Horses with colic requiring surgical correction often have some degree of hemodynamic compromise owing to underlying pathophysiologic processes that promote the development of hypovolemia and dehydration and can be further complicated by endotoxemia. Preoperative hemodynamic resuscitation is warranted in such patients, where practical, to improve their cardiovascular reserves and reduce the risk of anesthetic complications. 

Hemoconcentration (ie, PCV and circulating TP concentration greater than the respective reference limits) is common in horses with colic and has been shown to be an indicator of the severity of cardiovascular compromise and prognosis. In several studies, horses with PCV > 45 to 50 L/L have had poorer outcomes than those with lower values, although the relationship between variables was not always linear. Hemoconcentration increases blood viscosity, although the exact impact of this factor on survival remains undefined. For horses with colic and hemodynamic compromise, the goals of preoperative IV fluid therapy should be to improve cardiovascular reserves and lower Hct.

A prospective, randomized study was conducted to compare the effects of preoperatively administered pentastarch (10% concentration in isotonic saline [0.9% NaCl] solution) and hypertonic saline (7.2% NaCl) solutions on PCV and circulating total protein (TP) concentration in horses with colic undergoing emergency exploratory laparotomy and to assess survival rates of horses that received each treatment.

**Methods**

**Animals**—100 horses with signs of abdominal pain and PCV ≥ 0.46 L/L.

**Procedures**—Horses received a 4 mL/kg (1.8 mL/lb) dose of pentastarch solution (n = 50) or hypertonic saline solution (50) over a 10- to 20-minute period before anesthetic induction. Blood samples were collected at the time of evaluation and ≤ 5 minutes after fluid resuscitation; changes in PCV and TP concentration were compared. Survival was evaluated by Kaplan-Meier and Cox proportional hazards analyses.

**Results**—Age, weight, sex, PCV, and heart rate on initial examination were similar between treatment groups. Hypertonic saline solution treatment resulted in a significantly greater reduction in PCV (median change, –0.14 L/L) than did pentastarch treatment (median change, –0.07 L/L). Reduction in TP concentration was also significantly greater after hypertonic saline solution treatment (median change, –16 g/L) than after pentastarch treatment (median change, –2 g/L). Long-term survival was not significantly different between groups.

**Conclusions and Clinical Relevance**—Despite a greater reduction in preanesthetic hemoconcentration following administration of hypertonic saline solution (4 mL/kg infusion, once), no difference in overall long-term survival was found between horses that received this treatment and those that received an equal volume of pentastarch solution. Findings suggested that, in a clinical setting, either of these fluids would be appropriate for preoperative fluid resuscitation in horses with colic. 

**ABBREVIATION**

TP Total protein
the weight of abdominal viscera pressing on the vena cava and aorta in a dorsally recumbent horse, potentially worsening its cardiovascular status. For this reason, small-volume fluid resuscitation strategies, including the use of hypertonic saline solution, colloid solutions, or both, have gained popularity; although these treatments require follow-up administration of isotonic (or even slightly hypotonic) fluids such as Hartmann’s solution.4

Much debate surrounds the subject of fluid therapy in regard to the type, volume, and administration rate of fluids required in various circumstances. At present, there is little evidence for the optimum fluid type, rate, and dose for preoperative resuscitation of horses with hypovolemic or endotoxemic shock, although there is a shift away from recipe-driven fluid therapy toward more individualized, goal-directed fluid therapy in human medicine.14–18

Whereas hypertonic saline has a profound but relatively transient effect on hemodynamic variables (with durations ranging from 30 to 120 minutes), colloids, particularly hydroxyethyl-substituted starches, typically have a more sustained effect.4,19,20 In theory, combinations of these 2 fluid types should be synergistic, although this has not always been found in practice.10,21,22

For horses with colic, the more severe the cardiovascular disturbances at evaluation, the poorer the prognosis. It is difficult to determine whether this relationship is because colic patients with more severe cardiovascular disturbances are affected by a greater degree of endotoxemia; because fluid resuscitation before, during, and after surgery is inadequate; or because of a combination of both of these factors. As an example, an univariable analysis in 1 study11 indicated that preoperative administration of hypertonic saline solution to horses with colic was associated with poorer short-term survival, compared with results of horses that did not receive this treatment (ie, those with preoperative PCV ≥ 46 L/L), but this association was nonsignificant in the multivariable analysis, and the authors speculated that this treatment was indicative of the severity of the colic and cardiovascular compromise, rather than being directly associated with outcome.

There are few reports describing the changes in PCV and circulating TP concentration in horses with colic when hypertonic saline or colloid solutions alone are administered before anesthesia or surgery. Schusser et al13 administered 3 different doses of a 10% pentastarch solution (5, 10 and 13 mL/kg [2.3, 4.5, and 6.8 mL/lb],) isotonic saline (0.9% NaCl) solution at 15 mL/kg, and hypertonic saline (7.5% NaCl) solution at 4 mL/kg, and hypertonic saline (7.5% NaCl) solution at 4 mL/kg (1.8 mL/lb), IV, to 6 clinically normal horses and reported changes in PCV and TP 10 minutes after the end of the infusion (performed over ≥ 20 minutes) and then over a longer follow-up period. In addition, they evaluated 8 horses with colitis and 16 horses with surgically managed colic that had an initial PCV ≥ 0.47 L/L and reported changes in PCV and circulating TP concentration at these same time points after infusion of a combination of pentastarch solution (10 mL/kg) and isotonic saline solution (10 mL/kg), followed by infusion of isotonic saline solution at a rate of 4 mL/kg/h.

The purpose of the study reported here was to compare the effects of equal doses of preoperatively administered pentastarch (10% concentration in isotonic saline solution) or hypertonic saline (7.2% NaCl) solution on PCV and circulating TP concentration in horses with colic (and PCV ≥ 0.46 L/L at preoperative evaluation) that were undergoing emergency exploratory laparotomy and to assess survival rates of horses that received each treatment. Our hypotheses were that horses receiving hypertonic saline solution would have greater reductions in PCV and TP concentration than horses receiving pentastarch solution treatment and that the survival rate of pentastarch-treated horses would be greater than that of horses treated with hypertonic saline solution.

Materials and Methods

One hundred horses that underwent emergency exploratory laparotomy for treatment of colic at the University of Liverpool Philip Leverhulme Equine Hospital between July 31, 2004, and August 17, 2008, were recruited for the study after obtaining approval of the university’s ethics committee and informed owner consent. Study inclusion criteria were signs of abdominal pain and PCV ≥ 0.46 L/L; this cutoff was chosen on the basis of findings from a previous study,10 which showed that horses with colic and PCV > 0.45 L/L typically had poorer prognoses than did horses with PCV in the normal range, resulting in a hospital policy to provide preoperative fluid resuscitation to horses with colic and PCV ≥ 0.46 L/L. Each horse was randomly selected (by use of sealed, shuffled envelopes) to receive either pentastarch (10%) or hypertonic saline (7.2% NaCl) solution at a dose of 4 mL/kg, administered over 10 to 20 minutes before surgery. The pentastarch treatment was a 200/0.5 solution (ie, hydroxyethyl starch with a molecular weight of 200 and molar substitution of 0.5) in isotonic saline solution. No other preoperative fluids were administered. Horses with signs of pain unresponsive to opioid analgesia (primarily morphine) that required sedation with an α2-adrenoceptor agonist or immediate anesthesia for reasons of safety were excluded from study enrollment. There were 50 horses initially assigned to each group; however, 1 horse assigned to the hypertonic saline solution group was excluded from all analyses because of an error (the PCV was only 0.45 L/L, and it was thus disqualified), so the final group size of horses treated with hypertonic saline solution was 49 horses. Treatment of the horses was unaffected except for the random assignment of fluid type administered before anesthetic induction.

Jugular venous blood samples were collected for determination of PCV and plasma TP concentration. Approximately 5 mL of blood was obtained by venipuncture and transferred into an EDTA-containing sample tube at the initial evaluation (ie, baseline); a second sample was collected ≤ 5 minutes after completion of preoperative fluid administration, via the aseptically placed IV catheter, before any sedative or anesthetic drugs were administered. Approximately 5 mL of blood was withdrawn through the catheter and discarded before the blood sample used for analysis was collected. The PCV was determined after centrifugation of duplicate blood samples in microhematocrit tubes at 1,300 × g for 3 minutes and evaluation with a micro-
hematocrit tube reader. Plasma TP was measured by use of a handheld refractometer, which was calibrated with distilled water prior to each use. Any horses that were euthanized while under anesthesia or that died in the immediate postanesthetic recovery period were excluded from the long-term survival analysis.

Changes (median and range) in PCV and plasma TP concentration were reported as actual measured values (L/L and g/L, respectively) and also in terms of mean ± SD calculated proportional changes (as percentages), to help illustrate the difference in magnitude of effects between treatments. Proportional change was calculated as (median change)/(median starting value) × 100. Where means approximated median values, the mean and SD percentage change were reported. In addition to the hematologic information, data collected for each horse included the following: breed, age, sex, body weight, heart rate at initial evaluation, and the surgically determined cause of the colic. Attempts were made to record the total volumes of IV fluids administered; however, the volumes were not exact but were based on multiples and proportions of 5-L bags of Hartmann’s solution.

Long-term survival for horses surviving past the immediate postanesthetic period was tracked for 4 years following enrollment of the final horse in the study, either by use of the hospital’s colic database or by telephone follow-up with the owner. Treatments given to horses by referring veterinarians and during anesthesia and surgery were outside the control of the study and could not be standardized. Some of these treatments were poorly reported by referring veterinarians or poorly documented at the time of referral.

Statistical analysis—All patient data were entered into an electronic spreadsheet prior to analysis. All continuous data (age, weight, heart rate, PCV, and plasma TP concentration) were assessed for normality (Anderson-Darling test) at several stages of data analysis: at initial evaluation and following fluid treatment for all 99 horses enrolled in the study and at initial evaluation and following fluid treatment for all horses included in the survival analysis. Changes in PCV and TP, after initial fluid administration, were also assessed for normality in both of these data sets. All values entered into the electronic spreadsheet, including outliers, were checked for errors of data entry, and any necessary corrections were made. No remaining outliers were excluded from analyses. Normally distributed data were then compared between groups by use of 2-sample t tests. Nonnormally distributed data were compared between groups with Mann Whitney U tests. Post hoc Bonferroni-like corrections were applied for multiple comparisons such that for each single comparison, final values of P < 0.005 were accepted as significant. Survival data were displayed graphically as a Kaplan-Meier plot and were modeled by means of a Cox proportional hazards model. Differences in rates of death were considered significant for resulting values of P < 0.05.

Results

There were no significant differences between treatment groups for age, body weight, sex, baseline heart rate, baseline PCV, or baseline plasma TP concentration (all obtained at the time of initial evaluation at the veterinary teaching hospital; Table 1). For each treatment group, the breed distribution and types of colic were similar. Breed type distribution for the pentastarch and hypertonic saline solution groups, respectively, was as follows: hot bloods (Thoroughbreds, Arabsians, and other sporting-type horses), 25 and 20; warmbloods, 8 and 9; Cobs and Cob crosses, 7 and 8; ponies, 10 and 11; and miniature horses, 0 and 1. Colic types for the pentastarch and hypertonic saline solution groups, respectively, were small intestinal (excluding epiploic foramen entrapment), 25 and 19; epiploic foramen entrapment, 3 and 2; dysautonomia, 1 and 2; ileal or large bowel impaction, 2 and 4; large colon torsion, 6 and 4; and other (including peritonitis, fecaliths, idiopathic focal eosinophilic enteritis, large bowel displacements, anterior enteritis, colitis, and adhesions), 13 and 18. Epiploic foramen entrapment cases were considered as a separate colic type because of known poorer prognosis, compared with other types. Horses in each treatment group received an approximate mean ± SD volume of 10 ± 5 L of Hartmann’s solution during surgery. There was no significant (P = 0.90) difference between groups for this variable.

After the initial preoperative fluid administration, PCV and plasma TP concentration were significantly (P ≤ 0.001 for both treatment groups) reduced, but more so following administration of hypertonic saline solution than pentastarch solution (P < 0.001 for both PCV and TP comparisons; Figure 1). The PCV decreased by a median of 0.13 L/L (range, 0.03 to 0.34 L/L decrease) in the hypertonic saline solution group, compared with a median reduction of 0.07 L/L in the pentastarch solution group (range, 0.19 L/L reduction to 0.08 L/L increase). Plasma TP concentration was reduced by a median of 16 g/L (range, 6 to 32 g/L decrease) in the hypertonic saline solution group, compared with a median decrease of 2 g/L (range, 17 g/L decrease to 8 g/L increase) in the pentastarch solution group. In terms of mean ± SD percentage changes, these were equivalent to a 25 ± 11% reduction in PCV follow-

Table 1—Data collected at initial evaluation (ie, baseline) of 99 horses undergoing emergency laparotomy for treatment of colic that received a single infusion (4 mL/kg [18 mL/lb], IV over 10 to 20 minutes) of pentastarch (n = 50) or hypertonic saline (7.2% NaCl) solution (49) before any sedative or anesthetic drugs were administered.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pentastarch solution</th>
<th>Hypertonic saline solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>14 ± 6</td>
<td>13 ± 6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>530 (312–680)</td>
<td>516 (130–698)</td>
</tr>
<tr>
<td>Baseline measurements Heart rate (beats/min)</td>
<td>78 ± 18</td>
<td>81 ± 20</td>
</tr>
<tr>
<td>PCV (L/L)</td>
<td>0.50 (0.46–0.70)</td>
<td>0.52 (0.46–0.70)</td>
</tr>
<tr>
<td>Plasma TP concentration (g/L)</td>
<td>72 (50–106)</td>
<td>72 (46–103)</td>
</tr>
</tbody>
</table>

Data are mean ± SD or median (range). No evaluated variables differed significantly between groups.
ing hypertonic saline solution treatment, compared with a 14 ± 10% reduction following pentastarch solution treatment and a 24 ± 1% reduction in plasma TP concentration following hypertonic saline solution versus a 4 ± 1% reduction following pentastarch solution.

Eleven horses in the pentastarch solution group and 17 horses in the hypertonic saline solution group did not survive anesthesia or the immediate recovery period. These horses were euthanized during surgery (n = 11 from the pentastarch group and 13 from the hypertonic saline solution group) because of poor prognosis or inoperable lesions, died without recovering from anesthesia (1 from the hypertonic saline solution group), or died during recovery (1 from the hypertonic saline solution group); all were excluded from survival analysis because preoperative treatment type was very unlikely to have acutely affected lesion severity. Of 71 horses eligible for survival analysis (39 and 32 in the pentastarch and hypertonic saline solution groups, respectively), data for 20 (10/group) were censored within the follow-up period of 4 years after enrollment of the final horse because of loss of contact with the owners. There were no statistically significant differences between treatment groups included in the survival analysis with respect to baseline values for demographic data, heart rate, PCV, and plasma TP concentration for these 71 horses (Table 2).

When this subset of 71 horses was assessed for response to preoperative fluid treatment with hypertonic saline or pentastarch solutions, similar results to those for all 99 horses were obtained. Median PCV and plasma TP concentration were reduced (P ≤ 0.001) for both groups after treatment, but the reductions were significantly (P < 0.001 for both PCV and TP comparisons) greater following hypertonic saline solution than pentastarch solution treatment (Figure 1). The PCV decreased by a median of 0.14 L/L (range, 0.03 to 0.3 L/L decrease) in the hypertonic saline solution group versus a median reduction of 0.07 L/L in the pentastarch solution group (range, 0.0 L/L to 0.18 L/L decrease). Plasma TP concentration was reduced by a median of 13.5 g/L (range, 6 to 32 g/L) in the hypertonic saline solution group, compared with a median decrease of 2 g/L (range, 17 g/L decrease to 8 g/L increase) in the pentastarch solution group. In terms of mean ± SD percentage changes, these were equivalent to a 25 ± 11% reduction in PCV following hypertonic saline solution and a 13 ± 10% reduction following pentastarch solution. The percentage reduction in TP equated to 22 ± 7% following hypertonic saline solution versus 4 ± 7% reduction following pentastarch solution.

Survival analysis indicated that there was no significant difference in long-term survival between treatment groups (Cox proportional hazards model, P = 0.6; Figure 2).

Table 2—Baseline data for 71 of the horses in Table 1 that were included in long-term survival analysis (up to 4 years after enrollment of the last horse in the study; n = 39 and 32 for the pentastarch and hypertonic saline solution groups, respectively).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pentastarch solution</th>
<th>Hypertonic saline solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>14 ± 6</td>
<td>13 ± 6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>522 (312–860)</td>
<td>509 (308–896)</td>
</tr>
<tr>
<td>Baseline measurements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>77 (18)</td>
<td>78 (21)</td>
</tr>
<tr>
<td>PCV (L/L)</td>
<td>0.50 (0.48–0.70)</td>
<td>0.51 (0.48–0.68)</td>
</tr>
<tr>
<td>Plasma TP concentration (g/L)</td>
<td>74 (50–98)</td>
<td>72 (46–103)</td>
</tr>
</tbody>
</table>

Data are mean ± SD or median (range). No evaluated variables differed significantly between groups.

Figure 1—Box-and-whisker plots showing percentage changes in PCV and plasma TP concentration in horses undergoing emergency laparotomy for colic and enrolled in a study to evaluate effects of preoperative administration of a pentastarch (10% in 0.9% NaCl; PS) or hypertonic saline (7.2% NaCl; HS) solution on hematologic variables and long-term survival rates (A and B). The pentastarch treatment was a 200/0.5 solution (ie, hydroxyethyl starch with a molecular weight of 200 and molar substitution of 0.5) in isotonic saline (0.9% NaCl) solution. Blood samples were obtained at the time of evaluation (ie, baseline) and ≤ 5 minutes after infusion of pentastarch or hypertonic saline solution (4 mL/kg [18 mL/b], IV, over 10 to 20 minutes), before any sedative or anesthetic drugs were administered. Boxes represent interquartile ranges, horizontal lines within boxes represent median values, and whiskers represent 95% of ranges; circles indicate the means. Outlier values are indicated (asterisks). A—Percentage changes from baseline values for demographic data, heart rate, PCV, and plasma TP concentration for these 71 horses included in long-term survival analysis (up to 4 years after enrollment of the last horse in the study; n = 39 and 32 for the pentastarch and hypertonic saline solution groups, respectively).
EQUINE pain, and distress.26 Accompanies the sympathetic response to hypovolemia, have not been reported.12,13 Values of whole blood viscosity for equine blood flow can also affect whole blood viscosity, and the optimal approximate 30% to 35%, but plasma protein concentration gen delivery is suggested to occur at a PCV of approximately 150%.29 However, Silverstein et al29 reported the maximum volume expansion effect of a similar concentration of hypertonic saline solution on PCV in dogs was coincident with the end of infusion, whereas maximal blood volume increases following colloid administration (6% dextran-70 solution or 6% hetastarch solution) were achieved 30 minutes after the end of the respective infusions, possibly reflecting the time required for redistribution of fluid into the intravascular compartment in response to the osmotic effect of these macromolecules that are, at least initially, maintained in the intravascular space.29

Regardless of the cause, hemoconcentration increases blood viscosity, which increases cardiac work and may compromise perfusion, particularly through the microvasculature.3,13 Optimal microvascular oxygen delivery is suggested to occur at a PCV of approximately 30% to 35%, but plasma protein concentration can also affect whole blood viscosity, and the optimal values of whole blood viscosity for equine blood flow have not been reported.12,13 Our results revealed that hypertonic (7.2% NaCl) saline solution had a significantly greater effect on PCV and plasma TP concentration than did an equivalent volume of a 10% solution of the colloid pentastarch. This is in agreement with previous studies10,23,27,28 in which results suggested a large intravascular volume—expansion effect of hypertonic saline solution in healthy horses and in horses experimentally challenged with endotoxin. Indeed, in dogs, the volume expansion effect of a similar concentration of hypertonic saline solution has been reported as approximately 3 times that attributable to the volume administered (ie, approx 300%).29 In that same study in dogs, Silverstein et al demonstrated maximum volume expansion effects of approximately 140% for a 6% dextran-70 solution and 150% for a 6% hetastarch solution.

The approximately 25% decrease in mean PCV of horses that received hypertonic saline solution in the present study appeared slightly greater than the decrease observed in plasma TP concentration (approx 24% for all horses that received the treatment and 22% for the 32 horses that survived surgery and the immediate postoperative period). A greater proportional decrease in PCV might be explained by the possibility of erythrocyte crenation (shrinkage, thus affecting PCV determination following centrifugation) in the presence of increased plasma tonicity. Equine erythrocytes contain high concentrations of potassium and, like human erythrocytes, are more susceptible to volume changes in the presence of plasma osmolality changes than those of dogs.29–31 Blood viscosity depends on RBC count, erythrocyte mechanical properties (deformability and aggregation), plasma viscosity, and temperature. Blood viscosity is also flow dependent (ie, as a non-Newtonian fluid, the viscosity of whole blood varies with shear rate).32 With this in mind, future studies are warranted to investigate the effects of possible crenation on blood viscosity, microcirculatory perfusion, and life span of equine erythrocytes.

That pentastarch solution treatment had a significantly smaller effect on PCV, compared with that of hypertonic saline solution, of horses in the present study was not altogether surprising, despite the fact that a 10% pentastarch solution was used. The effect was of the order of approximately half that observed following hypertonic saline solution treatment, supporting evidence that if hypertonic saline solution has a maximum volume expansion effect of approximately 300% (of that attributable to the delivered volume), then hydroxethylated starch products have a maximum volume expansion effect of nearer 150%.30 However, Silverstein et al29 reported the maximum effect of hypertonic saline solution on PCV in dogs was coincident with the end of infusion, whereas maximal blood volume increases following colloid administration (6% dextran-70 solution or 6% hetastarch solution) were achieved 30 minutes after the end of the respective infusions, possibly reflecting the time required for redistribution of fluid into the intravascular compartment in response to the osmotic effect of these macromolecules that are, at least initially, maintained in the intravascular space.29

Figure 2—Kaplan-Meier survival plot for the 71 horses in Figure 1 that were included in long-term survival analysis. The vertical dashes represent censored horses (ie, those that died, were euthanized, or were lost to follow-up). The shapes of the curves for the pentastarch (dotted line) and hypertonic saline solution (solid line) groups are similar and the curves cross each other multiple times, indicating a nonsignificant difference (Cox proportional hazards model, \( P = 0.6 \)).

Discussion
To the authors’ knowledge, this is the first study to document changes in PCV and plasma TP concentration immediately following preoperative administration of hypertonic saline or pentastarch solutions to horses undergoing emergency laparotomy for colic, without contemporaneous administration of sedative and anesthetic drugs that can influence results, particularly the PCV. Hemoconcentration is common in horses with colic and may be attributable to several causes. These include dehydration following reduced oral intake, loss of fluid through sweat and sequestration in the gastrointestinal lumen where it cannot be reabsorbed (a type of third-space fluid loss),13 fluid redistribution from the intravascular to the interstitial compartment resulting from an inflammatory response and the concomitant increased capillary permeability that follow hypovolemia (which compromises microvascular tissue oxygenation) or endotoxemia (which also triggers a systemic inflammatory response),29 and splenic contraction that accompanies the sympathetic response to hypovolemia, pain, and distress.26

Regardless of the cause, hemoconcentration increases blood viscosity, which increases cardiac work and may compromise perfusion, particularly through the microvasculature.3,13 Optimal microvascular oxygen delivery is suggested to occur at a PCV of approximately 30% to 35%, but plasma protein concentration can also affect whole blood viscosity, and the optimal values of whole blood viscosity for equine blood flow have not been reported.12,13 Our results revealed that hypertonic (7.2% NaCl) saline solution had a significantly greater effect on PCV and plasma TP concentration than did an equivalent volume of a 10% solution of the colloid pentastarch. This is in agreement with previous studies10,23,27,28 in which results suggested a large intravascular volume—expansion effect of hypertonic saline solution in healthy horses and in horses experimentally challenged with endotoxin. Indeed, in dogs, the volume expansion effect of a similar concentration of hypertonic saline solution has been reported as approximately 3 times that attributable to the volume administered (ie, approx 300%).29 In that same study in dogs, Silverstein et al demonstrated maximum volume expansion effects of approximately 140% for a 6% dextran-70 solution and 150% for a 6% hetastarch solution.

The approximately 25% decrease in mean PCV of horses that received hypertonic saline solution in the present study appeared slightly greater than the decrease observed in plasma TP concentration (approx 24% for all horses that received the treatment and 22% for the 32 horses that survived surgery and the immediate postoperative period). A greater proportional decrease in PCV might be explained by the possibility of erythrocyte crenation (shrinkage, thus affecting PCV determination following centrifugation) in the presence of increased plasma tonicity. Equine erythrocytes contain high concentrations of potassium and, like human erythrocytes, are more susceptible to volume changes in the presence of plasma osmolality changes than those of dogs.29–31 Blood viscosity depends on RBC count, erythrocyte mechanical properties (deformability and aggregation), plasma viscosity, and temperature. Blood viscosity is also flow dependent (ie, as a non-Newtonian fluid, the viscosity of whole blood varies with shear rate).32 With this in mind, future studies are warranted to investigate the effects of possible crenation on blood viscosity, microcirculatory perfusion, and life span of equine erythrocytes.

That pentastarch solution treatment had a significantly smaller effect on PCV, compared with that of hypertonic saline solution, of horses in the present study was not altogether surprising, despite the fact that a 10% pentastarch solution was used. The effect was of the order of approximately half that observed following hypertonic saline solution treatment, supporting evidence that if hypertonic saline solution has a maximum volume expansion effect of approximately 300% (of that attributable to the delivered volume), then hydroxethylated starch products have a maximum volume expansion effect of nearer 150%.30 However, Silverstein et al29 reported the maximum effect of hypertonic saline solution on PCV in dogs was coincident with the end of infusion, whereas maximal blood volume increases following colloid administration (6% dextran-70 solution or 6% hetastarch solution) were achieved 30 minutes after the end of the respective infusions, possibly reflecting the time required for redistribution of fluid into the intravascular compartment in response to the osmotic effect of these macromolecules that are, at least initially, maintained in the intravascular space.29

Figure 2—Kaplan-Meier survival plot for the 71 horses in Figure 1 that were included in long-term survival analysis. The vertical dashes represent censored horses (ie, those that died, were euthanized, or were lost to follow-up). The shapes of the curves for the pentastarch (dotted line) and hypertonic saline solution (solid line) groups are similar and the curves cross each other multiple times, indicating a nonsignificant difference (Cox proportional hazards model, \( P = 0.6 \)).
With this in mind, our study may not have detected the maximum hematologic effects of the pentastarch solution because blood samples were collected ≤ 5 minutes after the end of fluid infusion. This hyperoncotic 10% pentastarch solution might also be expected to produce a greater dilutional effect than an equivalent volume of an isooncotic solution of the larger hetastarch molecules.33 Ideally, further blood samples should have been analyzed 30 minutes after fluid treatment; however, such results would have been confounded by the effects of general anesthesia and intraoperative crystalloid fluid administration. As this was a clinical study, anesthesia and surgery could not be delayed to enable sample collection at the optimal time to assess peak effects of pentastarch solution.

That plasma TP concentration changes were small following pentastarch solution treatment in the present study can be reconciled by the fact that synthetic colloids interfere with refractometric readings of plasma TP.34 Pentastarch produces refractometric readings of 75 g/L, such that hemodilution with this colloid would produce a tendency for refractometric readings to trend toward this value.35 Considering the median baseline TP concentration was approximately 72 g/L for both treatment groups in our study, it is not surprising that there was minimal change in the readings; any hemodilution of plasma proteins could have been partially offset by effects of pentastarch solution on the refractometer readings. Laboratory measurements of plasma proteins and determination of plasma colloidal oncotic pressure would have been more useful measures to evaluate effects on circulating TP concentration.

All horses with colic in this study were referred to our hospital, and we could not control for treatments already given to the horses prior to arrival (although none included IV fluid therapy), and some treatments (particularly α1-adrenoceptor agonists) could have affected PCV. Nevertheless, because preoperative fluid treatment was randomized, any confounding effects of such treatments would be expected to have been randomly distributed between treatment groups. Similarly, any effects of breed on PCV should have been negated by randomization of treatment.

Intraoperative cardiovascular support was also provided for all horses in both groups, in the form of further fluid therapy together with dobutamine, a vasopressor (phenylephrine or norepinephrine), or both. The goals of intraoperative support were to avoid hypotension, defined as mean arterial blood pressure < 70 mm Hg, and to avoid profound hypoxemia, defined as an arterial partial pressure of oxygen < 60 mm Hg; these goals were the same for all horses in both groups. It was not possible, in the present study, to quantify the relative requirements for these fluids and drugs between groups because exact volumes and doses were not always accurately recorded. However, Hallowell and Corley36 and Schusser et al37 demonstrated that hypertonic (7.5% NaCl) saline solution had a more transient effect on hemodynamics than did a 10% pentastarch solution, so it might be expected that further intraoperative cardiovascular support could be needed following preoperative hypertonic saline solution administration.

Although preoperative fluid therapy to increase cardiovascular reserves should help reduce the risks of anesthesia-related complications in the short term, continued cardiovascular support during and after surgery is expected to influence both short- and long-term outcomes.3 The influence of preoperative fluid therapy alone on long-term survival is somewhat difficult to establish because cardiovascular support does not cease during anesthesia and surgery. Results of 1 study38 indicated that long-term survival of human patients was statistically more strongly related (as determined by survival analysis and Cox modelling) to the development of complications 30 days after surgery than to any preoperative or intraoperative factors, and this warrants further investigation in horses.

Ongoing debate surrounds the different types of fluids administered to patients perioperatively, with recent studies13,14,34–40 focusing on their interactions with the endothelial glyocalyx and their immunomodulatory effects. Colloids, such as hydroxyethyl starches, and hypertonic saline can have useful effects during a systemic inflammatory response, although the timing of administration may be important.38,41 It should be noted that concern including nephrotoxicity of hydroxyethylated starch solutions at high doses in human patients have affected availability of such products in the United Kingdom in recent years, and restrictions and warnings regarding their use in humans have been issued by regulatory agencies in the United Kingdom and the United States.13,15,23,62–65 The role of albumin, as an alternative colloid, remains to be further investigated in horses.31

Nephrotoxicity is also a concern when crystalloid fluids containing high chloride concentrations are used, perhaps even as a vehicle for colloids, in large volumes; hyperchloremia causes renal vasoconstriction52 and has been shown to reduce gastric mucosal perfusion.25 Other concerns surround the use of fluids that contain race-mic lactate, including Hartmann’s solution, because the β-lactate isomer has proapoptotic effects.25 Furthermore, bolus fluid administration for resuscitation may itself have potentially detrimental effects.34 Further research is needed to answer the many questions regarding fluid therapy in veterinary medicine, as in human medicine.55

References


Citation: JAVMA, Vol 246, No. 10, May 15, 2015 Scientific Reports 1109


From this month’s AJVR

Ultrasonographic detection of early atrophy of the intrinsic laryngeal muscles of horses
Heather J. Chalmers et al

Objective—to describe the ultrasonographic changes in the cricoarytenoideus dorsalis (CAD) and cricoarytenoideus lateralis (CAL) muscles of horses before and at various times during the 32 weeks after unilateral neurectomy of the right recurrent laryngeal nerve.

Animals—28 healthy Standardbreds.

Procedures—For each horse, the appearance of the CAD and CAL muscles on the right (neurectomized) and left (control) sides was serially monitored ultrasonographically by percutaneous (CAD and CAL) and transesophageal (CAD) approaches. The ultrasonographic images were assessed to determine the mean pixel intensity, muscle thickness, and appearance grade, and comparisons were made between the muscles of the neurectomized and control sides.

Results—The muscle appearance grade and mean pixel intensity for the CAL and CAD muscles on the neurectomized side were significantly increased by 2 and 4 weeks, respectively, after the neurectomy. The transesophageal approach enhanced the ultrasonographic visibility of the CAD muscle and allowed us to detect a significant decrease in the thickness of the CAD muscle on the neurectomized side over time, compared with thickness of the CAD muscle on the control side.

Conclusions and Clinical Relevance—Results suggested ultrasonography can be used to successfully assess the CAL and CAD muscles of horses. A qualitative grading scheme was sufficient for successful detection and monitoring of muscle atrophy and reduced the need for image standardization. The transesophageal approach described for assessment of the CAD muscle warrants further investigation. (Am J Vet Res 2015;76:426–436).

See the midmonth issues of JAVMA for the expanded table of contents for the AJVR or log on to avmajournals.avma.org for access to all the abstracts.