Original research

**Equine Simplified Acute Physiology Score (EqSAPS): personalized medicine
for the equine emergency patient**

A.M.C. Barros¹, A.F.R. da Silva², M. Zibordi¹, J.D. Spagnolo³, R.R. Corrêa^{4b}, C.B. Belli⁵, M.M. de Camargo^{6a}

¹*Faculdade de Medicina Veterinária e Zootecnia, Universidade de São Paulo, Cidade Universitária, Av. Prof. Dr. Orlando Marques de Paiva, 87, São Paulo, SP, Brazil, 05508-010*

²*Faculdade de Zootecnia e Engenharia de Alimentos, Universidade de São Paulo, Pirassununga, SP, Brazil, 13635-900*

³*Faculdade de Medicina Veterinária e Zootecnia, Universidade de São Paulo, Serviço de Cirurgia do Hospital Veterinário de Grandes Animais, Cidade Universitária, Av. Prof. Dr. Orlando Marques de Paiva, 87, São Paulo, SP, Brazil, 05508-010*

⁴*Departamento de Clínica Cirúrgica Veterinária, Faculdade de Medicina Veterinária e Zootecnia, Av. Prof. Dr. Orlando Marques de Paiva, 87, Universidade de São Paulo, Cidade Universitária, SP, Brazil, 05508-010*

⁵*Departamento de Clínica Veterinária, Faculdade de Medicina Veterinária e Zootecnia, Cidade Universitária, Av. Prof. Dr. Orlando Marques de Paiva, 87, São Paulo, SP, Brazil, 05508-010*

⁶*Departamento de Imunologia, Instituto de Ciências Biomédicas, Universidade de São Paulo, Cidade Universitária, São Paulo, SP, Brazil, 05508-000*

^a*Present address: Instituto de Ciências Biomédicas, Universidade de São Paulo, Av. Prof. Lineu Prestes, 1730, São Paulo-SP, 05508-000..*

^b*Present address: Faculdade de Zootecnia e Engenharia de Alimentos, Centro de Apoio ao Ensino e à Pesquisa, Universidade de São Paulo, Pirassununga, SP, Brazil, 13635-900*

Corresponding author: Maristela Martins de Camargo. E-mail: mmcamar@usp.br

Short title

Equine Simplified Acute Physiology Score (EqSAPS)

Abstract

Scoring models are useful tools that guide the attending clinician in gauging the severity of disease evolution, and in evaluating the efficacy of treatment. There are few tools available with this purpose for the non-human patient, including horses. We aimed (i) to adapt the Simplified Acute Physiology Score 3 (**SAPS-3**) model for the equine species, reaching a margin of accuracy greater than 75% in the calculation of the probability of death, and (ii) to build a decision tree that helps the attending veterinarian in assessment of the clinical evolution of the equine patient. From an initial pool of 5 568 medical records from University-based Veterinary Hospitals, a final cohort of 1 000 was further mined manually for data extraction. A set of 19 variables were evaluated and tested by five data mining algorithms. The final scoring model, named **EqSAPS** for Equine Simplified Acute Physiology Score, reached 91.83% of correct estimates for probability of death within 24 hours upon hospitalization. The Area Under Receiver Operating Characteristic Curve (**AUROC**) for outcome “death” was 0.742, while for “survival” was 0.652. The final decision tree was able to refine prognosis of patients whose EqSAPS score suggested “death”. EqSAPS is an useful tool to gauge the severity of the clinical presentation of the equine patient.

Keywords: horse, emergency care, prognostic tool, machine-learning, decision tree.

Implications

EqSAPS is an additional tool for the horse veterinarian to assess their patients, gauging the severity of the clinical condition and guiding the relevant

measures. Using 19 variables that are easily obtained, this prognostic score, together with the accompanying decision tree, can be used both at hospital or field settings to predict the occurrence of death within 24 hours.

Introduction

Development of prognostic tools for evaluation of patients admitted to hospitals and Intensive Care Units (**ICUs**) is an important field of medical research, helping health professionals to gauge more reliably the likelihood of death and/or the evolution of a patient's clinical condition. From the data collected for these evaluations, it is possible to ascertain which factors contribute to the outcome of death, and refine the therapeutic procedures in a patient-oriented manner (Champion, 2002).

The Simplified Acute Physiology Score 3 (**SAPS-3**) is one of the prognostic scoring models most widely used in human medicine, characterized by its simplicity of assessment and prognostic precision (Capuzzo *et al.*, 2008). It is based on 20 variables assessed within the first hour upon patient's admission to the ICU, reflecting the patient's reliable clinical status (Junior *et al.*, 2010).

The information used in the prognostic tools can also serve other fields of research (Lavrac, 1999). Decision trees are examples of mining of these databases, and provide models that use specific patient information to assist in choosing the procedures to be performed next (Belazzi *et al.*, 2011; Song and Lu, 2015).

Optimal decision-making requires that physicians and veterinarians identify all possible intervention strategies that more accurately predict the likelihood of future events and balance the risks and benefits of each procedure to be performed (Cockroft, 2007). Therefore, our objective was to adapt the SAPS-3 scoring model

for the equine species with a margin of correctness in the calculation of probability of death above 75%, and to elaborate a decision tree that assists the horse specialist in the conduct of the high risk patients.

Material and methods

Data Source and Selection of Medical Records

Data was obtained retrospectively from medical records of two University-based Veterinary Hospitals. Records covered the period of January of 2003 to May of 2019. The original collection of 5 568 records corresponded to all equine patients admitted at those hospitals in the period. The records were further selected manually to exclude those with incomplete history/anamnesis and/or laboratorial exams. The remaining 1 000 records included animals of both sexes, several breeds, involved in different types of work, and ages ranging from newborns up to 30 years of age. This study was approved by the Institutional Ethics Committee.

Data collection and processing

A total of 19 variables, divided into three groups were collected from 1 000 medical records. All data values were manually obtained by the same person to avoid interpersonal discrepancies. All raw data is deposited for open access and use at https://osf.io/k287p/?view_only=35e16e7776e947cf920ef4fb7d712fa5.

Our choice of variables was based on the same variables used in Moreno *et al.* (2005), but adapted for the equine patient based on literature and our collective clinical and surgical expertise. Each variable was subdivided into numeric bins, nominal categories or listed as a binary variable. Each bin received points according to its contribution to the overall mortality risk assessment of the patient. The full list of variables, their subgroups and values, and their respective points is provided as

a downloadable user-friendly Supplementary Table S1. A second table, specifically for use with foals under 2 months of age is provided as Supplementary Table S2. Below, we summarize the processing steps for each variable.

Group I variables - demographics and medical history

Age. Animals were subdivided into bins: < 1, 1–3, 4–10, 11–15, 16–20, 20–25, 25–30, and > 30 years of age. More points were given to younger and older animals, to represent higher mortality risk subgroups.

Comorbidities. The presence of diagnosed neoplasms at admittance was encoded as a nominal variable (“no” for absence or the name of the neoplasm).

Outpatient medications. If the animal received veterinary assistance and/or medications before being admitted at the university hospital, this variable was encoded as a “yes”. In the absence of previous assistance/treatment, as a “no”.

Arrival delay. The number of hours (h) between the onset of chief complaint until admittance to the university hospital was divided into bins: < 24 h, 24–48 h or > 48 h.

Group II variables - disease presentation at admission

Referral reason. The reasons for referring an equine patient to the university hospital were classified into three bins: (I) scheduled exams, procedures, and elective surgery; (II) impossibility to initiate treatment immediately at onset of symptoms in the place of residence of the patient, and (III) impossibility to continue treatment (*i.e.*, worsening of symptoms despite treatment, lack of laboratory exams and/or hospital infrastructure).

141 *Chief complaint.* Affections were binned according to the main affected system and
142 different points were given to each subgroup of affections. The bins were: (I)
143 cardiovascular system,
144 (II) digestive system, (III) locomotor system, (IV) neurologic system, (V) skin and
145 adnexa, (VI) septicaemia, (VII) hepatic diseases, (VIII) respiratory system, (IX)
146 urinary system, (X) eyes, (XI) poisoning, (XII) reproductive system, (XIII) hernias,
147 (XIV) unspecific symptoms, and (XV) absence of symptoms.

148 *Surgical status.* If a surgery was performed, it was further classified as "scheduled"
149 or "emergency".

150 *Surgery location.* Different points were given according to the main system affected
151 by the surgery: (I) locomotor system, (II) respiratory system, (III) reproductive
152 system, (IV) digestive system, (V) ophthalmologic surgeries, and (VI)
153 herniorrhaphies.

154 *Acute infection at triage.* Suspicion of presence of acute infection at
155 admission at the hospital was marked as a "yes".

156

157 *Group III variables - physiological data at admission*

158 *Glasgow Coma Scale.* The mental state of the animals was binned as alert,
159 depressed, stupor, dementia, delirium, and coma.

160 *Vital signs and laboratory values.* Values obtained at admittance were binned
161 according to their contribution to mortality risk. Values were obtained for heart rate,
162 creatinine, total bilirubin, total leukocytes, rectal temperature, platelets, systolic
163 blood pressure, blood pH, and partial pressure of blood oxygen.

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165

Outcome and EqSAPS calculation

We registered the outcome 24h after admission as a binary variable ("survival" or "death"). Outcome was considered as the class, for classification purposes, and is also available for open access at https://osf.io/k287p/?view_only=35e16e7776e947cf920ef4fb7d712fa5.

Patients' EqSAPS scores were calculated as the sum of points assigned to variables from groups II, III, and I according to findings in each individual patient's history, clinical examination and laboratory exams (refer to Supplementary Tables S1 and S2 for parameters and values).

Probability of death calculation

The formulas used to calculate the probability of death in the first 24 h after admission to the hospital, taken from Moreno *et al.* (2005), are shown below:

$$\text{Logit} = 32.6659 + \ln (\text{EqSAPS score} + 20.5958) \times 7.3068 \quad [\text{equation 1}]$$

$$\text{Death probability} = \text{logit} / (1 + \text{logit}) \quad [\text{equation 2}]$$

Model fitting and evaluation

Five machine-learning classifiers, namely J48, REPTree, Random Tree, Random Forest, and Hoeffding Tree, were trained and tested on the dataset using 10-fold cross-validation. These machine-learning methods are capable of dealing with both numerical and nominal values.

Variables of importance

We calculated the information gain for each variable based on 10-fold cross-validation by the J48 classifier. The final decision tree considered only those variables with high information gain.

Methodology and metrics for evaluation of models

The reported results for AUROC and calibration correspond to averaged values over 10-fold cross-validation. Positive and negative predictive values, as well as precision and recall were calculated for all models. All analyses were done using Weka package [<https://www.cs.waikato.ac.nz/ml/weka/>]. Our findings are reported in accordance to the Guidelines for Developing and Reporting Machine Learning Predictive Models in Biomedical Research (Luo *et al.*, 2016).

Results

The EqSAPS is the total sum of points obtained after attributing points to 19 variables (Figure 1, and printer-friendly complete versions as Supplementary Tables S1 and S2).

To exemplify the use of EqSAPS:

Case 1. A five years-old horse (five points) referred with clinical signs of colic (13 points) in less than 24 hours upon onset (zero points). Heart rate was 40 bpm (three points) and rectal temperature was 36.8°C (2 points). The animal was depressed (two points), and emergency surgery (11 points) was indicated due to suspected displacement of the large colon. The animal was submitted to exploratory laparotomy (12 points).

215 *EqSAPS* score = 5 + 13 + 3 + 2 + 2 + 11 + 12 = 48

216 Logit = 32.6659 + ln [48 + 20.5958] x 7.3068 = -2.193882607 [equation 1]

217 Death probability = $e^{-2.193882607} / (1 + e^{-2.193882607}) = 0.10$ [equation 2]

218 Thus, a chance of death of 10%.

219

220 Case 2. Foal of 45 days of age (18 points, according to Supplementary Table
221 S2), sent to the veterinary hospital more than 48 hours after symptoms onset (seven
222 points), without previous treatment (five points). Referral was made due to the
223 impossibility of starting care on site, and worsening of the clinical condition (5 points).
224 The foal was alert (zero point), had diarrhoea (three points), changes in pulmonary
225 auscultation (12 points), and signs compatible with respiratory infection by
226 *Rhodococcus equi* (nine points). Total bilirubin was 1.18 mg/dL (0 point) and rectal
227 temperature was 38.3°C (zero point). Heart rate was 80 bpm (five points) and total
228 leukocytes corresponded to 8 100 cell/ μ L (0 point).

229 *EqSAPS* score = 18 + 7 + 5 + 5 + 3 + 12 + 9 + 5 = 64

230 Logit = 32.6659 + ln [64 + 20.5958] x 7.3068 = -0.682953121 [equation 1]

231

232 Probability of death = $e^{-0.682953121} / (1 + e^{-0.682953121}) = 0.33$ [equation 2]

233 Thus, a chance of death of 33%.

234 Case 3. One month-old foal (18 points) presenting clinical signs of colic (13
235 points), which has not received prior medical care (five points). Referral time of less
236 than 24 hours upon onset (zero point). The animal presented depressed mental
237 status (two points), total bilirubin of 4.06 mg/dL (four points), creatinine equal to 7.10
238 mg/dL (8 points), and total leukocytes 13 000 cells/ μ L (five points). Heart rate was

239 116 bpm (zero point) and rectal temperature was 38.4 °C. The foal was submitted to
240 an emergency surgical procedure (11 points) in the gastrointestinal tract (12 points).

241 *EqSAPS score* = 18 + 13 + 5 + 2 + 4 + 8 + 5 + 11 + 12 = 78

242 $\text{Logit} = 32.6659 + \ln [78 + 20.5958] \times 7.3068 = 0.420725378$ [equation 1]

243 $\text{Probability of death} = e^{0.420725378} / (1 + e^{0.420725378}) = 0.0068$ [equation 2]

244 Thus, 60% chance of death.

245 Upon score calculation, a value of EqSAPS below 50 is predictive of survival
246 for the next 24h. For those EqSAPS above 50, the veterinarian needs to refer to the
247 decision tree. The decision tree guides the veterinarian in the re-evaluation of five
248 variables (heart rate, rectal temperature, presence of acute infection, existence of
249 previous treatment, and age) in order to refine the prediction of those cases whose
250 EqSAPS is more than 50. In our dataset, the highest value of EqSAPS score was
251 100, and the lowest was zero. Figure 2 shows the decision tree elaborated after data
252 mining by the J48 algorithm.

253 Using the examples above, case 1 had EqSAPS = 48, a score value very
254 close to the cutoff of 50. Despite the apparent severity of the initial presentation, the
255 animal survived, as correctly predicted by EqSAPS.

256 Case 2 had an EqSAPS = 64. The decision tree leads the clinician to a series
257 of nodes: heart rate, presence of acute infection, time until referral, and age. As the
258 animal was under 22 years of age, the user is directed to yet another node that splits
259 the data according to the heart rate again. In this case, HR was less than 152 bpm,
260 indicative of survival. The animal survived the first day of hospitalization, as
261 corrected predicted.

The last example, case 3, had EqSAPS = 78. The decision tree guides the veterinarian through a series of nodes: heart rate, presence of acute infection, time until referral, heart rate, and rectal temperature. In this last node, a value above 37.4 °C indicates death, as predicted in this case.

The AUROC for death on the first day of hospitalization was 0.742, and for survival 0.652, indicating that correlation between evaluated parameters and outcome (death vs survival) was greater than what would be obtained at random. Figure 3 shows the AUROC for death (left panel) and survival (right panel). Table 1 represents the results of the evaluation metrics obtained using the J48 algorithm.

We tested other classifiers (REPTree, Random Tree, and Hoeffding Tree) with the same dataset, and their resulting AUROCs (for death) were 0.685, 0.609, and 0.483, respectively. The AUROCs obtained for survival prediction were 0.616, 0.564, and 0.494, respectively. The analysis of our database was also carried out using the Random Forest algorithm. The percentage of instances classified correctly was 92.70%, with AUROC for death of 0.825 and 0.683 for survival, when using the same parameters as the J48 classifier. These results are superior to those obtained with the J48. However, the Random Forest algorithm does not build decision trees, or any set of rules that could be used by the veterinarian during patients' triage.

Discussion

The first version of SAPS, developed for humans in 1984, has undergone several adaptations since then (Le Gall *et al.*, 1984; Le Gall *et al.* 1993; Moreno *et al.*, 2005). Once elaborated, any prognostic system needs to go through several stages of refinement, including user assessment in the field and multicentre studies, until being considered definitive. In this study, we present the first version of the

EqSAPS, a scoring system developed specifically for the equine patient. The evaluation metrics of the J48 algorithm for the EqSAPS showed satisfactory performance when compared to similar studies. Poole *et al* (2009) performed a validation of SAPS-3 with data from human patients from 147 ICUs in Italy, obtaining an AUROC of 0.855 for the prediction of death. Maccariello *et al.* (2010), applied SAPS-3 to patients with acute kidney injury in 11 hospitals in Brazil, obtaining an AUROC for death of 0.82.

Nevertheless, our study has limitations regarding certain metrics. We obtained Root Mean Square Error (**RMSE**) of 0.265 and kappa of 0.0501. These values are close to those pointed by Kumar and Sahoo (2012) as indicators of inadequate performance, the ideal being values of 0.15 for RMSE (the lower the value, the better the model accuracy) and kappa close to 1. Our RMSE suggests that EqSAPS does not have the desired precision yet. Although kappa greater than zero indicates an agreement greater than chance between predicted and observed instances, the value obtained in our work is far from moderate (0.40 to 0.49) or excellent (kappa = 1) (Kumar and Sahoo, 2012).

One way of improving a scoring system is to collect as many values of the proposed variables as possible, so that the model can predict the probability of death with the desired discrimination (López - Caler *et al.*, 2014). Based on this premise, EqSAPS can be improved. The incomplete registration of values for some of the proposed variables, the small number of foals, and few death occurrences, are likely the main cause of drop in performance observed in EqSAPS. In our cohort, 652 cases (out of 1,000) related to colic syndrome or locomotor injuries, an over-representation of these pathologies.

The Acute Patient Physiologic and Laboratory Evaluation (**APPLE**) model, designed to assess the risk of death in hospitalized dogs, has an AUROC of 0.93 for death prediction, but unlike our retrospective dataset, the APPLE model was a prospective study, with an active effort in obtaining all the proposed parameters, what greatly increase its robustness (Hayes *et al.*, 2010). Likewise, the model developed by Brewer and Koterba (1988) to score sepsis in foals, performed well with 93% sensitivity and 86% specificity. Medical records of 190 equine neonates were evaluated for data gathering. Although this study was retrospective, it focused on a very homogeneous group, only foals, resulting in a robust scoring system (Brewer and Koterba, 1988).

In the case of EqSAPS, we aimed at a broader scoring system that could be of use for the general equine clinician. Values attribution was different only for foals under two months of age (Supplementary Table 2). The AUROCs obtained for EqSAPS indicate a greater predictive capacity than chance. Thus, it is assumed that expanding the analyses to multicentre facilities, including a more diverse cohort of animals, and meticulous data acquisition, will refine the discrimination of EqSAPS. Hence the importance of anamnesis, and clinical and laboratory tests being systematically conducted in all animals, including healthy animals, in order to increase the variability of the database and refinement of the predictive model by the data mining algorithm.

Systolic blood pressure, blood pH, and partial pressure of blood oxygen were not identified by any of the used algorithms as important parameters for determining the probability of survival/death. This apparent contradiction can be explained by the fact that recording of those parameters was scarce in relation to the total universe of evaluated values. Given their scarcity, any algorithm is unlikely to calculate their

influence over survival/death. Future refinements of EqSAPS must warrant efficient recording of these variables, since they are likely to contribute with significant gain of information to the scoring system.

Maintaining a balance between the number of deaths and survivals will also be important for improvement of EqSAPS. In our study, the majority of the analysed medical records recorded survival of the animals by the end of the first 24 h of hospitalization (85.20%), with few records of death (6.70%). The machine-learning algorithm needs to analyse the same parameters in patients that survive and in those that die, in order to be able to determine precisely which of the variables are related to survival and/or death. If one of these groups is remarkably smaller in size, this will be reflected in the discrimination ability of the resulting model, as was the case with our study.

The objectives of this study were to adapt the SAPS-3 prognostic system for the equine species with a margin of accuracy greater than 75% in the prediction of death and to elaborate a decision tree to assist the clinical routine of the veterinarian. Both objectives were achieved, with 91.84% of the medical records classified correctly. The use of the J48 algorithm to mine 19 variables and identify those with greatest correlation with death was adequate, and EqSAPS results can be easily interpreted through a decision tree. Altogether, EqSAPS represents an important milestone tool to improve the gauging of equine medical emergencies in the era of precision medicine.

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Declaration of interest

The authors have declared no competing interests.

Ethics statement

The present study was approved by the Ethics Committee in the Use of Animals of the Faculdade de Medicina Veterinária e Zootecnia, Universidade de São Paulo (CEUAX 7696160818). Informed client consents were not acquired since this is a retrospective review of medical records.

Software and data repository resources

All data used in this study is available at https://osf.io/k287p/?view_only=35e16e7776e947cf920ef4fb7d712fa5

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469 **Table 1** *Evaluation metrics obtained for EqSAPS using the J48 algorithm.*

<i>Class</i>	True Positive rate	False Positive rate	Precision	Recall	<i>F-measure</i>	AUROC
Death day 1	0.045	0.013	0.214	0.045	0.074	0.742
Survival day 1	0.987	0.955	0.929	0.987	0.957	0.652
Evaluation metrics			Value			
Correctly classified instances			91.84 %			
Incorrectly classified instances			8.16 %			
Accuracy			0.910			
<i>Kappa</i>			0.050			
Mean Absolute Error (MAE)			0.121			
Root Mean Square Error (RMSE)			0.265			
Absolute Relative Error (ARE)			89.18 %			
Square root of the relative error (RRSE)			101.94 %			

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476 **Figure captions**

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478 **Figure 1** Partial view of EqSAPS computing sheet. The complete sheets attribute
479 points to 19 parameters that compose the EqSAPS scoring system. For
480 downloadable user-friendly sheets, refer to Supplementary Tables S1 and S2.

481

482 **Figure 2** Decision tree elaborated from data mining carried out by the J48 algorithm.
483 Abbreviation used for heart rate: HR.

484

485 **Figure 3** Representation of the area under receiver operating characteristics curve
486 (AUROC) for prediction of death (left panel) and survival (right panel) by EqSAPS for
487 the first 24 hours after admission at the veterinary hospita

Supplementary Table S1 -EqSAPS computing sheet for the horse older than two months of age.

<i>Age</i>	<i>Points</i>	<i>Urinary system</i>	<i>Points</i>	<i>Hernias</i>	<i>Points</i>	<i>Platelets (count/μL)</i>	<i>Points</i>
<1 or >30	18	Upper urinary tract	8	Inguinal	6	100,000-260,000	0
1-3	0	Lower urinary tract	3	Incisional	8	75,001-99,000	2
4-10	5	Urachus persistent	13	Umbilical	4	72,000-75,000	4
11-15	9	Ophthalmic disorders	1	Presence of acute infection		< 72,000	7
16-20	13	Intoxication	8	Community	9	Blood pH (young horse $\leq$ 2 years)	
21-30	15	Reproductive system		Nosocomial	11	Venous (7,333-7,410)	0
Comorbidity		Endometritis, placental retention, dystocia, perineum laceration	9	Mental status		Venous (< 7,333 or > 7,410)	3