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Scoring System for Multiple Organ Dysfunction in Adult Horses with Acute Surgical Gastrointestinal Disease

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Background: The prevalence of multiple organ dysfunction syndrome (MODS) in horses with acute surgical gastrointestinal (GI) disease is unknown. Currently, there are no validated criteria to confirm MODS in adult horses.

Objectives: To develop criteria for a MODS score for horses with acute surgical colic (MODS SGI) and evaluate the association with 6-month survival. To compare the MODS SGI score with a MODS score extrapolated from criteria used in people (MODS EQ).

Animals: Adult horses that required exploratory laparotomy (n = 62) for colic. Healthy adult horses undergoing elective surgical procedures (n = 12) established the reference range of some variables.

Methods: Prospectively, a MODS SGI score was developed based on organ-specific criteria established from a literature review, data collection, and clinical judgment. Data for scoring each horse were collected on Days 1 and 2 postoperatively. Horses were scored retrospectively using both scoring criteria. The prognostic performance of the MODS SGI score and its overall performance compared with the MODS EQ score were assessed with receiver operating characteristic (ROC) curve analysis.

Results: The MODS SGI score had excellent performance for predicting 6-month survival with an area under the ROC curve (AUC) of 0.95 (95% CI: 0.87–0.99). The AUC for the MODS SGI score was significantly higher than the MODS EQ (AUC: 0.76; 0.63–0.86).

Conclusions and Clinical Importance: The MODS SGI score predicts 6-month survival from discharge in horses with acute surgical colic. The MODS SGI score performed better than a score extrapolated from human scoring systems.

Key words: Colic; Equine; MODS; Systemic inflammatory response syndrome.

Critically ill human patients in medical or surgical intensive care units (ICU) often develop progressive organ dysfunction unrelated to the primary underlying condition, a clinical phenomenon coined multiple organ dysfunction syndrome (MODS).[1–3] The clinical importance of identifying sequential organ dysfunction is 2-fold. First, as multiple organs fail, the risk of death increases accordingly.[3] Second, since the introduction of MODS scoring systems for critically ill patients, overall MODS severity and mortality rates have declined.[4] This is likely due to earlier recognition of organ dysfunction[5] in combination with supportive and goal-directed interventions.[4,6]

Individual organ dysfunction has been reported in horses with acute gastrointestinal (GI) disease.[7–12] Criteria for MODS in horses were proposed recently based on MODS criteria used in people, referred to herein as MODS EQ, but remain unvalidated.[13] The MODS EQ provides a dichotomous outcome of organ dysfunction or no dysfunction and as such does not reflect a continuum of organ dysfunction. Multiple organ dysfunction syndrome is a dynamic process that can be reversible if detected and managed prior to end-stage disease. This highlights the need for an equine-specific scoring system that is validated for clinical use. Previous studies have applied clinical severity scores[14] or used unvalidated criteria to define multiple organ dysfunction[15] with the purpose of describing the equine population under investigation. To the authors' knowledge, no studies have critically evaluated the prognostic capability of a MODS scoring system or have compared existing proposed MODS scores in horses with acute surgical gastrointestinal disease.

The purpose of this study was to establish criteria of individual organ dysfunction reflecting a range of clinical severity for development of a MODS scoring system

Abbreviations:

AUC	area under the curve
cTnI	cardiac troponin I
GI	gastrointestinal
HRV	heart rate variability
MODS	multiple organ dysfunction syndrome
MODS EQ	a multiple organ dysfunction score extrapolated and modified for horses from human literature
MODS SGI	a multiple organ dysfunction score developed herein for horses with acute surgical gastrointestinal disease derived from equine literature and data from healthy horses
OR	odds ratio
ROC	receiver operating characteristic
SDNN	standard deviation of normal-to-normal intervals
SIRS	systemic inflammatory response syndrome
SVI	stroke volume index

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for use in horses with acute surgical GI disease (MODS SGI). The null hypotheses were that (1) the MODS SGI score developed herein would not be associated with 6-month nonsurvival, (2) the number of dysfunctional organs would not be associated with 6-month nonsurvival, (3) the MODS SGI score would not be associated with the systemic inflammatory response syndrome (SIRS), and (4) that the MODS SGI score would not be significantly different from the MODS EQ score at predicting nonsurvival.

Materials and Methods

Score Development

A literature search of electronic databases[a–c] was conducted in August 2011 and again in February 2014 to identify studies or reports of single organ dysfunction in horses with naturally occurring acute GI disease, primary organ failure, or organ dysfunction following general anesthesia. As an example, studies related to hepatic dysfunction were retrieved using a search string as follows: (horse or equine) AND (hepatic or liver) AND (colic or gastrointestinal). This was repeated for each individual organ or system of interest. In addition for each organ or system, anesthesia or peri-anesthetic was substituted for colic or gastrointestinal. Search results were manually narrowed down and relevant hits were added to a reference manager[d] database. The organ systems described most commonly included the cardiovascular,[e,9-11,16] renal,[6] hepatic,[8] GI,[17–19] musculoskeletal[20] (including laminitis),[21] respiratory,[22,23] and hemostatic[24–27] systems. Organ system-specific criteria were then chosen from this literature search and included serum cardiac troponin concentration (cTnI), stroke volume index (SVI), standard deviation of normal-to-normal intervals (SDNN), creatinine and serum bile acids (SBA) concentrations, nasogastric reflux volume, abdominal distension, serum creatine kinase activity (CK), Obel grade lameness, PaO_2/FiO_2 ratio, respiratory rate and effort, and platelet count or prothrombin time (PT). Neurologic system evaluation is routinely assessed in critically ill human patients, although it is infrequently performed or reported in horses with colic.[28] Therefore, in place of a neurologic score, attitude was assessed using a modified pain score (Appendix S1)[29] that incorporated both postural and social behaviors with the purpose of recording a general sense of demeanor (eg, lassitude, responsive, or agitated).

In order to develop a range of organ dysfunction criteria, the normal reference range from the hospital's clinical pathology laboratory, data extracted from the literature review, or data collected on 3 consecutive days from 12 healthy adult horses that underwent general anesthesia of at least 1-hour duration for an elective surgical procedure (control group) were used as aides for determining ranges for each organ criterion. Raw data were assessed for normality with visual inspection of a histogram and with the Shapiro-Wilk test. For normally distributed data, the mean and standard deviation were used to establish a 95% reference interval. When data were nonnormally distributed, the 95% reference interval was derived using a nonparametric approach. A range of values that corresponded to a score of 0–3 (0 = normal, 1 = mildly abnormal, 2 = moderately abnormal, 3 = severely abnormal) were assigned based on the reference interval for normal values and values reported in the literature associated with outcome when available for scores of 1–3. Ultimately, the collective clinical judgment of the 3 authors was also used to empirically propose cutoff designations, which followed a similar approach to what has been done for previous scoring systems in both human and veterinary medicine.[30,31] The criteria used to develop the individual scores for each organ system are presented in Table 1.

Score Assessment

The score developed herein was retrospectively evaluated in 62 horses that presented for colic and required exploratory laparotomy and were recovered from general anesthesia. The outcomes of interest were survival to 6 months and the presence of SIRS. Horses that were euthanized solely due to financial constraints were not included in the data set. Horses were categorized as having SIRS if they fulfilled criteria for SIRS on Day 1 or 2 postoperatively based on criteria used for adult horses in similar clinical studies and included 2 or more of the following: temperature ≥101.5°F or ≤98.5°F; heart rate ≥60 bpm; respiratory rate ≥30 bpm; white blood cell count ≥14,500 cells/μL or ≤4,500 cells/μL, and/or ≥10% bands.[12,13] Horses were scored based on data collected at Day 1 and Day 2 postoperatively with possible scores ranging from 0 to 24 for the MODS SGI score created herein (Table 2). The total number of organs affected (score ≥1) and the total number of organs with a score of 3 on each day were recorded for each horse. The Delta MODS SGI score was recorded (Day 1 MODS SGI score − Day 2 MODS SGI score) for each horse. Individual organ system scores were recorded for each horse on both days. A total score was given for the MODS EQ score, with a possible range of 0–7 for comparison to the MODS SGI score developed in this study (Appendix S2). Finally, a variation in the MODS SGI score, excluding the SDNN and SVI from the cardiovascular criteria, was recorded providing a MODS SGI score that did not require measurement of heart rate variability (HRV) or echocardiography.

Data Collection

This study was approved by the University's Clinical Research Committee. Horses undergoing general anesthesia for acute colic were enrolled over a 3-year period from November 2011 to August 2014. Owner consent was obtained prior to inclusion in the study. Horses that were not recovered from general anesthesia or that were euthanized solely due to financial constraints were excluded from the study. Clinical data were collected both prospectively and retrospectively from 62 horses with acute GI disease from Day 1 and Day 2 after surgery. All horses were then scored retrospectively on the 2 consecutive days. If 2 measurements were recorded in a 24-hour period, the measurement corresponding to the worst score was used for calculation of both MODS scores. For some organ systems, multiple criteria were proposed, in which case the variable that resulted in the highest score was applied. For organ systems with multiple criteria, only one score was given per organ system, meaning that scores for individual variables within an organ system were not tallied.

Data collection has been described previously for cardiovascular variables evaluated herein and included measuring indirect mean arterial blood pressure (MAP), continuous telemetry for HRV, and echocardiography for stroke volume index using the 4-chamber area-length as previously described. [e,16,32] For clinicopathologic data, blood was collected in serum, calcium EDTA and citrate tubes for measurement of serum bile acids, total bilirubin, and cTnI concentrations, GGT and CK activities, platelet count, and PT, respectively, at admission and on Day 1 and Day 2. Serum and citrated plasma were separated in a temperature-controlled centrifuge[f] at 3000-g for 30 minutes and stored at −80 °C for batch analysis at the University's clinical pathology laboratory,[gh] with the exception of cTnI which was analyzed with an ultrasensitive assay[i] at a regional hospital. Platelet counts were measured immediately on an automated analyzer[j] and were

Table 1. Rationale for MODS SGI score.

		Rationale for score criteria			
Organ system	Criteria	0	1	2	3
Cardiovascular	cTnI (ng/mL)[a]	Upper limit of laboratory RR	Literature review[8,9] (McConachie 2015)		
	Delta cTnI		Clinical judgment		
	SVI (mL/kg/min)[b]		Literature review[10] (McConachie 2015)		
	SDNN (ms)[c]		Literature review[13]		
Renal[d]	Creatinine (mg/dL)	Upper 95% CI from EC	Clinical judgment and literature review[6]		
	Delta creatinine		Clinical judgment		
Hepatic	Serum bile acids (μmol/L)	Upper limit of Laboratory RR	Clinical judgment and literature review[7]		
Respiratory	PaO_2/FiO_2	Lower limit of 95% CI from EC	Clinical judgment, reflects PaO_2 63–84 mmHg (unventilated horse breathing room air)	Literature review[20]	
	Respiratory rate/effort		Clinical judgment		
Musculoskeletal	CK U/L	Upper limit of laboratory RR	Clinical judgment and literature review[17]		
	Laminitis		Clinical judgment and literature review[18]		
Coagulation	Platelet count ($\times 10^3$ cells/μL)	Lower limit of laboratory RR	Clinical judgment and literature review[21–24]		
	Prothrombin time (sec)	Upper limit of laboratory RR	Clinical judgment and literature review[21]		
Gastrointestinal	Net nasogastric reflux (L/24 h)		Clinical judgment and literature review[14–16]		
	Abdominal distension		Clinical judgment		
Attitude	Modified behavior score[d]		Clinical judgment		

[a]Serum measured with ultrasensitive assay[e].

[b]4 chamber area length method measured with GE Vivid 7.

[c]5-min ECG recording with Kubios software; cTnI, cardiac troponin I; SVI, stroke volume index; SDNN, standard deviation of normal-to-normal intervals; CK, creatine kinase; RR, reference range; EC, elective cases.

[d]see Appendix S1. Where a score of 0 is unaffected, 1 or 2 is affected and 3 is failed.

confirmed with manual platelet estimates. Platelet counts accompanied by a morphology comment indicating platelet clumping were not used in the score. In addition, arterial blood was collected into a heparinized blood gas syringe from the transverse facial artery in standing, minimally restrained (halter, lead rope, and in few instances a rope twitch was used) horses breathing room air for immediate measurement of PaO_2 and heparinized blood creatinine concentration on a critical care analyzer[k] on Days 1 and 2 postoperatively. Attitude was scored prospectively by a single investigator (ELM) on Days 1 and 2 postoperatively (Appendix S1). Retrospective data collection included reviewing the record for respiratory rate and effort and the presence or absence of GI sounds at approximately 24 and 48 hours after recovering from surgery as well as measurement of net nasogastric reflux/24 hours on Day 1 and Day 2 postoperatively. Delta values for creatinine and cTnI concentrations were derived from the difference between admission and Day 1 values and from the difference between Day 1 and Day 2 values. Follow-up at 6 months for all horses that survived to discharge was obtained by phone or email communication with the referring veterinarian or client.

Statistical Analysis

The overall performance of MODS total scores, the total number of organs with a score ≥1, and the total number of organs with a score = 3 in predicting survival to discharge and 6-month survival was assessed using receiver operator characteristic (ROC) curve analysis. The optimal cut point to maximize sensitivity and specificity was selected based on the Youden index. Logistic regression was used to calculate the odds ratio at the optimal cut point. Multivariable logistic regression was used to investigate the association between scores for individual organs and 6-month survival. Variables were screened for multicollinearity using the variance inflation factor. Goodness-of-fit of the final model was evaluated using the Hosmer and Lemeshow test and −2 log likelihood fit statistics. The statistical significance of the difference between the areas under dependent ROC curves was assessed using the method described by DeLong et al.[33] A similar approach was used to assess the overall performance of MODS SGI in predicting SIRS. For all analyses, significance was set at $P < .05$. Statistical analyses were performed with commercially available software.[lm]

Results

Of the 62 horses with colic that required exploratory laparotomy that were evaluated in this study, 49 horses survived to 6 months and 13 horses were euthanized prior to 6 months. Ten horses were euthanized prior to hospital discharge due to reasons related to their primary complaint or development of severe complications [clinical evidence of multiple organ failure (n = 4), postoperative ileus (n = 2), adhesions diagnosed with a repeat laparotomy (n = 2), septic peritonitis and abdominal incision dehiscence (n = 1), and hemoabdomen (n = 1)]. Three horses were euthanized at their respective farms within 45 days [14 (10–45) days] of hospital discharge due to repeat colic episodes. Field

Table 2. Equine MODS SGI scoring system.

Organ or system	Criteria	Score criteria 0	1	2	3	Organ score
Cardiovascular	cTnI (ng/mL)	≤0.03	0.04–0.14	0.15–0.25	>0.25	
	Delta cTnI	Positive		Negative		
	SVI (mL/kg/min)	≥1.4	1.2–1.3	1.0–1.1	≤0.9	
	SDNN (ms)	>56	40–56	26.7–39	<26.7	
Renal[γ]	Creatinine (mg/dL)	≤1.9	1.9–2.2	2.3–3	>3	
	Delta creatinine	Positive or zero (when RV <1.9) or >1.9 prior to fluid therapy that is within RR within 24 hours	0 to ≤0.2 (when RV 1.9–2.2) or ≤−0.3 when RV <1.9	≤−0.1 (when RV ≥1.9); or 0 to ≤0.2 (when RV ≥2.3)	<−0.1 to or <−0.2 or ≤−0.3 when RV >2.3	
Hepatic	Serum bile acids (μmol/L)	≤15	16–30	30–50	>50	
Respiratory	PaO_2/FiO_2	>400	300–400	200–300	<200	
	Respiratory rate/effort	Normal	Abnormal (RR at rest >30 bpm, nostril flare, increased abdominal effort)			
Musculoskeletal	CK U/L	<343	343–643	644–943	>943	
	Laminitis	None	Obel grade I		Obel grade II or >	
Coagulation	Platelet count ($\times 10^3$ cells/μL)	≥104	88–103	55–88	<55	
	Prothrombin time (sec)	<11.6	11.6–13.6	13.7–14.3	>14.3	
Gastrointestinal	Net nasogastric reflux (L/24 hours)	<10	10–36	36–50	>50	
	Abdominal distension	No	Yes			
Attitude	Modified behavior score [7–27]	7–12	13–18	19–23	24–27	
					Total score	

necropsies were not performed, but all 3 of these horses had spontaneous nasogastric reflux and evidence of small intestinal distension upon palpation per rectum.

Surviving horses had the following diagnoses: strangulating lipoma (n = 14), right dorsal displacement (n = 10), ileal impaction (n = 6), left dorsal displacement (n = 5), cecal impaction (n = 3), large colon volvulus ≥360° with partial resection (n = 2), mesenteric volvulus (n = 2), enterolith (n = 2), large colon volvulus ≥360° with no resection (n = 1), epiploic foramen entrapment (n = 1), gastrosplenic ligament entrapment (n = 1), inguinal hernia with small intestinal incarceration (n = 1), and focal infarction of the left dorsal colon (n = 1). Two horses that survived beyond 6 months had repeat exploratory laparotomies within the hospitalization period, which revealed a right dorsal displacement in 1 horse and a nonfunctional jejunoileostomy which was subsequently revised.

Horses that were euthanized had the following diagnosis at initial exploratory laparotomy: strangulating lipoma (n = 5), large colon volvulus ≥360° (n = 4), epiploic foramen entrapment (n = 1), omental entrapment (n = 1), mesenteric volvulus (n = 1), and a right dorsal displacement with small intestinal distension (n = 1). Four horses in the nonsurviving group had repeat exploratory laparotomies within the hospitalization period at which time 2 horses were euthanized due to adhesion formation. The other 2 horses were recovered from surgery after decompression of the small intestine with no revision of the original jejunoileostomy and resection and oversewing of a necrotic section of the large colon, respectively.

The overall prognostic performance of the MODS SGI score for predicting survival to discharge on Day 1 (AUC = 0.92 ± 0.03) and on Day 2 (AUC = 0.92 ± 0.04) was similar to the performance of the score for predicting 6-month survival. Therefore, all subsequent analyses used the outcome parameter of 6-month survival. The overall prognostic performance of the MODS SGI score on Day 1 (AUC = 0.93 ± 0.04) was similar and not significantly different ($P = .90$) from that obtained on Day 2 (AUC = 0.94 ± 0.03) for predicting 6-month survival. Therefore, the average of the MODS SGI score from Days 1 and 2 was used in subsequent analyses. The MODS SGI score had an AUC of 0.95 ± 0.03 (95% CI: 0.87–0.99) for predicting 6-month survival. The optimal cut point was ≥8 with a resulting sensitivity of 92% (95% CI: 64–99%) and specificity of 88% (95% CI: 75–95%). The odds of 6-month nonsurvival were 86 times (95% CI: 9.4–785.2; $P = .0001$) higher for horses with a MODS SGI score ≥8. Horses with ≥4 organs given a score of ≥1 and with ≥2 organs that had a score 3 were significantly less likely to survive to 6 months (Table 3). Figure 1 demonstrates sensitivity and specificity for predicting survival to 6 months based on total MODS SGI score

Table 3. Association between 6-month survival with the total score and number of organs affected or failed when scored with the MODS SGI score.

MODS SGI scoring system	Cut point	OR	95% CI	*P*
Total MODS SGI score	≥8	86.0	9.4–785.2	.0001
No. of organs affected (score of ≥1)	≥4	21.9	2.0–240.2	.012
No. of organs failed (score = 3)	≥2	57.9	6.3–529.6	.0003

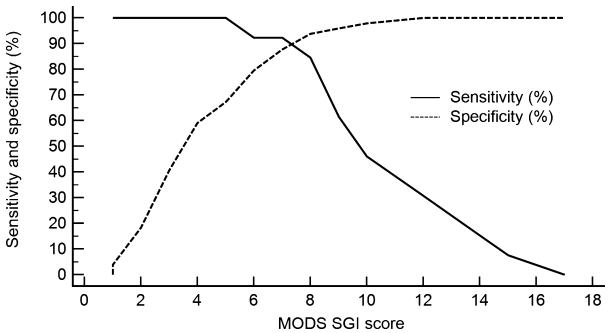

Fig 1. Sensitivity and specificity for the average MODS SGI score at various cut points. A score of ≥8 had a sensitivity of 92% and specificity of 88% for predicting survival to 6 months.

at various cut points. In addition, horses with a score of ≥8 were 10.7 times (95% CI: 2.7–43.1; $P = .0008$) more likely to have SIRS.

Prognostic performance of the MODS EQ score on Day 1 had an AUC of 0.61 ± 0.11 versus an AUC of 0.82 ± 0.07 on Day 2 ($P = .058$). The MODS EQ score was subsequently averaged, which resulted in fair test performance (AUC = 0.76 ± 0.08). The MODS SGI score performed significantly better for predicting 6-month survival compared with the average MODS EQ score ($P = .008$; Fig. 2). The most frequently affected organ systems were the cardiovascular system, coagulation, and musculoskeletal system for the MODS SGI score and the hepatic, GI, and coagulation system for the MODS EQ score. Finally, the MODS SGI score excluding SDNN and SVI from the cardiovascular criteria was evaluated and had similar performance to the total MODS SGI score for predicting 6-month survival [(AUC excluding SDNN and SVI: 0.92; 95% CI: 0.83–0.98) versus (AUC total MODS SGI: 0.95 ± 0.03; 95% CI: 0.87–0.99)].

Discussion

The MODS SGI score proposed herein had excellent test performance for predicting 6-month survival in horses that underwent exploratory laparotomy for acute GI disease. In addition, there was an association with the number of organs affected (score ≥1) and the number of organs that had a score of 3 with 6-month survival where horses with ≥4 organs affected and ≥2 organs with a score of 3 were significantly less likely to

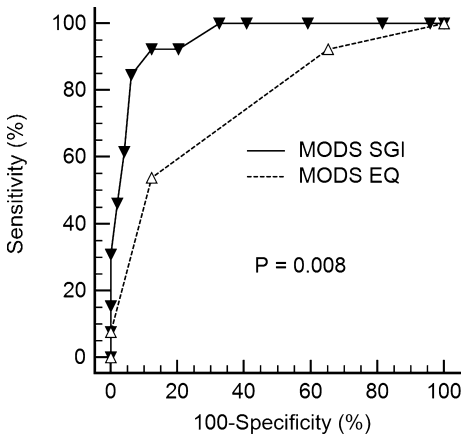

Fig 2. Receiver operator characteristic curve analysis comparing the ability of the MODS SGI score (AUC = 0.95; 95% CI: 0.87–0.99) and the MODS EQ score (AUC = 0.76; 95% CI: 0.63–0.86) to predict 6-month survival.

be alive at 6 months. Finally, the MODS SGI score developed herein was significantly better at predicting 6-month survival compared with the MODS EQ score (Fig. 2).

Performance of the MODS EQ score on Day 1 (AUC = 0.61 ± 0.11) versus Day 2 (0.82 ± 0.07) suggests that the performance of the MODS EQ score might vary from day to day. The impact that variation in the MODS EQ score might have could limit its usefulness as a system to score organ dysfunction on consecutive days. In addition, with the overall lower performance of the score when compared with the MODS SGI score, the MODS EQ score is less likely to be useful for describing a continuum of organ dysfunction in adult horses.

Several of the individual organ system criteria in the proposed MODS SGI score incorporated a choice of multiple possible criteria rather than limiting assessment to a single variable. As an example, the criteria for the cardiovascular system include the choice to score cTnI concentration, the delta cTnI concentration, SVI, or SDNN (a variable from HRV). Despite the possibility that multiple variables within an organ system might be abnormal, a single score was given for each organ system with the purpose of avoiding organ score inflation. In this study, when data were available for more than one modality for an individual organ, the criterion giving the highest possible score was used. It could be argued that tallying the scores for each variable within an organ system might be another reasonable approach. The rationale for providing multiple methods or criteria for scoring an individual organ system was centered on the principle that the organ could be scored even if all variables were not measured in an individual horse. Recognizing that HRV is not routinely performed in the clinic and echocardiography might not be available to all practitioners, the total score was evaluated when SDNN and SVI were excluded from the cardiovascular criteria and the performance of the MODS SGI score remained similar. It should be acknowledged that while the score could still prove useful without measuring the

SDNN or SVI, the single best criterion for each individual organ system was not established in this study; therefore, it is not possible to determine the performance of the score under all other conditions.

The range of the score from 0 to 24 is similar to the range established in human critical care and provides a continuum of organ dysfunction rather than a dichotomous outcome of failed or not failed.[3] In this study, a score of ≥8 had the best sensitivity (92%) and specificity (88%) for the outcome of survival to 6 months. The overall case fatality rate in the study herein was 13/62 (21%), concording well to scoring and case fatality rates in the human literature where a MODS or SOFA score between 6 and 10 corresponds with a case fatality rate between 7% and 26%.[3,34]

The frequency of organ systems affected (score ≥1) varied according to the scoring systems. The cardiovascular system was more frequently affected when scored by the MODS SGI score, whereas the hepatobiliary system was more frequently affected when scored by the MODS EQ score. The reason for this is directly related to the differences in the criteria used to define dysfunction for each organ system. For example, the use of bilirubin and GGT as criteria for dysfunction in the MODS EQ score likely results in overestimation of hepatobiliary dysfunction in horses with acute GI disease since bilirubin is increased in association with fasting[35] and GGT is often transiently increased in horses with large colon displacements.[36] In a small pilot study of horses with GI disease, there was no significant difference between the survivors and nonsurvivors with the magnitude of increase in bilirubin concentration; however, bile acids concentration was significantly higher in nonsurvivors.[8] However, the cardiovascular system was rarely abnormal when scored by the MODS EQ score which might be a factor of measuring a single parameter to evaluate a complex and dynamic system. Alternatively, the multiple criteria used to define dysfunction in the MODS SGI score might be too sensitive. This possibility seems unlikely owing to the fact that the MODS SGI score was significantly better at predicting outcome than the MODS EQ score.

While the MODS SGI score shows potential for objective assessment of critically ill horses following exploratory laparotomy, prospective studies are needed to test the performance of this score in horses at other institutions and with various acute disease etiologies. The MODS and SOFA scores were originally validated in human patients in the surgical ICU[3] or in a mixed group of medical and surgical ICU patients.[37] Since the initial inception of the multiple organ dysfunction scoring systems in those specific groups, both scores have been successfully validated in patients with a broad spectrum of medical and surgical conditions.[38–40]

The limitations in this study include (1) the lack of a specific definition for what constitutes organ dysfunction and failure in each evaluated organ system, (2) the determination of specific cutoff criteria based on data collected from horses at one center, and (3) the score criteria were in part limited to the opinion of 3 board-certified internal medicine clinicians. A fundamental problem with creating or "validating" a severity score of any kind is choosing the most appropriate outcome parameter. The inherent problem is that there is not a universally accepted pathognomonic histopathologic lesion or clinical correlate that corresponds with organ dysfunction or failure.[41–43] Instead, the definition of dysfunction and subsequent failure of an organ or system is a clinical entity that is to some extent opinion dependent. Therefore, a seemingly appropriate outcome measure for the total score is survival to a clinically relevant time point. Survival to 6 months was chosen as the primary outcome of interest, rather than survival to discharge, because in people with MODS, organ dysfunction is related not only to short-term mortality but also to long-term mortality, typically 28- or 90-day outcomes and out-of-hospital complications.[44] In the group of horses that survived to hospital discharge but were euthanized prior to 6 months, euthanasia occurred at Days 28, 39, and 68 postoperatively, which more closely reflects the 28-day and 90-day case fatality rates often used as outcomes in human critical care.[45,46]

The criteria proposed herein were developed primarily from the normal reference ranges of the clinical pathologic laboratory at this institution, information gathered through a literature review, and the clinical judgment of the authors. Empirically chosen criteria were used to establish the original SOFA score in humans and have been validated repeatedly.[30] In fact, the cardiovascular criteria used in the SOFA score performed more robustly than the MODS score.[47] Whenever available, data in the literature collected from other institutions were incorporated herein for determining the cutoffs for each score within an organ system.[8,20] Furthermore, the use of ROC analysis on the data set to define cut points for organ scores was deliberately avoided to prevent choosing criteria that were only associated with nonsurvival as the goal of the score was to reflect a range of organ dysfunction. Instead, the organ scores were proposed first and retrospectively applied to a clinical data set. Despite the excellent performance of the MODS SGI score in the horses that comprised this data set, it will be necessary to validate the MODS SGI score in multiple centers before it can be employed as a routine clinical assessment or as a definition for MODS in clinical research.

The proposal of this MODS SGI scoring system provides an initial step for studying and understanding the pathophysiology and incidence of multiple organ dysfunction in critically ill horses following exploratory laparotomy for acute colic. Prospective studies will be needed to establish the clinical utility of using this scoring system with the goal of determining if the MODS SGI score enhances a clinician's ability to recognize organ insufficiency at an earlier stage in these cases. This ultimately might provide objective criteria to monitor and measure responses to both well-established and novel therapies. At present, in horses with acute surgical GI disease, the MODS SGI score provides an objective method to measure disease severity and assess the risk of death. Finally, similarly to what was one of the original purposes of severity scoring systems in people, a reliable equine MODS score could be applied across

various equine critical care units facilitating the comparison of the performance of goal-directed therapy. This might assist equine clinicians in meeting the ultimate target of improving outcomes in horses with surgical gastrointestinal disease.

In conclusion, the MODS SGI score provides prognostic information in horses with acute surgical colic when scored postoperatively. A MODS SGI score of ≥8 provided good test sensitivity and specificity and was associated with the presence of SIRS. The MODS SGI score performed better at predicting 6-month survival compared with the MODS EQ score. Future studies will be necessary to test the validity of this scoring system prospectively on critically ill horses in different centers and with different disease etiologies.

Footnotes

[a] PubMed, Bethesda, MD
[b] Elseiver, BV, Amsterdam, the Netherlands
[c] Wiley, Hoboken, NJ
[d] EndNote X3, Thomson Reuters, Philadelphia, PA
[e] McConachie EL, Giguère S, Rapoport G, Brown S, Barton MH. Assessment of cardiovascular status in horses with naturally acquired ischemic intestinal disease. J Vet Cardiology. In review
[f] Sorvall Legend X1, Thermo Fisher Scientific Inc, Suwanee, GA
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[h] Trinity AMAX Destiny Coagulation Analyzer, Diamond Diagnostics
[i] ADVIA Centaur cTnI Ultra Assay, Immulite 1000 Siemens, Deerfield, IL
[j] Heska CBC-Diff, Heska Corp, Loveland, CO
[k] Nova Biomedical, Critical Care Xpress, Waltham, MA
[l] Sigmaplot 12.5 Systat Software, Inc, San Jose, CA
[m] MedCalc 14.8.1; Ostend, Belgium

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Appendix S1. Modified Attitude score[1].
Appendix S2. MODS EQ[1] criteria.