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PROSPECTIVE STUDY

Assessment of shock index in healthy cats and in cats presenting to an emergency room with shock

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Abstract

Objective: To prospectively compare the shock index (SI) in a population of healthy cats with a population of cats presenting to the emergency room (ER) deemed to be in a state of shock.

Design: Prospective cohort study of cats.

Setting: University teaching hospital.

Animals: Twenty-seven healthy control cats were enrolled to establish a reference interval, and 27 cats were enrolled that were presented to the ER with clinical signs of shock. Shock was defined as abnormalities in at least 2 of the following inclusion criteria: plasma lactate concentration > 2.5 mmol/L; peripheral vasoconstriction (at least 2 of the following parameters: capillary refill time >3 s, rectal-interdigital temperature gradient [RITG] >8°C, femoral pulse not palpable, pale mucous membranes); or systolic blood pressure (SBP) < 100 mm Hg.

Interventions: Upon presentation, SI (SI = heart rate [HR]/SBP), HR, SBP, and RITG were recorded in both groups, along with peripheral venous blood sampling for lactate measurement.

Measurements and Main Results: The mean SI in the control group was 1.47 ± 0.2 and was 1.87 ± 0.47 in the shock group ($P = 0.001$). Using equality in sensitivity and specificity of 0.7, an SI cutoff point of 1.54 (95% confidence interval [CI]: 0.49–0.86) was determined with an estimated area under the receiver operating characteristic curve of 0.78 (95% CI: 0.65–0.90). HR, plasma lactate concentration, and RITG did not differ between the groups. Systolic arterial blood pressure ($P = 0.01$), rectal temperature ($P = 0.02$), and interdigital temperature ($P = 0.04$) differed significantly.

Abbreviations: CI, confidence interval; ER, emergency room; HR, heart rate; PVR, peripheral vascular resistance; RITG, rectal-interdigital temperature gradient; ROC, receiver operating characteristic; SBP, systolic arterial blood pressure; SI, shock index.

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Conclusions: The SI is a noninvasive, easy, and reliable parameter for distinguishing cats in shock from normal cats.

KEYWORDS
blood pressure, feline, heart rate, hypothermia, lactate, triage

1 | INTRODUCTION

Cats are commonly presented to the emergency room (ER) in shock, and early identification is important for implementing therapy.[1] Shock is defined as a state of impaired delivery of oxygen and nutrients unable to meet tissue metabolic demand; it can be divided into 4 main categories: hypovolemic, cardiogenic, obstructive, and distributive.[1,2] Shock-state evaluation is usually based on compensatory physiological alterations in response to an impaired relationship between oxygen delivery and demand.[2] Vital signs such as heart rate (HR), respiratory rate, and blood pressure typically guide the emergency treatment of critically ill patients.[3] Because these variables often lack specificity and sensitivity to predict tissue perfusion, the ability to identify patients in shock remains challenging.[4–6]

The presence of occult hypoperfusion, which is characterized by persistent hyperlactatemia in the absence of hypotension, is defined as cryptic shock.[7] Blood lactate concentration can be used as an early marker of tissue hypoperfusion during cryptic shock.[7–9] However, a clinical study reported that hyperlactatemia may be present in cats with or without shock, highlighting the lack of specificity for lactate concentration in cats.[10]

The shock index (SI) is defined as HR divided by systolic arterial blood pressure (SBP). It has been used to identify hemorrhagic shock in dogs,[3,4] to predict massive blood transfusion requirement in human trauma,[11] and for the early recognition of sepsis in human patients.[12] Our hypothesis was that the SI would be a reliable tool for identifying shock in cats.

2 | MATERIALS AND METHODS

Cases were selected from client-owned cats that were presented to the University Teaching Hospital between January 2015 and June 2017. The study protocol was approved by the Institutional Animal Use and Care Committee (protocol number 28055), and client consent for study enrollment was obtained.

All cats were allocated into 2 groups: a control group and a shock group. The control group was composed of cats with no clinical evidence of systemic disease that were admitted to the veterinary hospital for routine evaluation (consultation, preoperative for elective surgery, revaccination). All cats in the control group were acclimated to the environment for 10–15 minutes before starting the physical examination. The shock group comprised cats that were presented to the ER, met the study shock criteria, and were evaluated by 1 of the investigators.

Cats were included in the shock group if at least 2 of the following 3 criteria were identified on admission: (1) hypotension (SBP <100 mm Hg)[13]; (2) peripheral vasoconstriction parameters (at least 2 of the following parameters: capillary refill time >3 s, rectal-interdigital temperature gradient [RITG] >8°C, femoral pulse not palpable, pale mucous membranes)[1,15]; or (3) plasma lactate concentration >2.5 mmol/L.[10,15]

To ensure consistency in data collection, a standardized protocol was established before the study began. This protocol was designed to be adhered to by all the investigators who were responsible for conducting the evaluations, thereby mitigating potential disparities in data collection.

Upon arrival to the hospital, patient histories were obtained, and a physical examination was performed. SBP was measured using a Doppler ultrasound[a]. The cuff was positioned between the elbow and the carpus, with the width of the cuff being 40% of the limb circumference. Four consecutive measurements were recorded. The initial value was discarded, and the mean of the other 3 measurements was used.[15] HR was obtained by thoracic auscultation of heart beats in 1 minute. SI was calculated by dividing HR by SBP. One of the vasoconstriction parameters used in this study was RITG,[14,17] which was calculated by subtracting the interdigital temperature from the rectal temperature as mesaured using a digital infrared thermometer with 2 laser tips; the emissivity was set at 0.98[b] in the interdigital space (2nd–3rd) of the left hindlimb. The thermometer's distance to the measurement point (i.e., the range where the lasers from the 2 tips came together at a single point) was approximately 13 cm, and the laser was left in contact with the skin for 10 seconds to perform each measurement.[13] The RITG that is typically reported in people is between 3 and 7°C and should be <6.5°C in dogs and <8°C in cats.[1,18] Peripheral venous blood was collected and run on a point-of-care lactate analyzer to determine lactate concentrations[c].

2.1 | Statistical methods

SI and rectal temperature, peripheral temperature, RITG, SBP, HR, and lactate concentration were expressed as means and SD. The sample size calculations were performed with the following variables: a mean difference in the SI between groups of 0.53, an estimated SD of 0.20 for the control group, and an SD of 0.47 for the shock group. The

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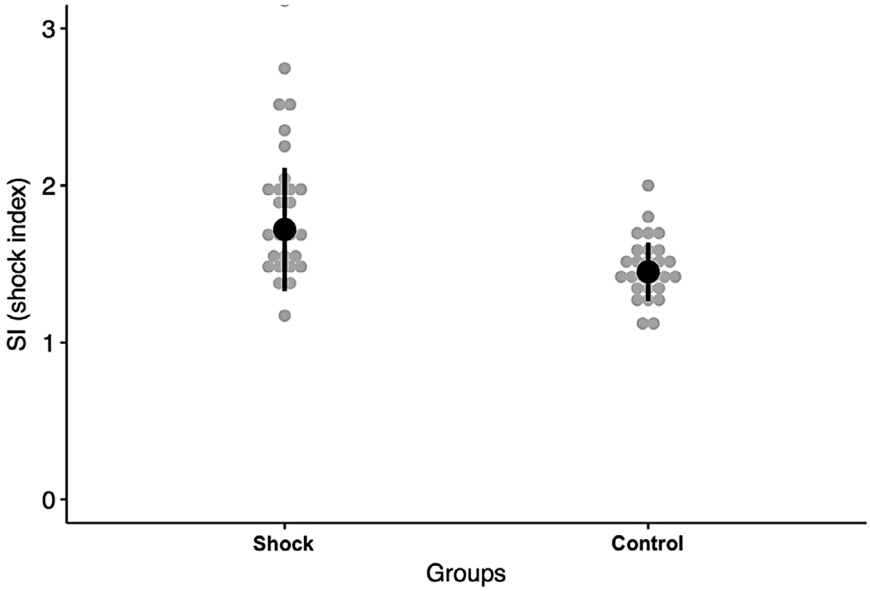


FIGURE 1 The whisker plot shows the distribution of shock index (SI) among cats in both the control and shock groups. A statistically significant difference between the 2 groups is shown, with the shock group exhibiting the highest SI ($P = 0.001$).

significance level (type I error rate) of 0.05 was used, and the prespecified level of statistical power for the sample size calculation was set at 0.95.[19,20]

To determine the statistical difference between the groups, we first tested the normality assumption of each group's measurement values using the Shapiro–Wilk test. The skewness, kurtosis, and homogeneity were then assessed with Levene's test. Finally, the independent samples were compared using the nonparametric Wilcoxon test. The receiver operating characteristic (ROC) curve was used to determine the optimal cutoff value for classifying the animals as more likely to fit in each group. The cutoff value was based on 2 optimization alternatives: first, the Youden index (J), defined as $J = \max_c \{\mathrm{Se}(c) + \mathrm{Sp}(c) - 1\}$, where the cutoff point that achieves this maximum is referred to as the optimal cutoff point (c^*) because it is the cutoff point that optimizes the SI differentiation ability when equal weight is given to sensitivity and specificity,[17] and second, similar sensitivity and specificity criteria, based on the equality of sensitivity and specificity.[21,22] Because specificity may not be precisely equal to sensitivity, the absolute value of the difference between the 2 was minimized. The statistical process was analyzed using the R-language[d].

3 | RESULTS

Fifty-four cats were enrolled in this study. The animals were separated into control and shock groups. The mean ages and weights were 3.25 years and 3.98 ± 1.38 kg, respectively. Two main disease conditions were found among the patients in the shock group: urethral obstruction in 9 animals and trauma in 8 animals. Other observed clinical conditions included 6 animals with immunosuppression related to oncological, hematological, and viral infections and 2 with metabolic endocrine disorders. It was not possible to determine which illness caused shock in 2 cats.

The SI range was different ($P < 0.001$) between the groups (Figure 1). Differences in rectal temperature, interdigital temperature, and SBP were also significant between the groups, with P-values of 0.02, 0.04, and 0.01, respectively (Figure 2). No differences in lactate concentration, HR, or RITG were found between the shock group and the control group (Figure 3), although plasma lactate concentration was measured in only 13 of 27 cats that were diagnosed with shock. Therefore, the remaining 14 cats met the other shock criteria. The results of all parameters measured during the study are shown in Table 1.

The distribution of the SI values was assessed in each group; the mean ± SD was 1.47 ± 0.20 for the control group and 1.87 ± 0.47 for the shock group. Based on Youden criteria, the optimal cutoff value was estimated at 1.65, with a calculated sensitivity of 0.62 (95% confidence interval [CI]: 0.42–0.80) and a specificity of 0.81 (95% CI: 0.61–0.93). If equality in sensitivity and specificity was taken into consideration, the cutoff was 1.54, with sensitivity and specificity of 0.70 (95% CI: 0.49–0.86), and the area under the curve was 0.78 (95% CI: 0.65–0.90) (Figure 4). The positive predictive value was determined to be 0.61 (95% CI: 0.42–0.78), while the negative predictive value was calculated as 0.65 (95% CI: 0.42–0.83).

4 | DISCUSSION

This study documented that SI is significantly higher in cats with shock than in healthy cats, a finding consistent with a previous pilot study presented as an abstract[e]. Shock can be challenging and requires timely identification. This study aimed to evaluate the use of the SI as a diagnostic or adjunct tool that could be used to improve ER clinicians' awareness when managing cats in emergency settings.

Shock is often recognized as a clinical manifestation of hypotension and does not always present as occult or cryptic shock.[7] Therefore, the identification of peripheral vasoconstriction (decreased peripheral

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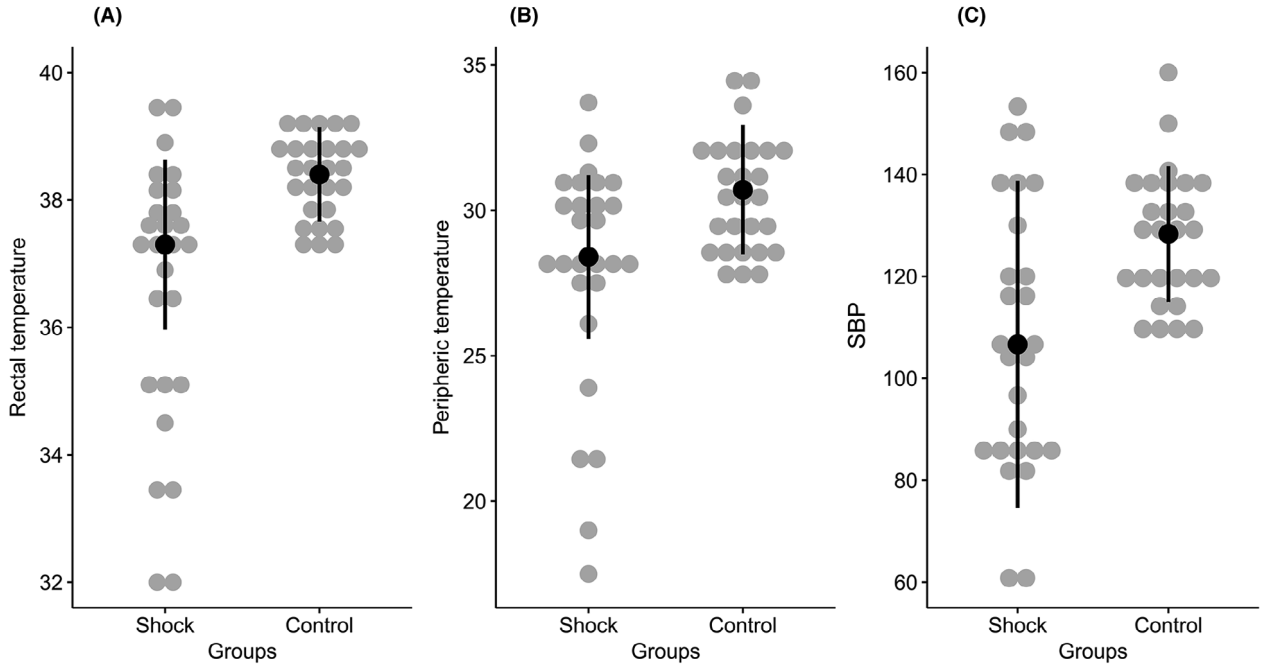


FIGURE 2 The whisker plot shows the distribution of statistically significant parameters, including rectal and peripheral temperatures and systolic blood pressure, between the shock and control groups. It is noteworthy that the shock group exhibited the lowest values for all 3 parameters. SBP, systolic arterial blood pressure

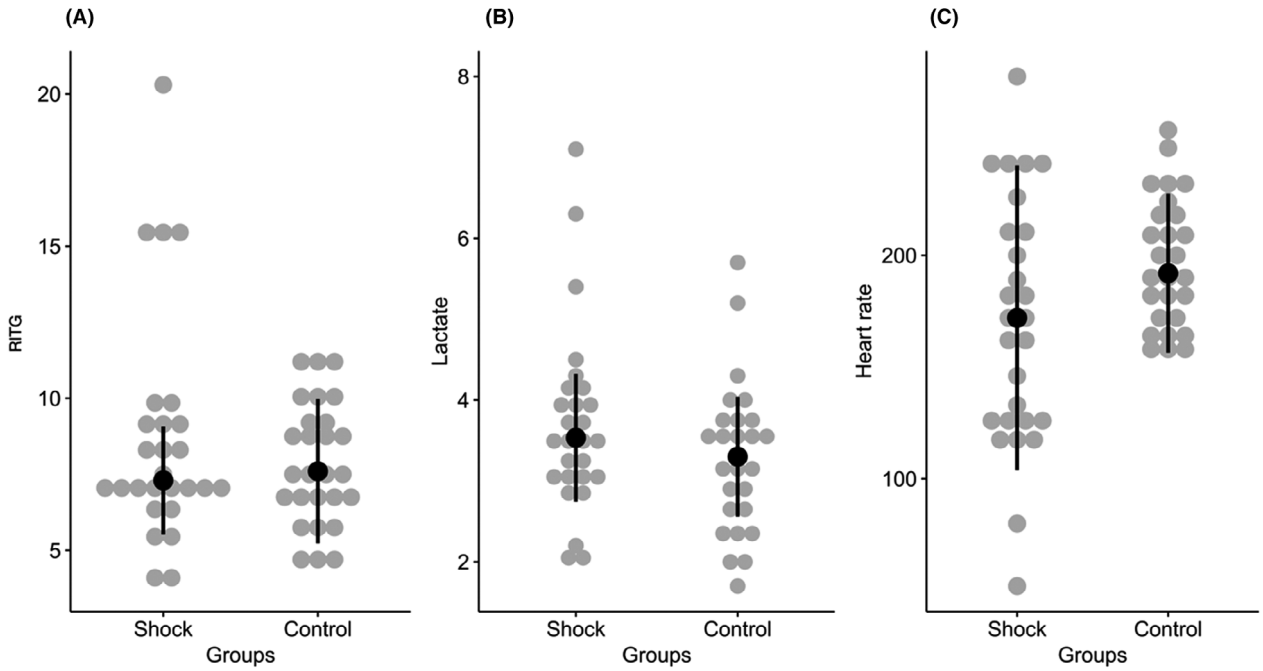


FIGURE 3 The whisker plot displays the distribution of nonstatistically significant parameters, including rectal to interdigital temperature gradient (RITG; degrees Celsius), lactate concentration (mmol/L), and heart rate (beats / minute), evaluated between shock and control groups.

temperature, pale mucous membranes, delayed capillary refill time, oliguria, decreased bowel sounds, or loss of sensitivity to detect a pulse curve by a pulse oximeter) is an essential part of emergency patient evaluation.[23] Vasoconstriction is caused by activation of the sympathetic nervous system in the face of poor effective circulating volume or inadequate cellular energy production and may be so effective that this compensatory response may prevent hypotension.[24] However, hypotension is a negative predictive factor for cats during admission

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TABLE 1 Physiological variables, lactate concentration, and shock index (SI) in cats with shock and in healthy cats.

Variable	Group	
	Shock	Control
Rectal temperature (°C)	37.30 (1.33)*	38.40 (0.74)
Interdigital temperature (°C)	28.40 (2.82)*	30.70 (2.22)
RITG (°C)	7.30 (1.78)	7.60 (2.37)
SBP (mm Hg)	106.67 (32.12)*	128.33 (13.34)
Lactate (mmol/L)	3.53 (0.79)	3.30 (0.74)
Heart rate (beats/min)	172 (68.20)	192 (35.58)
SI	1.72 (0.39)*	1.45 (0.19)

Note: Values are shown as mean (absolute deviation).
Abbreviations: SBP, systolic arterial blood pressure; RITG, rectal to interdigital temperature gradient; SI, shock index
*Significantly different from the control group ($P < 0.05$).

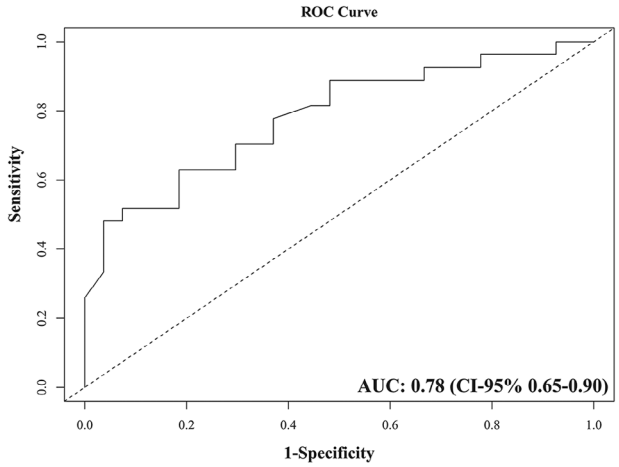


FIGURE 4 The receiver operating characteristic (ROC) curve demonstrates an area under the curve (AUC) of 0.78 for the shock index, indicating its effectiveness in detecting shock in cats.

to the intensive care unit.[13] In our study, as expected, the SBP differed between groups. Animals with shock signs showed lower SBP values, although the group's mean was above the limit at which it was considered hypotension.[10,12] Most animals were likely in a compensatory state.

Primary physiological compensatory responses to shock include tachycardia and increased peripheral vascular resistance (PVR).[24] The HR is a determinant of cardiac output. Cats naturally have a higher HR than dogs and people; for this reason, they have unique features when facing tachycardia.[25] The cardiocardiac sympathovagal reflex in cats was first described in the 1970s, indicating that when cats have persistent tachycardia,[25] this reflex inhibits sympathoadrenal stimuli and decreases the HR to a normal range or even to a bradycardic state. Because there may be patients with shock that demonstrate normal HR, tachycardia, or bradycardia, this reflex complicates the use of HR as a shock parameter in cats. In a retrospective study, there was no difference in the HR of cats that survived and those that died.[12] The HR in the current study was not found to be significantly different between the shock and control groups, which corroborates these findings.

The increase in PVR is another mechanism related to the compensatory state of shock that sustains the SBP.[22] Usually, an increase in PVR follows tachycardia when tachycardia alone is not adequate to maintain systemic blood pressure. The increase in PVR may be appreciated clinically as signs of vasoconstriction, including mucous membrane pallor, poor pulse quality, and prolonged capillary refill time. In a previous study, it was demonstrated that the odds for an unfavorable outcome were 6.4 times higher for a critically ill patient with abnormal peripheral perfusion, assessed by central and peripheral temperatures and its gradient, RITG.[26] Increased RITG is associated with vasoconstriction and a decrease in peripheral tissue perfusion. Its primary importance is as an objective and quantitative parameter, in contrast to the color of mucous membranes and quality of pulses, which are subjective. The human reference value for RITG is <6°C, and values >6°C are attributed to peripheral vasoconstriction.[18] The reference of normal RITG in cats is < 8°C.[14] In our study, no evidence was found of significant difference in RITG between the groups; however, the shock group's individual rectal and peripheral temperatures were significantly different. This could be explained if RITG is more useful when the central temperature is normal. We found a mean rectal temperature of 37.3 ± 1.33°C in the cats with shock and 38.4 ± 0.74°C in the control group. A recent study corroborating these results found that rectal temperatures <37.8°C in cats were associated with poor perfusion and shock.[10]

Lactate has emerged as an essential biomarker of shock, particularly in the early stages of compensated shock, and has been described and validated as a byproduct of anaerobic metabolism in various species.[10,27] Early identification of shock is critical for establishing prompt treatment and reducing mortality[5,28]; therefore, it is crucial to monitor a parameter that reflects the adequacy of cellular energy production like plasma lactate concentration . Although the published literature on lactate in feline medicine is controversial, different studies have evaluated whether struggling during physical restraint and venous occlusion time at the venipuncture site can interfere with results.[28,29] Here, lactate evaluation was not different between the groups (shock group, 3.53 ± 0.59 vs. control group, 3.3 ± 0.74), and, interestingly, these results agree with another study performed in cats in shock,[10] probably because both studies had heterogeneous groups of cats. Therefore, lactate concentrations should be interpreted along with physical perfusion parameters and other monitoring measurements such as systemic blood pressure in cats. As proposed in the literature, even a sample of cats considered healthy may present hyperlactatemia, tachycardia, and signs of peripheral vasoconstriction due to sympathetic activation, confusing the initial physical examination. Therefore, it is essential for a detailed clinical history and other laboratory findings to complement the physical examination.[10,12,28,29]

The SI was initially described in people in the 1960s, and 2 studies have experimentally and clinically shown the relationship between SI and physiological parameters, such as cardiac index, stroke volume, and mean arterial pressure.[30,31] In our study, the shock group presented an SI of 1.72 ± 0.39 while the control group's SI was 1.45 ± 0.19

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($P < 0.001$). Cats are expected to have a higher HR, reflecting a higher normal HR/SBP value than in people, in whom the SI cutoff is approximately 0.5–0.7.[32] Recently, there was a report of a cutoff of > 0.9 in dogs,[4] meaning that values above this reference should be investigated for early stages of shock. Based on our analysis, we estimated that the optimal cutoff value for the SI in cats was 1.54, with a corresponding area under the ROC curve of 0.78. These values indicated an acceptable level of performance in clinical evaluations, particularly when considering diverse and heterogenous populations.

The current study has some limitations. First, our sample of cats in shock encompassed a diverse range of etiologies and clinical presentations, deliberately including animals with both acute and chronic diseases to capture the inherent heterogeneity that is observed within the emergency setting. Although this approach aimed to provide a comprehensive representation of the feline patient population, it inevitably introduced confounding factors that may have influenced compensatory responses and subsequently affected the SI. Our investigation revealed a notable subset of cats presenting with urethral obstruction, which constituted nearly one third of the shock group. Urethral obstruction is known to cause hyperkalemia, a condition that can lead to a decrease in HR.[33] This pathophysiological response poses a potential challenge to accurately assessing SI in cats with hyperkalemia, as it deviates from the expected increase in HR that is typically observed in most states of shock. Furthermore, it is essential to recognize that different etiologies can elicit different physiological responses. This highlights the importance of considering factors such as HR and SBP when interpreting the SI. For instance, apart from urethral obstruction, conditions such as hypoadrenocorticism, which is uncommon in cats, and neurogenic shock may also present with a relatively or absolutely decreased HR.[25]

The influence of pain on the assessment of the SI warrants careful consideration. Pain is a complex physiological and psychological phenomenon with varying effects on the cardiovascular system. It is well known that pain can activate the sympathetic nervous system, leading to an increase in HR and subsequently affecting the SI. Pain-induced tachycardia may contribute to an elevation of SI in some cases, and it is essential to recognize that pain has important implications. Pain experienced by animals can disrupt the normal regulatory mechanisms that govern oxygen delivery.[34] These unique scenarios emphasize the need to understand the specific pathophysiological mechanisms that are involved when applying SI to different clinical contexts. Although the sample size employed in our study was adequate to yield statistically meaningful results, we acknowledge the necessity for additional investigations with larger cohorts. Expanding the sample size would not only enhance the statistical robustness of the findings but also facilitate the validation of the SI for cats across diverse clinical scenarios and diseases.

The determination of the SI in cats is simple, is noninvasive, and can be performed within minutes. Our study does not suggest that SI should be used alone, but the data support its ability to differentiate between a healthy population of cats and a population of cats deemed to be in a state of shock when the SI is above 1.54. Lactate alone could not identify occult shock in cats in the current study; therefore, the SI measure should be used in conjunction with other clinical and laboratory assessments as an additional triage tool. To the best of our knowledge, this is the first peer-reviewed study to evaluate the SI in cats.

AUTHOR CONTRIBUTIONS

Leandro Fadel: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **Rodrigo Cardoso Rabelo**: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft; writing—review and editing. **Denise Tabacchi Fantoni**: Data curation; formal analysis; supervision; visualization; writing—review and editing. **Marina Candido Duarte**: Formal analysis; validation; visualization; writing—original draft. **Gabriela da Cruz Schaefer**: Formal analysis; validation; visualization; writing—original draft; writing—review and editing. **Mariana Pires Oliveira**: Formal analysis; supervision; visualization; writing—original draft. **Fernanda Vieira Amorim da Costa**: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; supervision; validation; visualization; writing—original draft.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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