Comparison of electroacupuncture and butorphanol on respiratory and cardiovascular effects and rectal pain threshold after controlled rectal distention in mares

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Objective—To compare effects of electroacupuncture and butorphanol on hemodynamic and respiratory variables and rectal analgesia in mares after controlled rectal distention.

Animals—8 healthy mares.

Procedure—Each horse received saline (0.9% NaCl) solution (0.01 mL/kg, IV; control treatment), butorphanol tartrate (0.1 mg/kg, IV), or 2 hours of electroacupuncture (EA) at acupoints Bladder 21, 25, and 27 on both sides of the vertebral column, Bai hui, and Stomach 36 (right side only). Order of treatments in each mare was randomized. At least 7 days elapsed between treatments. A balloon was inserted in the rectum of each mare, and controlled distention of the balloon (pressures of ≤ 220 mm Hg) was used to measure nociceptive rectal pain threshold. Rectal temperature and cardiovascular and respiratory variables were measured before (baseline) and 5, 15, 30, 60, 90, and 120 minutes after onset of each treatment.

Results—Butorphanol produced greater increases in rectal pain threshold, compared with EA (mean ± SD, 214 ± 24 vs 174 ± 35 mm Hg of balloon pressure). Electroacupuncture produced minimal cardiovascular and respiratory changes. Although clinically not important, butorphanol produced moderate significant increases in heart and respiratory rates, arterial blood pressure, and rectal temperature and decreases in arterial oxygen tension. Arterial pH, carbon dioxide tension, bicarbonate concentrations, base excess, Hct, and concentration of total solids were not significantly different from baseline values after EA, butorphanol, and control treatments.

Conclusions and Clinical Relevance—Electroacupuncture and butorphanol (0.1 mg/kg, IV) may provide useful rectal analgesia in horses. (*Am J Vet Res* 2003;64:137–144)

In another study[1] conducted by our laboratory group, we documented that acupuncture and **electroacupuncture (EA)** can provide cutaneous analgesia in horses without adverse cardiovascular and respiratory effects and that EA is more effective than acupuncture for activating the spinal cord to release β-endorphins into the CSF of horses. There is considerable evidence that acupuncture[2-4] and EA[5,6] provide relief of visceral pain in horses with colic. However, acceptance that acupuncture and EA produce visceral analgesia in horses has been hindered by inconclusive knowledge of its mechanism of action and inadequate controlled clinical studies. To our knowledge, the effects of EA on visceral analgesia in horses have not been evaluated.

In other studies,[7-9] investigators have used balloons that were surgically inserted into the cecum of ponies and horses to study the effects of visceral pain through ramped increases in distention of the cecum and subsequent pain relief achieved by systemic administration of analgesic medication. In 1 study,[10] investigators introduced a balloon into the duodenum via a gastric cannula in horses and produced signs of discomfort, which was not prevented by bilateral EA at the Guan-yuan-shu (similar to Bladder 21) acupoints. Contrary to those studies, we have developed a technique for barostatically controlled rectal distention in horses to deliver noninvasive and quantifiable stimulus for evaluation of relief of pain of rectal origin in conscious adult horses.[11]

Butorphanol is a popular and potent synthetic morphine derivative with narcotic agonist and antagonist properties that produces minimal gastrointestinal and behavioral effects in horses.[12,13] A dose of 0.2 mg of butorphanol/kg, IV, has been used in studies[12-14] to produce good to excellent visceral analgesia with moderate apprehension, blunt the hemodynamic response to experimentally induced colic pain, and cause ataxia in some horses. In another study,[15] a single injection of butorphanol (0.1 mg/kg, IV) caused brief ataxia, decreased borborygmi and defecation of horses, and resulted in an elimination half-life of approximately 45 minutes, volume of distribution of 1.25 L/kg, and total systemic clearance of 21.0 mL/kg/min.

Our hypothesis was that EA produces rectal analgesia similar to that achieved by administration of butorphanol (0.1 mg/kg, IV) but without producing cardiovascular stimulation. For this reason, the objective of the study reported here was to evaluate and compare rectal nociception and hemodynamic and respiratory effects of resting conscious horses treated by use of EA and butorphanol.

Materials and Methods

Animals—Eight healthy mares (4 Standardbreds, 4 Thoroughbreds) that were between 5 and 20 years of age and weighed between 400 and 550 kg were included in the study.

Received June 24, 2002.
Accepted October 9, 2002.
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Supported in part by Equine Research Funds of The Ohio State University College of Veterinary Medicine and the Morris Animal Foundation.
Presented in part at the 28th International Congress on Veterinary Acupuncture, Kauai, Hawaii, August, 2002.
The authors acknowledge Dr. Jean Powers for assistance with statistical analyses and Jennifer Gadawski, Cheri Edwards, and Chad Andrews for technical assistance.
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Ten or more weeks before the study, the left carotid artery of each horse was surgically elevated to a subcutaneous position. Other surgery was not performed. The study protocol and experimental design were approved by The Ohio State University Laboratory Animal Care and Use Committee.

Preparation of horses—Each horse was restrained in a standing position in a stock in a quiet, climate-controlled room from 9AM to 3PM. Horses were considered healthy on the basis of results of physical examination, WBC count, and ECG. They were allowed to eat hay during the experiment. Prior to each experiment, hair over the area of the left carotid artery and right jugular furrow was clipped, and the skin was prepared for aseptic placement of catheters. The skin and subcutaneous tissues in these areas were infiltrated with a 2% solution of lidocaine hydrochloride.[a] An 18-gauge, 30-cm catheter[b] was inserted into the left carotid artery for measurement of **systemic arterial blood pressure (ABP)** and collection of arterial blood samples. Proper positioning of the arterial catheter was confirmed at the time of insertion and prior to blood pressure determinations by observing characteristic pressure waveforms on an oscilloscope. Arterial pressure waveforms were obtained by use of a calibrated strain-gauge transducer.[c] The point of the shoulder was used to determine the zero pressure point. Mean blood pressure in the carotid artery was obtained by electronic integration of the signal obtained from the blood pressure transducer. Surface ECG leads were placed for continual monitoring of a base-apex ECG, and a thermometer probe[d] was positioned approximately 20 cm into the rectum for determination of deep rectal temperature. A 30-cm-long piece of 240-polyethylene tubing was inserted into the right external jugular vein for administration of butorphanol tartrate[e] or saline (0.9% NaCl) solution.[f]

Acupuncture points and stimulation—Acupuncture points **Bladder (BL)** 21, 25, and 27 on both sides of the vertebral column, Bai hui, and **Stomach (ST)** 36 (only on the right side of the body) were selected on the basis of our experiences when treating horses with visceral pain **(Fig 1)**. These points were located on the basis of anatomic landmarks described by the International Veterinary Acupuncture Society.[16] In addition, each acupoint was verified by measuring the skin resistance, using the search electrode of an electroacupuncture stimulator[g] that displayed identified points on the basis of decreased electrical resistance and provided an audible tone as well as an electrical deflection on the meter. Hair over each acupuncture site was clipped, and the skin was prepared for aseptic placement of sterile, disposable, single-use acupuncture needles (0.3 × 100 mm).[h] The needle sleeve guide was used to tap the needle tip through the skin. The guide was then removed, and approximately 9 cm of the needle was advanced vertically into the soft tissues at BL 21, 25, and 27, and Bai hui. The acupuncture needle at ST 36 was inserted at an angle of approximately 30º from the vertical and advanced distally for a distance of approximately 5 cm. A nose twitch was used to restrain some horses for placement of the needle into ST 36. We were careful to avoid bending the needles. Passage of a straight needle was confirmed by palpation of minimal resistance to needle rotation during insertion and removal. Needles were left in position during the entire 2-hour experiment.

For EA, the acupuncture needles were connected to 4 bipolar leads (each lead was connected to 1 positive and 1 negative probe) that were connected to an EA stimulator.[i] Needles were stimulated by use of 4 V, 1 milliamp, and 0.1 milliseconds in bipolar square-wave patterns with alternating frequencies of 2 and 100 Hz at 1.5 seconds and pulse width of 50 and 150 microseconds at 100 and 2 Hz, respectively; thus, the current flowed across the vertebral column between the opposite leads and between Bai hui and ST 36 throughout the 2-hour experiment. The current was adjusted as needed to produce small vibrations in the stimulated muscles and only minimal changes in ABP.

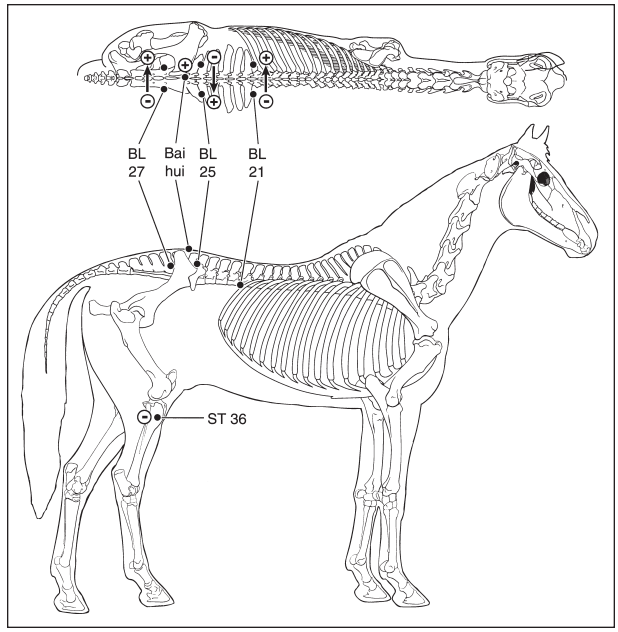

Figure 1—Dorsal (top) and lateral (bottom) views of the equine skeleton indicating location of acupuncture points Bladder (BL) 21, 25, and 27; Bai hui; and Stomach (ST) 36. In this study, we stimulated BL 21, 25, and 27 bilaterally; Bai hui; and ST 36 on the right side of each horse.

Drug administration—A 1% solution of butorphanol tartrate[e] (experiment 2) or saline solution[f] (control treatment, experiment 3) was administered via the right jugular vein catheter. Stock solutions of butorphanol (10 mg/mL) and saline solutions were prepared so that the volume (0.01 mL/kg) of saline solution administered IV was similar to the volume of the calculated dose of butorphanol (0.1 mg/kg). Butorphanol and saline solution were dispensed from coded and masked bottles; the code was not revealed until statistical analysis of data was completed.

Acupuncture needles were not inserted into horses that received saline solution (control treatment). The procedures used for control horses were identical to those for EA and butorphanol treatments. Horses were randomly assigned to the order in which they would receive control, EA, and butorphanol treatments. Horses were allowed at least 7 days between subsequent treatments.

Experimental protocol—After placement of catheters, a rectal thermometer probe, and ECG leads, each horse was allowed to stand undisturbed for at least 60 minutes prior to initiation of treatment. Baseline measurements were obtained immediately before (time 0) administration of butorphanol or saline solution and after insertion of acupuncture needles at BL 21, 25, and 27 on both sides of the vertebral column, Bai hui, and ST 36 (right side only) of horses immediately prior to EA treatment. Scores of nociceptive rectal pain threshold were determined before (baseline) and 30, 60, 90, and 120 minutes after onset of administration of saline solution, butorphanol, or EA treatment. Hemodynamic and respiratory variables were measured prior to rectal distention and were recorded before (baseline) and 5, 15, 30, 60, 90, and 120 minutes after onset ofadministration of saline solution, butorphanol, or EA treatment. Time 0 for recording data for all treatments was at least 60 minutes after IV insertion of catheters.

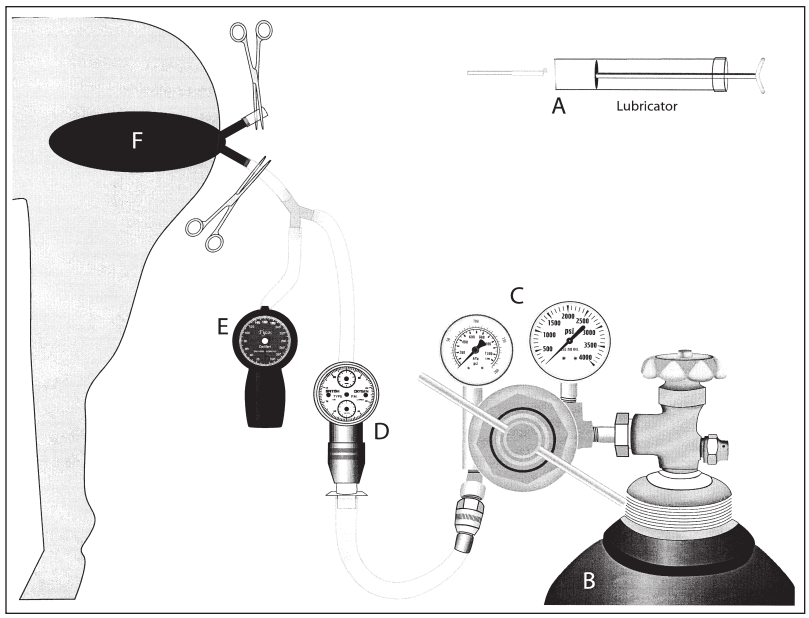

Figure 2—Illustration of the equipment used for rectal distention (balloon technique) of an adult horse. Components of the system were as follows: A, lubricator; B, cylinder of nitrogen gas; C, pressure manometer; D, respirometer; E, sphygmomanometer; and F, modified balloon inserted in the rectum of a horse.

Assessment of hemodynamic and respiratory effects—Heart rate (HR) and rhythm were determined from the ECG. **Respiratory rate (RR)** was determined for each horse by counting thoracic and abdominal excursions during a 1-minute period. Arterial blood samples (2 mL/sample) were collected anaerobically into heparin-coated plastic syringes by use of the catheter inserted in the carotid artery. Syringes were capped and placed in an iced water bath, and samples were analyzed within 20 minutes after collection for determination of Pa_{O_2}, Pa_{CO_2}, and pHa by use of a microprocessor blood gas analyzer.[j] All blood gas values for each horse were adjusted on the basis of rectal temperature, which was measured immediately before collection of each blood sample. The Hct and concentration of **total solids (TS)** were measured in arterial blood samples by use of a microhematocrit method[k] and refractometer,[l] respectively. Standard bicarbonate concentration and **base excess (BE)** were calculated. Electrocardiograms and systolic, diastolic, and mean ABP were monitored on the oscilloscope and recorded simultaneously by use of a photographic recorder[m] at a rate of 10 mm/s at each sample collection time.

Assessment of analgesia—Nociceptive visceral pain threshold of horses was measured by use of a novel test that consisted of manually inserting a modified deflated rubber balloon[n] into the rectum of each horse to a depth of approximately 40 cm. Prior to insertion of each balloon, fecal material was manually removed from the rectum, and approximately 400 mL of lubricant[o] was infused into the rectum by use of a dose syringe[p] with 75-cm tubing. We observed each horse's **avoidance response (AR)** to a ramped increase in balloon inflation (approx 100 mL/s), which was achieved by use of compressed nitrogen from a cylinder[q] **(Fig 2)**. Balloon pressure at the beginning of inflation was 0 mm Hg. After initial delivery of approximately 1,200 mL of nitrogen, the pressure was gradually increased. At final distention of the rectum, the anus was distended by the inflated balloon. Balloon volume at maximal inflation pressure was recorded. Balloon pressure and volume were continuously monitored by use of a sphygmomanometer[r] and respirometer,[s] respectively. Baseline balloon pressure was measured for each horse in each experiment and was defined as the balloon pressure that produced an AR. The cutoff pressure to prevent rectal damage was 220 mm Hg, which was determined in preliminary experiments.[11] A nociceptive index was calculated as the percentage of maximal rectal distention pressure (ie, **percentage of maximal effect [%ME]**) and used to assess the degree of rectal analgesia of each mare for each treatment. The following equation was used:

$$\%ME = \left(\frac{\text{posttreatment balloon pressure} - \text{baseline balloon pressure}}{\text{cutoff balloon pressure} - \text{baseline balloon pressure}} \right) \times 100$$

The balloon was carefully inspected after each measurement for evidence of sanguineous material or blood smears. To avoid observer-dependent subjective differences, the same investigator (RTS) performed scoring of threshold responses in all horses.

Analgesia was defined as an increase in response threshold (ie, increase in balloon pressure or volume), compared with baseline values, to application of noxious rectal distention. Rectal pressure was applied until an AR was noticed; AR included increased restlessness, a change of weight bearing from 1 hind limb to the other, abrupt movement of the tail, limbs, or torso, turning the neck and head toward the stimulus coincident with application of the stimulus, groaning, or increased ABP. To prevent damage to the rectum, the balloon was immediately deflated when the inflation pressure reached 220 mm Hg, regardless of whether an AR was observed.[11]

Catheters and needles were removed after completion of each treatment, and horses walked back to their stalls. All horses were examined for evidence of infection at needle and catheter puncture sites 24 hours after insertion of acupuncture needles and catheters. Horses were also monitored for evidence of neurologic deficits and changes in behavior (ie, posture, locomotor activity, and response to human interactions such as greetings, petting, and feeding).

Statistical analysis—Mean ± SD values for nociceptive visceral pain threshold (ie, balloon pressure and volume)

and hemodynamic and respiratory variables were determined for each treatment. Mean values were compared among and within treatments over time by use of a 2-way ANOVA with repeated measures on 2 factors (time and treatment) and a Dunnett *t*-test.[i] Values of $P < 0.05$ were considered significant.

Results

All of the horses tolerated the procedures well. Rectal distention did not result in visible rectal damage. None of the horses developed neurologic deficits or infections at needle or catheter puncture sites or sites for insertion of acupuncture needles by 24 hours after treatments. All horses had typical behavior 24 hours after treatments.

Baseline mean ± SD pressure threshold for rectal distention in the 8 horses before administration of saline solution, EA treatment, and administration of butorphanol was 142 ± 19, 130 ± 24, and 152 ± 21 mm Hg, respectively. Pressure threshold significantly increased to 174 ± 35 and 214 ± 24 mm Hg at 30 minutes after beginning treatment with EA and butorphanol, respectively (**Fig 3**). Mean pressure threshold significantly increased 30 to 120 minutes after onset of EA and butorphanol treatments, compared with values for the saline solution. Mean pressure threshold did not change significantly throughout the 2-hour experiments in horses when administered saline solution.

Horses tolerated significantly greater balloon volumes in the rectum during EA and butorphanol treatments, compared with baseline values or saline treatment (**Fig 4**). Horses administered saline solution did not tolerate rectal distention (as measured by balloon volume) above baseline values throughout the 2-hour period. Mean balloon volume of horses at maximal balloon inflation was 5,814 ± 1,349; 4,831 ± 1,112; and 5,908 ± 1,226 mL before and 6,088 ± 1,484; 5,653 ± 1,122; and 7,790 ± 1,284 mL at 30 minutes after saline, EA, and butorphanol treatments, respectively.

Mean %ME of the 8 horses 30 minutes after onset of saline, EA, and butorphanol treatment was 7.5 ± 13.2, 51.4 ± 30.4, and 94.6 ± 36.2%, respectively. Mean %ME was also significantly increased 30 to 120 minutes after onset of EA and butorphanol treatment, compared with values for the saline treatment (**Fig 5**).

Cardiovascular and respiratory variables, including pHa, Pa_{O_2}, Pa_{CO_2}, bicarbonate concentration, BE, Hct, and TS concentration, were not significantly changed after EA and saline treatment. Significant changes of mean values for cardiovascular and respiratory variables of horses after butorphanol treatment were detected (**Table 1**). When mean values for cardiovascular and respiratory variables of the 8 horses at baseline and 30 minutes after butorphanol treatment were compared, there were significant increases in HR (34 ± 5 to 39 ± 5 beats/min), RR (20 ± 7 to 21 ± 7 breaths/min), rectal temperature (37.6 ± 0.1 to 37.9 ± 0.2°C), systolic ABP (154 ± 15 to 174 ± 19 mm Hg), mean ABP (121 ± 15 to 139 ± 12 mm Hg), and diastolic ABP (97 ± 10 to 111 ± 11 mm Hg) and a significant decrease in Pa_{O_2} (105.3 ± 6.3 to 95.5 ± 5.5 mm Hg). Arterial pH, Pa_{CO_2}, bicarbonate concentration,

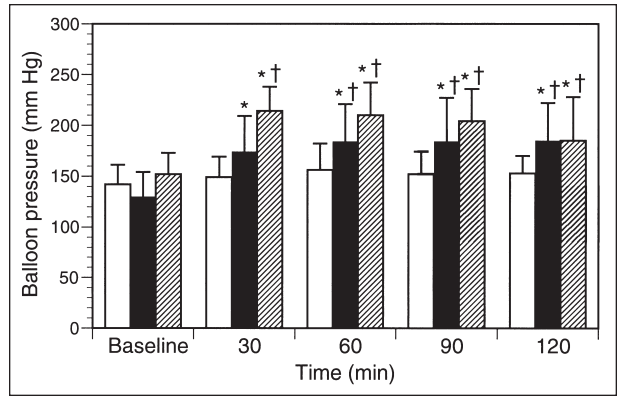

Figure 3—Mean ± SD balloon pressure for 8 horses before (time 0) and 30, 60, 90, and 120 minutes after onset of administration of saline (0.9% NaCl) solution (control treatment; white bars), electroacupuncture (black bars), or butorphanol (striped bars). Maximum inflation pressure applied to the rectum was 220 mm Hg. Pressure was increased to determine visceral analgesia, which was defined as the pressure required to induce an avoidance response. *Within a treatment, value is significantly ($P < 0.05$) different from baseline (time 0) value. †Within a time period, value is significantly ($P < 0.05$) different from value for control treatment.

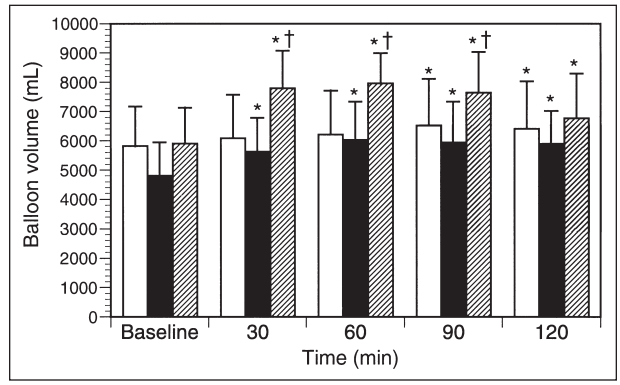

Figure 4—Mean ± SD balloon volume for 8 horses before (time 0) and 30, 60, 90, and 120 minutes after onset of administration of saline solution (control treatment; white bars), electroacupuncture (black bars), or butorphanol (striped bars). *See* Figure 3 for key.

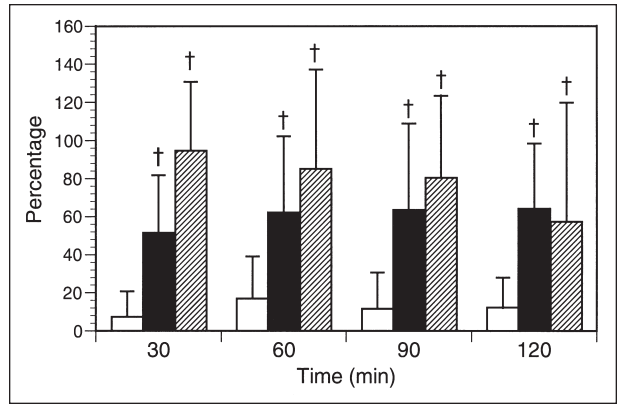

Figure 5—Mean ± SD nociceptive index to assess degree of rectal analgesia by means of percentage maximal rectal distention pressure (maximal pressure, 220 mm Hg) for 8 horses determined 30, 60, 90, and 120 minutes after onset of administration of saline solution (control treatment; white bars), electroacupuncture (black bars), or butorphanol (striped bars). *See* Figure 3 for key.

Table 1—Mean ± SD values for respiratory and cardiovascular variables determined for 8 healthy adult horses before (time 0) and after onset of administration of saline (0.9% NaCl) solution, electroacupuncture (EA), or butorphanol

	Time (min)						
Variable	**0**	**5**	**15**	**30**	**60**	**90**	**120**
Respiratory rate (breaths/min)							
Saline	17 ± 6	18 ± 6	16 ± 6	18 ± 6	19 ± 6	21 ± 7	20 ± 6
EA	24 ± 6	25 ± 7	24 ± 6	24 ± 6	22 ± 6	24 ± 8	23 ± 6
Butorphanol	20 ± 7	22 ± 6	23 ± 7	21 ± 7	25 ± 4*	30 ± 5*†	33 ± 8*†
Arterial oxygen tension (mmHg)							
Saline	104 ± 10	105 ± 7	108 ± 10	110 ± 11	107 ± 6	104 ± 10	104 ± 7
EA	101 ± 4	100 ± 5	102 ± 7	103 ± 8	105 ± 5	107 ± 6	105 ± 5
Butorphanol	105 ± 6	98 ± 8	93 ± 8*†	94 ± 7*†	95 ± 5*†	96 ± 7*†	102 ± 7
Rectal temperature (°C)							
Saline	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1
EA	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.1	37.6 ± 0.2	37.6 ± 0.1	37.6 ± 0.1
Butorphanol	37.6 ± 0.1	37.8 ± 0.2	37.9 ± 0.2*†	37.9 ± 0.2*†	38.0 ± 0.3*†	37.9 ± 0.2*†	38.0 ± 0.1*†
Heart rate (beats/min)							
Saline	36 ± 6	36 ± 6	37 ± 7	37 ± 7	36 ± 9	35 ± 5	35 ± 5
EA	34 ± 4	36 ± 5	36 ± 4	36 ± 4	34 ± 4	34 ± 3	35 ± 5
Butorphanol	34 ± 5	48 ± 5*†	39 ± 5*†	39 ± 6*†	39 ± 5*†	40 ± 5*†	40 ± 5*†
Systolic arterial pressure (mm Hg)							
Saline	154 ± 20	155 ± 20	155 ± 20	155 ± 20	155 ± 20	155 ± 19	156 ± 19
EA	151 ± 6	150 ± 8	150 ± 9	150 ± 7	150 ± 9	146 ± 8	148 ± 12
Butorphanol	154 ± 15	178 ± 18*†	174 ± 10*†	174 ± 19*†	167 ± 18*†	167 ± 19*†	165 ± 16*†
Diastolic arterial pressure (mm Hg)							
Saline	101 ± 17	102 ± 16	100 ± 15	97 ± 19	101 ± 17	105 ± 13	102 ± 16
EA	100 ± 6	98 ± 5	97 ± 8	98 ± 5	97 ± 9	94 ± 7	94 ± 6
Butorphanol	97 ± 10	114 ± 6*	112 ± 8*	111 ± 11*	112 ± 13*	109 ± 13*	101 ± 13*
Mean arterial pressure (mm Hg)							
Saline	122 ± 20	123 ± 19	122 ± 20	122 ± 20	122 ± 18	124 ± 16	124 ± 18
EA	121 ± 5	122 ± 9	122 ± 8	122 ± 8	119 ± 9	117 ± 8	118 ± 10
Butorphanol	121 ± 15	140 ± 11*	142 ± 10*	139 ± 12*	136 ± 17*	133 ± 14*	128 ± 14*

*Within a treatment, value is significantly ($P < 0.05$) different from baseline (time 0) value. †Within a time period, value is significantly ($P < 0.05$) different from value for saline solution (control treatment).

BE, Hct, and TS concentration did not significantly change from baseline values after butorphanol administration.

Discussion

Data reported here support the effectiveness and reproducibility of our technique for barometrically controlled rectal distention as a reliable method for inducing rectal pain in adult horses. In addition, use of rectal distention by a balloon was able to reveal greater increases of rectal pain threshold and nociceptive index (%ME) in horses treated with butorphanol (0.1 mg/kg, IV) than EA at acupoints BL 21, 25, and 27 on both sides of the vertebral column, Bai hui, and ST 36 (right side only).

Use of a slow (100 mL/s) increase in rectal distention was used to induce subtle increases in stimulation and make the pain threshold more obvious. We speculate that EA and butorphanol altered the threshold response to rectal distention as a result of their analgesic properties rather than through reduction of smooth muscle tone. We do not know whether horses reacted after or at the exact moment at which the mechanical stimulus became painful. We controlled for the wide range of pain tolerance or perception among horses by comparing the pain threshold values before and after saline (control), EA, and butorphanol treatments in the same horse at each time period. Application of EA or IV administration of butorphanol, compared with IV administration of saline solution, allowed greater rectal distention on the basis of pressure and volume required to induce an AR, thereby increasing the nociceptive index (%ME) for measurement of rectal analgesia. During the control treatment, horses had balloon volumes larger than baseline at 90 and 120 minutes, implying an increase in tolerance to the balloon pressure over time. We cannot explain the overlap of the balloon volumes after saline and EA treatments.

Classic signs of abdominal pain in horses, such as pawing, stretching, looking at the flank, and kicking at the abdomen, were not observed during the short-term (< 1 minute) balloon inflation, indicating that the degree and duration of abdominal discomfort could be considered mild to moderate. However, we observed a consistent moderate increase (by 20%) of HR, RR, and ABP during periods when the balloon was inflated and a return of HR, RR, and ABP to preinflation values immediately after balloon deflation. Cardiovascular changes at maximum balloon inflation were less obvious in horses when they were treated with butorphanol, compared with when they were treated with EA, because of the already increased HR, RR, and ABP induced by butorphanol.

Analysis of our data did not permit an unequivocal definition of the mechanism of rectal analgesia induced by EA. It is probable that visceral analgesia was produced by opioid and nonopioid endocrine mecha-

nisms.[17,18] We inserted the acupuncture needles to almost full depth (9 cm) bilaterally at acupoints BL 21, 25, and 27; Bai hui; and ST 36 of horses to stimulate the cutaneous branches and underlying tissues supplied by the eighteenth thoracic (BL 21), fifth lumbar (BL 25), first sacral (BL 27) spinal nerves, lumbosacral nerve (Bai hui), and femoral nerve (ST 36), respectively. Because mechanical stimuli were applied between S1 and L1, which is also where acupuncture points BL 21, 25, and 27 and ST 36 were stimulated, it is possible that the electrical current stimulated A-β fibers and inhibited small C fibers, thereby interrupting (or gating) pain input into the CNS.[19] When treated with EA, horses were calm and cooperative and had HR, RR, and ABP within reference ranges throughout the 2-hour EA treatment, which is inconsistent with the possibility that EA-induced rectal analgesia was induced by stress.

Because inserting a needle anywhere in the body may involve some degree of afferent sensory stimulation, it is necessary to define the sites of tissue and neural elements involved and the frequency, intensity, or waveform modulation of stimulation. Location, intensity, and frequency of electrical stimulation are important determinants of analgesic efficacy in humans and domestic animals. Several studies[20-22] have documented that electrical stimulation with differing frequencies at traditional acupuncture sites induces the release of various opioid peptides (β-endorphin, met-enkephalin, dynorphin) in the spinal cord of rats, which results in antinociceptive effects for several methods of pain measurement (tail-flick latency to radiant heat, hot-plate, hot water, paw pressure) via various opioid receptors.

We stimulated acupoints BL 21, 25, and 27 on both sides of the spinal column, Bai hui, and ST 36 (right side only) and produced analgesia of the rectum. Chinese investigators have used acupuncture to stimulate a single acupoint such as Guan-yuan-shu (similar to BL 21),[2] Er-ding (similar to Tripple Heater 21), or Jian-wei (similar to Large Intestine 18)[6]; hemoacupuncture to stimulate several acupoints such as San-jiang (similar to ST 2), Jiang-ya (similar to Large Intestine 20), Wei-jian (Tip of Tail), and Er-jian (Tip of the Ear);[5] and EA to stimulate Fen-shui (similar to Governing Vessel 26), Dai-mai (Governing Vessel), and Ti-tou (similar to Tripple Heater 1). Other acupoint combinations used include Jue-yin-shu (similar to BL 13), Du-shu (similar to BL 14), and San-jiao-shu (similar to BL 18)[4] or Er-men (similar to Tripple Heater 21) and Guan-yuan-shu (similar to BL 21), which have yielded varying degrees of success in the management of visceral pain in horses with colic, although there is little scientific information available from controlled clinical studies to support such treatments.[10]

In the study reported here, a mixed pattern of alternating frequencies (ie, dense-disperse mode electrical stimulation) of 2 and 100 Hz was used in horses. Varying the frequency of the electrical stimulus allegedly can decrease accommodation (ie, adaptation) and improve analgesic effects produced by peripheral electrical stimulation.[23] A similar mixed pattern (2 and 100 Hz; dense-disperse model) of electrical stimulation in humans has produced the greatest decrease in pain, improvement in physical activity and quality of sleep, and a decrease in requirements for orally administered medications.[24]

Horses of the study reported here appeared relaxed and drowsy during EA treatment. One acupuncture needle was inserted on the dorsal midline at the lumbosacral junction (Bai hui [Governing Vessel 20]), which may have triggered the unique sedative behavior commonly seen in horses after acupuncture at the Bai hui acupoint. In 1 study,[25] acupuncture stimulation for 10 minutes at the Bai hui acupoint in 14 horses produced sedation and a decrease of serum cortisol concentration (from 2.6 ± 1.9 to 1.9 ± 1.7 mg/100 mL; decrease of 27%) 60 minutes after initiation of the acupuncture treatment.

Our research has lead to the development of a safe and reliable method of producing rectal analgesia in horses by the use of EA at specific points associated with the stomach (BL 21, ST 36), large intestine (BL 25), and small intestine (BL 27). We do not imply from the study reported here that EA at BL 21, 25, and 27 produces analgesia of the stomach and large and small intestines. We did not determine the effects of EA at BL 21, 25, and 27 (bilateral), Bai hui, and ST 36 (right side only) on gastrointestinal function. Effects of acupuncture on intestinal motility have been studied in 100 rabbits and 45 human patients with postoperative gastrointestinal atony.[26] Acupuncture with or without electrical current at ST 36 increased intestinal motility by increasing the amplitude of contractions and number of contractions per minute, produced immediate relief of abdominal distention and pain in patients, and helped patients to defecate within 24 hours after surgery, whereas they did not defecate until ≥ 72 hours after surgery without acupuncture treatment. Additional studies are necessary to determine whether EA at ST 36 relieves ileus in postoperative patients through analgesic effects.

In 1 study,[27] continuous electrical stimulation or manipulation of a needle at ST 36 caused a decreased rate of blood flow in the mesenteric vessels and a decrease in carotid arterial blood pressure in rats. After sectioning the sciatic nerve, vasodilatation did not occur after stimulation of ST 36, indicating that acupuncture at ST 36 inhibits sympathetic vasoconstrictor activity in rats. Acupuncture at ST 36 also hastens the return of intestinal motility in rabbits in which the vagal nerves have been transected.[26,28] In the study reported here, we produced rectal analgesia without changes of respiratory and cardiovascular variables in adult horses that were treated with EA at BL 21, 25, and 27 (bilateral); Bai hui; and ST 36 (right side only).

It is difficult to test rectal analgesia in horses. The study reported here documents that EA is capable of producing rectal analgesia without producing stress or apprehension in conscious adult horses. Pain and discomfort at insertion sites of catheters were prevented by use of a 2% solution of lidocaine for infiltration of the subcutaneous tissues. Analgesia was quantitatively assessed and cardiopulmonary data monitored to evaluate stress through observation of purposeful movements of the legs, trunk, neck, and head of horses in

response to rectal distention. Acupuncture needles were aseptically placed, and we did not detect evidence of infection, localized pain, swelling, or heat at needle insertion sites. None of the horses had evidence of fresh blood on the palpation sleeve or rectal balloon, indicating that grade-3 or -4 rectal tears did not occur after maximal balloon inflation (220 mm Hg).[29] The rectum and balloon were copiously lubricated for each experiment.

Administration of butorphanol (0.1 mg/kg, IV) to horses in this study produced significant rectal analgesia and moderate cardiovascular and respiratory stimulation, as evidenced by increased HR, RR, ABP, and rectal temperature. The cardiovascular stimulation can be considered clinically unimportant. Other investigators have given higher doses of butorphanol (0.4 mg/kg, IV) to pain-free adult horses and have produced minimal cardiopulmonary depressant effects.[14]

Butorphanol has the highest relative visceral analgesic property, compared to other opioid analgesic drugs. Assuming that the visceral analgesic potency of morphine in horses is assigned a value of 1, then values for other opioids are as follows: meperidine, 0.5; fentanyl, 0.5; methadone, 1.5; oxymorphone, 2; and butorphanol, 2.5.[12,13] The analgesic effect of butorphanol in ponies and adult horses as determined by use of a similar method of intestinal dilatation (balloon distention of the cecum) for production of visceral pain has been described.[12,13,30-32] Duration of visceral analgesia reportedly is related to the dose of butorphanol administered. Doses of 0.2 and 0.4 mg/kg, IV, have produced visceral analgesia with a duration that ranges from 30 minutes[31] to 4 hours.[13] A smaller dose (0.1 mg/kg, IV) of butorphanol given to 66 horses with abdominal pain produced noticeable analgesic effects for a time period adequate to permit specific treatment[33] and produced minimal effects on intestinal sounds, time to first defecation after treatment, and fecal consistency.[34]

Analgesic potencies of other opiates (morphine, pentazocine, meperidine, methadone, oxymorphone, fentanyl) and α_2-adrenergic agonists (xylazine, detomidine) have been most commonly evaluated by the use of methods to induce visceral pain in ponies and horses (cecal distention with a balloon or cecal impaction).[7,8] Methods that induce superficial pain have been used to determine the pain threshold in response to heating of the skin.[9,35] Recommended doses of morphine, meperidine, pentazocine, and oxymorphone produce increases in HR, ABP, and cardiac output with minimal changes in arterial pH, Pa_{O_2}, and Pa_{CO_2} in pain-free adult horses.[36] Changes in motility of the gastrointestinal tract, decreased sounds in the gastrointestinal tract, delayed defecation, and production of dry feces have resulted and are considered adverse effects that have limited the clinical use of opiate drugs by equine practitioners.[34] In addition, behavioral changes such as excitement, apprehension, increased locomotor activity, restlessness, shivering, pacing, pawing, and ataxia are commonly observed after systemic administration of opiates in horses. Opioid-induced gastrointestinal and behavioral effects in horses are good reasons to avoid the use of opiate drugs in horses and ponies. Currently, xylazine and detomidine are effective analgesics available for management of horses with visceral pain, although the clinical importance of their inhibition of gastrointestinal motility needs further investigation.[37]

Results reported here were obtained in healthy horses. Further studies are necessary to determine whether stimulation of acupuncture points BL 21, 25, and 27 (bilateral); Bai hui; and ST 36 (right side only) can be used to effectively treat horses with disturbed intestinal and colon function (ie, diarrhea, constipation, ileus), similar to its effects in laboratory animals and humans.[38,39]

None of the horses in the study reported here had signs of abdominal pain during inflation of the balloon inserted in the rectum. Therefore, the mild to moderate discomfort caused by the balloon is not a good method for assessing visceral abdominal pain associated with colic. In horses, colic attributable to large intestinal impaction or during recovery from exploratory celiotomy is likely to be influenced by many factors, including endotoxemia, hypovolemia, and drug administration.

[a]Lidocaine 2% injectable, Phŏnix Scientific Inc, St Joseph, Mo.
[b]Vialon polymer resin radiopaque intracath, Deseret Medical Inc, Sandy, Utah.
[c]TruWave, disposable pressure transducer, Edwards Lifesciences LLC, Irvine, Calif.
[d]YSI 400 probe tele-thermometer, Yellow Springs Instrument Co, Yellow Springs, Ohio.
[e]Torbugesic, Fort Dodge Animal Health, Fort Dodge, Iowa.
[f]Biostatic sodium chloride for injection, USP 0.9%, Elkins-Sinn Inc, Cherry Hill, NJ.
[g]ITO IC 4107, M. E. D. Servi-Systems Canada LTD, Stittsville, ON, Canada.
[h]Cherry handy acupuncture needle, M. E. D. Servi-Systems Canada LTD, Stittsville, ON, Canada.
[i]ITO IC 4107, M. E. D. Servi-Systems Canada LTD, Stittsville, ON, Canada.
[j]ABL 500-K pH and blood gas analyzer, Radiometer-Copenhagen, Copenhagen, Denmark.
[k]Criticaps, microhematocrit capillary tube reader, Monoject Scientific, St Louis, Mo.
[l]10436 veterinary refractometer, Cambridge Instruments, Buffalo, NY.
[m]Datascop Passport XG, Datascope Corp, Mahwah, NY.
[n]Headstrom, Target, Ashland, Ohio.
[o]Lubrivet, Butler Co, Columbus, Ohio.
[p]Dose-syringe, 400 mL, Jorgensen Laboratories, Loveland, Colo.
[q]H tank, compressed medical nitrogen Nf grade USP, Stores Gas Warehouse, Columbus, Ohio.
[r]Tycos, Welch Allyn Ltd, Skaneateles Falls, NY.
[s]Wright respirometer, Fraser Harlake, Orchard Park, NY.
[t]Systat for Windows, version 5.2, Statistics, Evanston, Ill.

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