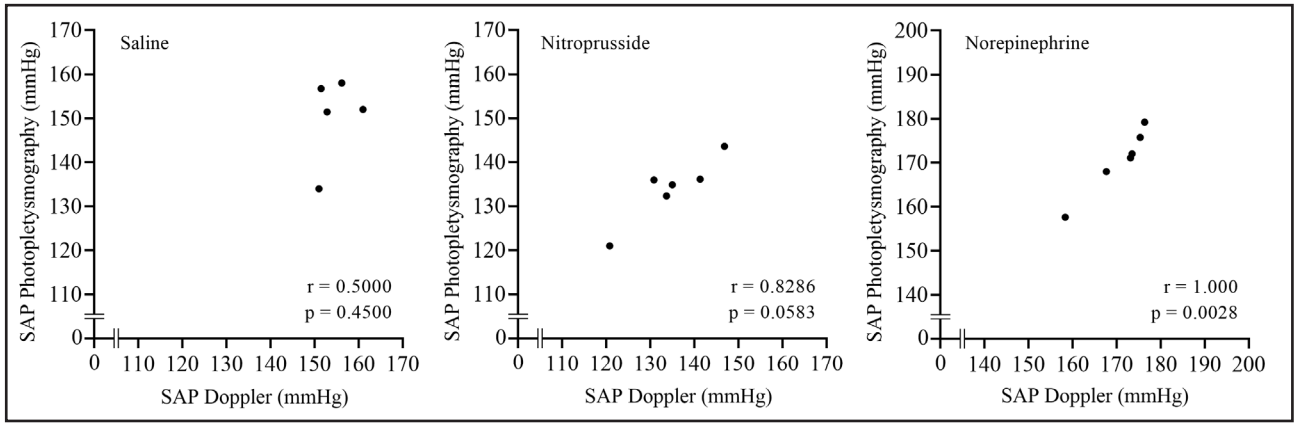


Figure 1. Spearman correlation between systolic arterial pressure (SAP) values obtained using a Doppler device or photopletysmography in 11 healthy propofol-anesthetized dogs subjected to pharmacologically induced vasoconstriction with norepinephrine, vasodilation with nitroprusside or control treament of normotension with saline. Significant very strong correlation found only during norepinephrine infusion ($P = 0.0028$, r = 1.0).

DISCUSSION

The present study demonstrated a very strong correlation between PPG and DOP in the measurement of SAP during norepinephrine infusion in dogs anesthetized with propofol. This finding suggests that although PPG is less established in veterinary medicine, it is capable of accurately detecting pressure variations under pharmacologically induced vasoconstriction. We believe that norepinephrine, as an α1-adrenergic agonist, promoted a degree of vasoconstriction sufficient to increase pulse pressure, thereby enhancing the detection of peripheral blood volume oscillations by PPG. Within this range of vasoconstriction, in which peripheral perfusion is still maintained, the photoplethysmographic signal would be expected to become clearer and more stable, which could explain the high correlation observed in this treatment.

During NIT, the correlation remained strong but was lower than that observed with NOR treatment. Sodium nitroprusside, acting as both an arterial and venous vasodilator, reduces venous return and peripheral vascular resistance, resulting in a decrease in SAP [9,13,20]. Vasodilation likely reduced vascular tone and skin perfusion, thereby decreasing peripheral pulse amplitude and compromising the quality of the photoplethysmographic signal. Nevertheless, PPG maintained clinically acceptable performance, suggesting that it may still provide useful information even under hypotensive conditions.

In the SAL treatment, the correlation between PPG and DOP was moderate. Although dogs were normotensive and under stable anesthesia, greater variability between methods was observed, possibly related to the absence of significant hemodynamic stimuli, which reduces peripheral pulse amplitude and

may limit the sensitivity of optical sensors [7]. Under stable physiological conditions, pulsatile signals tend to be more subtle, hindering precise detection of systolic events by PPG. Furthermore, due to the distinct operating principles of each method, small oscillations in baseline SAP may be interpreted differently [23]. In the NIT treatment, differences compared with SAL occurred sporadically and at different time points between the methods. However, direct comparison between DOP and PPG did not reveal significant discrepancies, indicating that both methods similarly tracked the decrease in SAP induced by nitroprusside.

Considering that propofol maintenance rates did not differ among treatments, it is plausible to assume that anesthetic depth remained consistent, and that the observed variations in SAP and in the correlation between methods were mainly due to the hemodynamic effects of the vasoactive drugs rather than fluctuations in the anesthetic plane.

Our findings partially align with those reported by Vaccarin *et al*. [21], who observed a high correlation between PPG and DOP in bitches undergoing inhalation anesthesia under stable hemodynamic conditions. Unlike that study, the present investigation evaluated the performance of these methods in the presence of pharmacologically induced blood pressure changes under total intravenous anesthesia with propofol, thereby expanding knowledge on the applicability of PPG in conditions of extreme vasoconstriction or vasodilation. It was observed that PPG performance is influenced by hemodynamic conditions, reinforcing the need for clinical contextualization when interpreting values obtained through indirect methods [17,19].

Our findings are partly consistent with those reported by Vaccarin *et al*. [21], who observed a strong correlation between PPG and DOP in female dogs undergoing inhalation anesthesia under stable hemodynamic conditions. In contrast to that study, the present investigation assessed the performance of these methods in the context of pharmacologically induced blood pressure alterations during total intravenous anesthesia with propofol, thereby broadening the understanding of PPG applicability under conditions of marked vasoconstriction or vasodilation. The results indicate that PPG performance is influenced by hemodynamic status, underscoring the importance of clinical contextualization when interpreting values obtained from indirect methods [17,19].

To date, no studies have assessed the accuracy of PPG for the direct measurement of SAP in animals subjected to pharmacologically induced changes in vascular tone. Jeong *et al*. [11] investigated the behavior of the photoplethysmographic waveform during dopamine and epinephrine infusion, but only as an indirect marker of hemodynamic alterations compared with invasive blood pressure. Therefore, this study represents, to the best of our knowledge, the 1st experimental assessment of SAP by PPG in dogs anesthetized under pharmacologically induced vasodilation and vasoconstriction, providing a basis for future clinical investigations in critical situations such as shock, hypovolemia, or deep anesthesia, with validation against invasive reference methods.

Despite these interesting results, one limitation worth mentioning of PPG is intense dark pigmentation of the paws, which prevents acquisition of an adequate photoplethysmographic waveform and has been reported previously in several species [2,5,6,18].

CONCLUSIONS

Photoplethysmography showed very strong agreement with Doppler for the estimation of systolic arterial pressure in dogs anesthetized with propofol under norepinephrine-induced vasoconstriction (r = 1.0), strong correlation during sodium nitroprusside-induced vasodilation (r = 0.82), and weak correlation under baseline conditions (r = 0.50). These results indicate that PPG performance is influenced by vascular tone. In conclusion, PPG may be considered a complementary tool for the non-invasive measurement of systolic arterial pressure, although further studies with larger sample sizes and direct comparison with invasive methods are required to confirm its accuracy across different hemodynamic contexts.

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***Ethical approval*.** The study was approved by the Animal Use Ethics Committee (CEUA) of the Central Education Unit Faem Colleges (Uceff, Chapecó-SC campus), under protocol no. 10/2023.

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