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Original Study

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Evaluation of the shock index in dogs presenting as emergencies

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Abstract

Objectives – To (1) determine a reference interval for shock index (SI) [defined as heart rate (HR)/systolic blood pressure (SBP)], in a group of healthy dogs, and (2) compare SI in healthy dogs with dogs presenting to the emergency room (ER) deemed to be in or not in a state of shock.
Design – Prospective study.
Animals – Sixty-eight clinically normal dogs, 18 dogs that were presented to the ER deemed to be in shock and 19 dogs presenting to the ER not deemed to be in shock.
Setting – University teaching hospital.
Interventions – Peripheral or central venous blood sampling.
Measurements and Main Results – Heart rate and SBP were recorded on simulated presentation (healthy dogs), and emergency presentations for both dogs deemed to be in shock and dogs not deemed in shock. Dogs in shock had a median SI of 1.37 (0.87–3.13), which was significantly higher than both other groups; dogs not deemed in shock had median SI 0.73 (0.56–1.20), $P < 0.0001$ and healthy dogs had median SI 0.78 (0.37–1.30) $P < 0.0001$), respectively. Receiver operator characteristic curve analysis suggested a SI cut-off of 1.0, yielding an area under the receiver operator characteristic (AUROC) of 0.89 (Specificity (Sp) 89, Sensitivity (Sn) 90) when comparing dogs deemed in shock with healthy dogs, and 0.92 (Sp 95, Sn 89) when comparing dogs in shock with to dogs not deemed in shock.
Conclusions – The SI is an easy and noninvasive patient parameter that is higher in dogs that are deemed to be in shock than both healthy dogs and dogs presented as emergencies but not deemed to be in a state of shock. The measurement of SI may have some benefit in clinical assessment of emergency patients.

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Introduction

Early identification of shock is paramount in triaging and implementing goal-directed therapy in an emergency setting. As shock is a significant contributor to death of patients from a variety of diseases in an ER setting, and is potentially reversible, identifying early signs of hypoperfusion becomes fundamental in guiding treatment and prognosticating outcome.[1–3] Shock,

Abbreviations

AUROC	area under the receiver operator characteristic
BP	blood pressure
ER	emergency room
HR	heart rate
LVSW	left ventricular stroke work
NIBP	noninvasive blood pressure
ROC	receiver operator characteristic
SBP	systolic blood pressure
SI	shock index

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defined as inadequate oxygen delivery to meet tissue demands, is difficult to measure since there is a current lack of sensitive tools to assess tissue oxygen status.[4] In general veterinary clinical practice, the diagnosis of shock relies on indicators of the body's compensatory response to shock, namely increases in heart rate (HR) and reduction in blood pressure (BP) as well as the presence of other physical examination findings such as pale mucous membranes, or dull mentation. Unfortunately, in the early stages of shock (ie, well-compensated shock) the HR and BP may not be noticeably abnormal such that shock may not be appropriately recognized until it progresses into a more advanced stage.[5,6]

In addition to physical exam findings and vital sign monitoring, some biochemical markers serve as useful biomarkers of shock. Lactate is one of the most commonly accepted of these biomarkers, and has been demonstrated to be a useful marker for both diagnostic purposes and as a reliable prognostic indicator in both human and veterinary ER settings.[7–10] Lactate, a byproduct of anaerobic metabolism, is primarily of interest when produced secondary to poor tissue perfusion (ie, Type A hyperlactatemia), and an increased lactate concentration is widely accepted as an indicator of shock in animals.[9] Hyperlactatemia in the absence of hypoperfusion (ie, Type B hyperlactatemia) can be seen associated with seizures, hepatic disease, and neoplasia, but this is much less commonly encountered in the ER setting. A plasma lactate < 2.5 mmol/L is typically considered to be normal in dogs, while plasma lactate >5 mmol/L is considered a moderate increase and >7 mmol/L considered severe increase in plasma lactate concentration.[11]

The shock index (SI), which is defined as the ratio of HR to systolic arterial blood pressure (SBP), was developed as a simple means of quantifying the severity of shock on presentation to the ER, and has also been used to monitor the response to treatment in people.[12,13] The SI was initially developed in a porcine model of hemorrhage, which determined that SI was inversely related to cardiac index, stroke volume, mean arterial pressure, and left ventricular stroke work (LVSW), as well as oxygen delivery and mixed venous oxygen saturation.[14] The SI has shown value in assessing human ER patients in numerous studies since these initial trials, particularly following trauma, and is considered to be a good estimate of initial LVSW (in turn, a measure of left ventricular function) and its response to therapy.[15–17] In people, a value of greater than 0.9 is indicative of serious illness, requiring immediate treatment and close monitoring.[12] The proposed advantage of the SI is that it allows identification of derangements in perfusion status in the face of outwardly normal cardiovascular parameters, specifically in cases of occult hypoperfusion.[12] The ease of use and low cost of the SI make it an easily implemented procedure for the identification of occult shock as well as for the identification of patients at risk of deterioration. While these features of the SI make it appealing for application in veterinary medicine, to the authors' knowledge the SI has not yet been evaluated in veterinary patients, even in those with overt evidence of shock.

The purposes of this study were to (1) determine a normal range for SI in simulated patients and (2) to investigate whether SI is increased in dogs deemed to be in moderate to severe shock (via assessment of plasma lactate) and compare SI in this group to that of healthy dogs and dogs not to be in shock on presentation to the ER.

Materials and Methods

This prospective study was approved by the Tufts University Institutional Animal Care and Use Committee.

Simulated ER patients

Healthy dogs belonging to the students and staff of a teaching veterinary hospital were recruited to serve as controls. Inclusion in the control group required a normal physical examination and no current administration of medication that may alter HR or SBP. Control dogs were evaluated in the treatment area of the ER away from their owners, mimicking presentation to the ER, where their HR and SBP were obtained. Heart rate was determined by auscultation in conjunction with palpation of pulses. The oscillometric BP technique[a,18] was the preferred method used to obtain the SBP. In cases in which SBP was unobtainable using this technique, Doppler methodology was used and the SBP was determined by the return of audible pulses. In accordance with the American College of Veterinary Internal Medicine (ACVIM) guidelines for blood pressure measurement, cuff size was chosen based on the width of the cuff approximating 40% of the circumference of the measured limb and a series of 3 BP measurements were taken, with the average SBP reported.[19] The SI was calculated by dividing the HR by SBP. No attempt was made to exclude any dog that appeared particularly nervous or excited.

ER dogs not deemed to be in shock

This group comprised dogs that were presented to the ER lacking biochemical evidence of shock (venous lactate of ≤1.5 mmol/L)[11] on presentation and were enrolled as ER dogs not deemed to be in shock.

ER dogs deemed to be in shock

This group comprised dogs that were presented to the ER with biochemical evidence of moderate to severe shock (venous lactate >5 mmol/L).[9,11] Exclusion criteria included inability to obtain SBP and the diagnosis of a

Table 1: Population characteristics stratified by group*

Group	*n*	Age (yrs)	HR (per minute)	SBP (mm Hg)	SI
Healthy	68	4.5 (0.75–14.0)	112 (60–195)	140 (98–220)	0.78 (0.37–1.30)
Not in shock	19	7 (0.5–19)	100 (66–132)	137 (88–205)	0.73 (0.56–1.20)
Shock	18	10 (3.0–11.5)	158 (120–207)	108 (56–150)	1.37 (0.87–3.12)

HR, heart rate; SBP, systolic blood pressure; SI, shock index.
*All data displayed as median (range) except population n, which displays number of individuals in each group.

disease condition that could result in hyperlactatemia in the absence of shock (eg, increased oxygen demand or type-B lactic acidosis).

Plasma lactate measurement

Venous blood samples were drawn directly into a syringe from all dogs presenting to the ER, either through a venous catheter at the time of placement, or by jugular venipuncture. Five hundred microliters of blood was then immediately transferred to a heparinized blood collection tube, yielding a final heparin concentration of 30 U/mL. A blood gas autoanalyzer[b] was used to determine plasma blood lactate concentration. Samples were analyzed within 5 minutes of collection.

Statistics

Nonnormally distributed data were compared using the Wilcoxon rank sum test, yielding a *P* value for comparisons of SI and age. The chi-square test was used to test for an association between sex and whether or not the dog was in shock. Shock index was classified a priori as a binary variable: >1 versus ≤1. A cut off of 1 was considered clinically relevant and higher than what is used in people since dogs generally have more rapid heart rates than people, despite having similar systolic blood pressure. Thus, a normal dog would be expected to have a higher SI than a normal person. The sensitivity and specificity, along with area under the receiver operator characteristic (ROC) curve, were calculated to determine the discrimination of the shock index in healthy dogs versus shock dogs, and, separately, to determine the discrimination of the SI for ER dogs not in shock versus ER dogs in shock. The area under the ROC curve (AUCROC) investigates the predictive ability of shock index to predict a diagnosis of shock.[20] The 95% confidence intervals for the ROC values were calculated. All statistical calculations were conducted by a statistician (L.L.P.) using a commercial statistical software package.[c] A *P* value of < 0.05 was considered significant.

Results

Healthy dogs

Sixty-eight healthy dogs were enrolled in the control group; including 36 neutered males, 1 intact male, 28 neutered females, and 3 intact females. A number of breeds were represented, with all breeds having only one representative other than mixed-breed (17), Golden Retriever (6), Labrador Retriever (6), American Staffordshire Terrier (4), English Bulldog (3), Australian Shepherd Dog (2), Beagle (2), Dachshund (2), Parson Russell Terrier (2), and German Shepherd Dog (2). Median age was 4.5 years (0.75–14.0) years. Median HR was 112/min (60–195/min), median SBP was 140 mm Hg (98–220 mm Hg), and median SI for the control group was 0.78 (0.37–1.30) (Table 1).

Study dogs

One hundred and thirty-eight dogs presented to the ER over a 3-month period were eligible for inclusion in the study group. Of these, 19 dogs had no biochemical evidence of shock (lactate ≤1.5 mmol/L) and were included in the ER group not deemed in shock. A total of 23 dogs initially qualified for the ER group deemed in shock based on biochemical evidence of shock (lactate >5 mmol/L) but 5 dogs were later excluded due to the presence of disease conditions that could contribute to hyperlactatemia in the absence of shock. These conditions included seizure/muscle tremors (3), and lymphoma (1). Additionally, 1 dog with 3rd degree AV block with an increased lactate was excluded due to a known inability to have a tachycardic response to shock. The other 96 dogs were excluded from further analysis due to lack of inclusion criteria as established above.

ER dogs not deemed in shock

Nineteen dogs presenting to the ER lacked biochemical evidence of shock were deemed not to be in shock and were enrolled into the study. These dogs included 9 male neutered, 1 intact male, and 9 neutered females. Breed breakdown included 4 mixed-breed dogs, 3 Labrador retrievers and 1 each of the following; Airedale, Dogo Argento, Dachshund, Newfoundland, Border Collie, Standard Poodle, Italian Greyhound, Treeing Walker Hound, Rottweiler, Pit bull, and English Bulldog. Underlying disease conditions for these patients included gastroenteritis/possible foreign body (4), spinal disease (3), minor trauma (3), history of possible seizure (2), stable diabetic with lethargy/anorexia (2), fever (1), resolved

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supraventricular tachycardia (1), cutaneous mass (1), local neoplasia (1), and possible toxicity (1). Median age was 7 year (0.5–19 years), median HR of 100/min (66–132/min), median SBP 137 mm Hg (88–205 mm Hg) for the ER dogs not deemed in shock. Median SI was 0.73 (0.56–1.20) for these dogs (Table 1), while median lactate was 1.1 mmol/L (0.5–1.5).

ER dogs in shock

Eighteen dogs with biochemical evidence of shock were enrolled, including 10 male neutered, 1 intact male, 6 neutered females, and 1 intact female. Breeds included 5 mixed-breed dogs, 3 Golden Retrievers, 3 Labrador Retrievers, and 1 each of the following; American Bulldog, Doberman Pinscher, Irish Wolfhound, Keeshond, Standard Poodle, Shetland Sheepdog, and Siberian Husky. Underlying disease conditions for these patients included pericardial effusion with cardiac tamponade (6), gastric dilatation-volvulus (3), hemoabdomen (2), and a single case of each of the following; pneumonia, severe epistaxis with associated blood loss, insulinoma with collapse, immune-mediated hemolytic anemia, severe poly-trauma, post intraoperative respiratory arrest presenting for on-going care, and septic abdomen. Median age was 10 years (3.0–11.5 years). Median heart rate was 158/min (120–207/min) and SBP was 108 mm Hg (56–150 mm Hg). The median SI was 1.37 (0.87–3.12) (Table 1). Median plasma lactate was 7.1 mmol/L (5–12.9 mmol/L).

A significant difference existed between the SI of both healthy dogs ($P < 0.0001$) and ER dogs not deemed in shock ($P < 0.0001$) compared to the dogs deemed to be in shock, with both healthy and dogs not in shock having a lower SI than shock dogs. In addition, a significant difference existed in age between healthy dogs and dogs in shock ($P < 0.0001$), but not between ER dogs not deemed in shock and dogs in shock (P = 0.30). No significant difference existed when comparing sex between healthy and shock dogs ($P = 0.61$) or ER dogs no in shock and ER dogs in shock ($P = 0.74$). The sensitivity (Sn), specificity (Sp) and ROC area were calculated using a cut off of SI>1 defined a priori as a clinically relevant cutpoint. In healthy dogs compared to those dogs in shock, an area under the receiver operator characteristic (AUROC) of 0.89 (CI 0.81–0.98) was seen, with a Sn of 89% and Sp of 90% (Figure 1). In ER dogs not deemed in shock compared to those deemed in shock, an AUROC of 0.92 (CI 0.83–1.00) was seen, with a Sn of 89% and Sp of 95% (Figure 2).

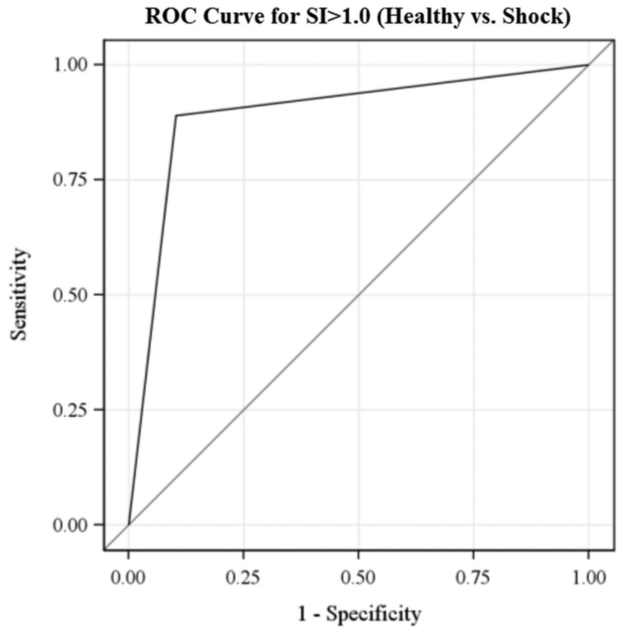

Figure 1: Receiver operator characteristic (ROC) curve comparing shock index between healthy dogs and dogs in shock (AUROC 0.89, sensitivity = 89, specificity = 90) to predict shock when shock index >1.0.

Discussion

This study documented that the SI may be determined in dogs and that SI is significantly higher in dogs with shock compared to both healthy dogs and dogs presenting to the ER but not deemed to be in shock. Specifically, an SI of >1.0 is a highly sensitive and specific indicator to distinguish ER dogs not in shock and healthy dogs from dogs with biochemical evidence of moderate to severe shock. Our findings support that SI has value as an indicator of shock in sick dogs presenting to the ER, and may serve as part of an initial evaluation. In addition, the SI has not previously been evaluated in a veterinary population, so this study serves to introduce the SI and establish a reference interval for shock index in dogs (0.37–1.30).

These data provide a pilot evaluation of SI in shock patients, but our study did not evaluate shock in occult hypoperfusion, which is an important distinction. In human studies, the proposed use and proven value of the SI is in identification of early hypovolemia or occult hypoperfusion, as well as in sustained occult shock during resuscitation.[12,13,21,22] This study was designed to introduce the SI to veterinary medicine; further studies evaluating dogs with early, developing shock are warranted.

In this study, we defined dogs as being in shock when there was biochemical evidence of moderate to severe shock (ie, plasma lactate >5.0 mmol/L) and excluded dogs whose underlying disease could predispose to non-shock related hyperlactatemia. This relatively high lactate value was chosen to select for patients that were clearly in shock, as this value represents a 2-fold increase

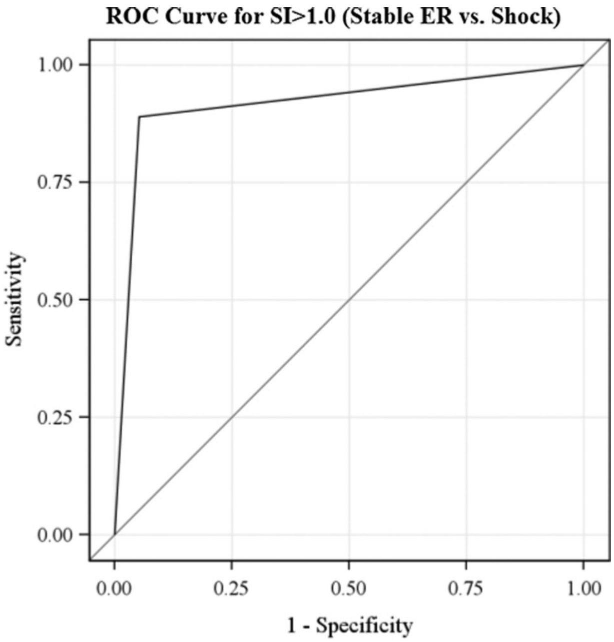

Figure 2: Receiver operator characteristic (ROC) curve comparing shock index between emergency room (ER) dogs not in shock and ER dogs in shock (AUROC 0.92, sensitivity = 89, specificity = 95) to predict shock when shock index >1.0.

of the >2.5 mmol/L consistent with hyperlactatemia, while a low lactate (≤1.5 mmol/L) was used for the definition of ER dogs not deemed to be in shock in order to include dogs that were clearly not in shock from a biochemical perspective.[11]

While defining shock solely on a biochemical marker such as lactate is not conventional nor advised in a clinical setting, shock was defined in this manner for several reasons. The first, and most relevant, is that, if selection were based upon heart rate and presence of hypotension, there would be a clear selection for dogs with a high SI. By instead selecting a biochemical marker consistently linked with shock,[1,4,9,10,23] this study was attempting to avoid this bias. Importantly, assessment of HR and blood pressure are clinically relevant, and should be performed in a clinical setting. Secondly, classic objective parameters used to identify shock in a clinical setting vary drastically between breeds and even individuals within a breed. Setting an inclusion criteria for tachycardia (ie, 160/min) may exclude large breed dogs in shock while including small, anxious dogs that are not in shock. Clinical evaluation of shock status of an individual dog requires the synthesis of a number of parameters, but for the purpose of population analysis use of a biochemical marker of increased plasma lactate to define shock allowed for a more objective inclusion criteria.

Some limitations do exist secondary to defining our study population using lactate. Duplicate measurements of lactate were not conducted for each patient, so the possibility of measurement error exists, although the blood gas analyzer used in this study is frequently calibrated and these errors are considered unlikely. Lactate was not consistently measured from a standardized venipuncture site (eg, cephalic versus jugular vein), but one study revealed that, although lactate can differ statistically between venipuncture sites in the same animal, clinically significant differences did not exist between these samples.[24] Lactate values were also not measured in the control group, as normal values for lactate in dog have been established in numerous studies.[9,10]

Despite the statistical significance when comparing SI in this study, there was a degree of overlap between normal dogs and sick dogs with shock, with one normal dog having a shock index as high as 1.30. A similar finding was seen when comparing the ER group not in shock to the ER dogs with shock, with one stable dog, with an undiagnosed inflammatory disease process, that had an SI of 1.20. These findings could be explained by a number of factors, but the most likely explanation is the potential for a high heart rate yet normal blood pressure in healthy, stressed dogs. This effect in healthy dogs may be attributed to the "white coat effect" described in previous studies.[25,26]

A significant difference was also seen in age between groups. Age may play a factor in SBP, as studies in people have shown that SBP may vary with age.[27,28] Although this area has not been researched extensively in veterinary medicine, one study did show age and breed-related changes in SBP,[29] yet others have shown no significant difference in heterogeneous populations of dogs and cats.[19] Therefore, the significant difference in age within this study between the healthy and ill groups bears unknown significance, and may have had an effect on the comparison between the shock and healthy dogs. No significant difference existed between the age of the stable ER dogs and the shock dogs, which showed that, at least in this comparison, age played no statistical role.

Important considerations when evaluating the potential value of the SI in dogs in an ER setting are that (a) BP may not be routinely measured in every presenting patient, (b) noninvasive BP (NIBP) measurements are less reliable in dogs than in human patients, and (c) SBP may be difficult to determine with the Doppler technique.[30,31] In order to maximize accuracy of SBP measurements in dogs it is recommended to use the oscillometric technique and ensure appropriate cuff size and positioning of the dog.[19] Also of note is that NIBP measures are most inaccurate in the setting of severe hypotension, which will subsequently affect the accuracy of the calculated SI.[30]

Another limitation of this study, as previously stated, is the concept that SI is primarily used to define occult

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hypoperfusion in people, while the purpose of this study was to introduce SI to veterinary literature and demonstrate that it correctly predicts overt shock. Further evaluation would be required to demonstrate whether the SI is superior to HR and SBP alone in predicting shock in cases of occult hypoperfusion, as is seen in people. Another limitation was the overlap between the normal dogs and shock dogs, with one healthy dog having a shock index as high as 1.30. This demonstrates the necessity to evaluate the SI in the context of the patient, as these dogs may have had an increased SI from stress. Finally, using a biochemical marker such as plasma lactate as the inclusion criteria determining whether the dog was or was not in shock is unconventional in the context of an individual patient, where cardiovascular parameters, a subjective assessment, perfusion parameters and other clinical findings are used in patient assessment. However, in this study, an objective biochemical marker was used to define shock to remove the impact of HR and SBP as they are variables being assessed with SI.

In conclusion, this study introduced the SI to a veterinary population and demonstrated that SI may have use in identifying patients in shock in comparison to healthy dogs. Since most practices have the ability to measure SBP, the SI is easily determined. The SI may be particularly appealing to try to detect dogs in early shock, as is the case in people, where detection and treatment are more likely to be effective. This has not been demonstrated in our study, as we looked at dogs in overt shock, but it is an area of interest for future research concerning the SI. Serial monitoring of SI, as well as evaluation in a larger, more severely affected population may also provide more information on the true utility of the SI in the veterinary emergency or critical care settings.

Footnotes

[a] Dinamap 8300, Critikon, Tampa, FL.
[b] NOVA statprofile, NOVA Biomedical, Waltham, MA
[c] SAS 9.2, SAS Institute, Inc., Cary, NC.

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