Localization of the cutaneus trunci muscle reflex in horses

Cynthia M. Essig, DVM, MS; Jonathan S. Merritt, PhD; Narelle C. Stubbs, PhD; Hilary M. Clayton, BVMS, PhD

Objective—To determine the magnitude and location of skin movement attributable to the cutaneus trunci muscle reflex in response to localized stimulation of the skin of the dorso-lateral aspect of the thoracic wall in horses.

Animals—8 horses.

Procedures—A grid of 56 reflective markers was applied to the lateral aspect of the body wall of each horse; markers were placed at 10-cm intervals in 7 rows and 8 columns. A motion analysis system with 10 infrared cameras was used to track movements of the markers in response to tactile stimulation of the dorsolateral aspect of the thoracic wall at the levels of T6, T11, and T16. Marker movement data determined after skin stimulation were used to create a skin deformation gradient tensor field, which was analyzed with custom software.

Results—The sites of maximal skin deformation were located close to the stimulation sites; the centers of the twitch responses were located a mean distance of 7.7 to 12.8 cm ventral and between 6.6 cm cranial and 3.1 cm caudal to the stimulation sites.

Conclusions and Clinical Relevance—Findings of this study may have implications for assessment of nerve conduction velocities of the cutaneus trunci muscle reflex and may enhance understanding of the responses of horses to placement of tack or other equipment on skin over the cutaneus trunci muscles. (Am J Vet Res 2013;74:1428–1432)
of horses. Our hypothesis was that skin deformation during the cutaneus trunci muscle reflex would have a predictable spatial relationship to the site of stimulation. This information would have application in determination of the optimal sites at which to observe the response and to measure nerve conduction velocities in the cutaneus trunci muscle reflex.

Materials and Methods

Animals—Eight adult horses (mean ± SD height at the withers [most dorsal aspect of the shoulders], 155 ± 9 cm; weight, 499 ± 74 kg; age, 17 ± 6 years) with an intact cutaneus trunci muscle reflex were included in the study. The study was performed with approval of the Michigan State University Institutional Animal Care and Use Committee.

Motion analysis—Horses were marked with a grid of 56 reflective markers that covered the left shoulder, thorax, and abdomen regions in the area overlying the cutaneus trunci muscle. The grid was drawn on each horse with a paint pen starting 10 cm ventral to the spinous process of T10. From this point, the rest of the grid was drawn in a pattern of 7 rows and 8 columns, with adjacent markers 10 cm apart. Reflective 6-mm markers were taped to the skin over each point on the grid (Figure 1). Reflective markers were also attached over the spinous processes of T6, T10, L1, L5, S2, and S4; the left and right tuber coxae; and the lateral surface of each hoof to detect body movements during the trials. A motion analysis system with 10 infrared cameras operating at 120 Hz was used to track the markers automatically with commercial software.

Data collection—The cutaneus trunci muscle reflex was stimulated by the same operator for all trials (NCS). The operator stood on a step on the right side of the horse to avoid obstructing the camera view of the markers. The skin was stimulated with a wand (Figure 2) equipped with an array of 4 reflective markers that allowed its movements to be tracked by the motion analysis system. To locate the tip of the wand, a static trial was recorded in which an additional marker was located on the wand tip that was not present during stimulation trials. The position of the tip of the wand was recreated as a virtual marker indicating the position of the end of the wand relative to the skin surface during the stimulation trials. The stimulus consisted of a brief indentation of the skin at 3 predetermined sites that were identified by marks on the coat. These sites were located along the circumference of the body wall 25 cm ventral to the spinous processes of T6, T11, and T16, which was between the second and third rows from the top of the marker grid.

A complete data set consisted of 5 repetitions of each of 5 conditions (negative control, positive control, stimulation at T6, stimulation at T11, and stimulation at T16); the 25 trials were performed in random order. The control trials were used to determine whether horses had a twitch response in anticipation of a skin stimulus. In the negative control trials, horses stood with no surrounding human movement. In the positive control trials, the operator made the motions of tactile stimulation with the wand without making contact with the skin of horses. In the stimulation trials, the wand touched the skin at 1 of the 3 marked sites on the horse's left side. The operator was informed of which type of trial to perform immediately prior to the start of the trial. Spoken notification was given when the cameras began recording data so the operator could apply the wand at an appropriate time. Data were recorded continuously for 6 seconds, which was sufficient time to record the stimulus and the response. For the cutaneus trunci muscle reflex, repeated stimulation is possible without fatigue or habituation in the reflex.

Data and statistical analyses—Trials were initially reviewed to eliminate those in which there were movements of the horses' hooves or generalized body movements. The remaining trials were analyzed with software that tracked the movement of the markers and generated .TRC (track row column) files in which the positions and movements of the markers in 3-D space were represented as Cartesian coordinates.

Figure 1—Photograph of a representative horse indicating placement of a marker grid and reference markers used to determine the magnitude and location of skin movement in response to localized cutaneous stimulation of the dorsal aspect of the thoracic wall. The operator is standing on the right side of the horse applying tactile stimulation with a wand at the level of T16.

Figure 2—Photograph of the wand used to stimulate the skin of horses. Notice the 4 reflective markers used to track movements of the wand.
Because the tracking of skin displacement is a novel application of motion analysis, custom software was written in a commercial software program. For each trial, 2 tracking files were read: the trial’s own tracking file and the static trial associated with that horse. The additional marker that was placed on the tip of the wand during the static trial was used to determine the virtual location of the wand tip during the stimulation trials by applying a least-squares rigid body transformation. Gaps in the data attributable to marker obstruction during data collection were joined by means of linear interpolation. A forward-reverse, low-pass Butterworth filter with a cutoff frequency of 5 Hz was used to filter and smooth the marker data.

The moment when the wand touched the skin to apply the tactile stimulation and the exact point of skin contact were determined by calculating the intersection of the virtual marker on the wand tip with the horse’s skin. To compute the intersection, the skin surface was represented as a polygon mesh with the markers located at the vertices. The deformation gradient tensor was computed and used to calculate the Biot strain field at the vertices. The deformation gradient tensor was also computed as a measure of the magnitude of the response across the skin surface. For each trial, the point of application of the stimulus was located in terms of its y (dorsoventral; positive values ventrally) and x (cranio-caudal; positive values caudally) coordinates, expressed relative to the grid. The point of maximal skin deformation was measured as the distance from the point of stimulation along the x- and y-axes. Mean ± SD values were calculated for each horse, then the mean ensemble value was calculated for all horses.

Skin deformation was represented by a contour map that was color coded according to the magnitude of the first invariant of the left Cauchy-Green deformation tensor. The principal components of the Biot finite strain tensor were plotted at each marker location with orthogonal quiver arrows to indicate the variation in the principal strains. For each trial, the first invariant of the left Cauchy-Green deformation tensor was also computed as a measure of the magnitude of the response across the skin surface. For each trial, the point of application of the stimulus was located in terms of its y (dorsoventral; positive values ventrally) and x (cranio-caudal; positive values caudally) coordinates, expressed relative to the grid. The point of maximal skin deformation was measured as the distance from the point of stimulation along the x- and y-axes. Mean ± SD values were calculated for each horse, then the mean ensemble value was calculated for all horses.

To compare the twitch response among stimulus and control trials, the minimum (most compressive) principal Biot strain at the point of maximum response was used as a variable to measure the scalar magnitude of the twitch. The control conditions were pooled and values for the T16 trials were significantly (P < 0.001) different from the control value. A value is significantly (P < 0.001) different from the control value. A value is significantly (P = 0.003) different from the value for T16 stimuli. Value is significantly (P = 0.001) different from the value for T16 stimuli.

![Figure 3—Box plots of maximum principal compressive Biot strain (unitless) for the cutaneous trunci muscle reflex of horses (n = 8) during control trials (pooled data) and trials during which the body wall was stimulated 25 cm ventral to the spinous processes of T6, T11, and T16. Boxes represent the first and third quartiles, horizontal lines in boxes represent the median values, and whiskers extend to the highest and lowest values that are within 1.5 times the upper and lower limits of the interquartile range. Values outside the range of the whiskers are indicated as circles (outlier values, which were included in statistical analyses). Data were analyzed by means of a post hoc pairwise Wilcoxon rank sum test with Holm-Bonferroni probability adjustment. Value is significantly (P < 0.001) different from the control value. Value is significantly (P = 0.003) different from the value for T16 stimuli. Value is significantly (P = 0.001) different from the value for T16 stimuli.](image)

<table>
<thead>
<tr>
<th>Site</th>
<th>Total</th>
<th>Dorsoventral</th>
<th>Craniocaudal</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6</td>
<td>20.1 ± 11.1</td>
<td>12.0 ± 13.1</td>
<td>3.1 ± 15.8</td>
</tr>
<tr>
<td>T11</td>
<td>15.5 ± 5.9</td>
<td>7.7 ± 8.1</td>
<td>-6.1 ± 10.2</td>
</tr>
<tr>
<td>T16</td>
<td>18.2 ± 9.5</td>
<td>12.6 ± 12.1</td>
<td>-6.6 ± 8.0</td>
</tr>
</tbody>
</table>

The total distance was measured along a straight line, and the dorsoventral and craniocaudal distances were determined accounting for the curvature of the skin. For the dorsoventral direction, positive values are ventral and negative values are dorsal. For the craniocaudal direction, positive values are caudal and negative values are cranial.

Table 1—Mean ± SD distance from the site of skin stimulation 25 cm ventral to the spinous processes of T6, T11, and T16 to the site of the maximal twitch response of the cutaneous trunci muscle in horses (n = 8).
different from values for the T6 ($P = 0.003$) and T11 ($P = 0.001$) trials. The magnitude of the response in the control trials was small, compared with that for the other trial types (Figure 3). Therefore, we were able to distinguish the response of the horses in stimulus trials from their response in control trials, and no evidence of a skin twitch was detected for control trial responses that would have suggested the horses had learned to anticipate the stimulus. For stimulation trials, significantly ($P < 0.005$) greater principal compressive strains were detected during T16 trials versus T6 and T11 trials.

The site at which the skin was maximally deformed was in a localized area ventral to the site of tactile stimulation (Table 1). The position of maximal response relative to the site of stimulation did not differ significantly among the 3 stimulation sites, although the maximal response location seemed to be caudoventral to the stimulus location for the T6 site and cranioventral for the T11 and T16 sites. The precise location of the maximal response varied within and among horses. Contour maps indicated the locations of the actual stimulation points and the location of the mean response for each stimulation site (T6, T11, and T16) for all trials (Figure 4). The principal components of the Biot strain tensor indicated that the direction of compression in the skin matched the muscle fiber orientation of the underlying the cutaneus trunci muscle.

**Discussion**

Results of this study indicated skin deformation in horses in response to cutaneous stimulation of the dorsal aspect of the thoracic region was a localized response and not a generalized response of the cutaneous trunci muscles. The findings supported the hypothesis that contraction of the cutaneous trunci muscle would be localized to sites of stimulation. Variation was detected in the precise locations of the stimulation points as a consequence of randomization of the order in which the sites were stimulated and the fact that the operator reached across the dorsal midline aspects of horses to avoid obstructing the view of the cameras; this made it difficult to contact the skin in exactly the same positions during each trial. The stimulation sites were not identical; therefore, the sites of maximal response were measured relative to the location of the corresponding stimulation point. The maximal twitch response was detected approximately 32 to 38 cm from the dorsal midline aspect of the horses. Results of an anatomic study of horses indicate that the cutaneous trunci muscles typically extend to within 8 cm from the dorsal midline aspect of horses and are closest to the dorsal midline aspect in the area caudal to T10. The most dorsal parts of the muscle are thin, typically forming isolated patches of muscle tissue near the dorsal midline aspect where the skin is immobile because it is adhered to the spinous processes. In the region of maximal skin response detected in horses of this study, the cutaneous trunci muscle is thicker and the skin is more mobile.

In another study of the cutaneus trunci muscle reflex in horses, a more precise method of mechanical stimulation of the skin was used than was used in the present study and electromyographic recording of the muscular response was performed to estimate nerve conduction velocities. In that study, stimulation was applied in the middle lateral aspect of the body wall over the left or right 16th rib, and the response was measured with electrodes clipped to skin at 5 sites; the locations of these sites were not specified. Results of the present study indicated that the site of maximal response was approximately 8 to 13 cm ventral to the stimulation site and 3 cm caudal to that site for stimulation in the withers region (ie, at the most dorsal aspect of the shoulders) and 6 to 7 cm cranial for stimulation in the mid to caudal aspect of the thoracic region. Determination of an optimum detection site on the basis of the results of this study may improve the accuracy of measurement of nerve conduction velocities.

Results of other studies indicate that the cutaneous trunci muscle reflex does not habituate in guinea pigs or rats; results of the present study did not indicate habituation (change in responsiveness over time) of that reflex in horses. However, the sensitivity of horses to the stimulus and the strength of the response differed among horses; some of the horses had particularly high skin responses.
strong reactions to the stimulus. Differences in sensitivity and responsiveness to a stimulus among horses may account for the strong reactions of some horses to the application of a surcingle and girth during foundation training. Another investigator assessed the response of the cutaneous trunci muscle to manual stimulation of the skin in the region of girth application in horses during foundation training. Horses in that study had high sensitivity to stimulation at the start of training remained sensitive to the presence of a surcingle or girth throughout the training period, whereas horses that had low sensitivity at the start of the training became habituated to the presence of the tack and had less vigorous responses as training progressed. Therefore, the variability of responses among horses may be attributable to an ability to tolerate noxious stimuli.

The marker grid used in the present study was constructed geometrically so that it had the same dimensions for all horses. However, the 8 horses used in the study varied in conformation and morphological characteristics, which affected the amount of the body covered by the grid. Furthermore, results of another anatomic study indicate that the cutaneous trunci muscle is variable in its extent among horses, particularly with regard to the dorsal aspect of the muscle; therefore, we expected that marker grid coverage of the cutaneous trunci muscle would differ among horses in the present study. However, maximal twitch responses were detected in the area where that muscle is well developed in all of the horses; that finding may be important for future studies of the activity of the cutaneous trunci muscle in horses.

The procedure developed in the present study for measurement of skin deformation in response to the application of a stimulus on the dorsal aspect of the body could be used for other anatomic locations, such as the area of girth application; responses in that area may be important in horses with hypersensitivity. Placement of a saddle or girth or pressure of the legs to the tendons of the latissimus dorsi and teres major muscles; it is not known whether pressure of the legs applied closer to these tendons would cause tension in the tendons.

The findings of the present study may be useful for interpretation of results of clinical testing of the cutaneous trunci muscle reflex in horses. Epidurally derived evoked potentials are representative of somatosensory processing in the spinal cord and range from 28 to 67 milliseconds for nociceptive fiber activity. Knowledge of site specificity of the cutaneous trunci muscle reflex may increase the accuracy of neurologic testing by means of analytic methods such as electromyography.

In the present study, a technique for assessment of skin deformation during a twitch response of the cutaneous trunci muscle was used to determine the site of maximal response to site-specific cutaneous stimulation. The results indicated that the area of maximal response had a close spatial relationship that was ventral to the sites of stimulation on the dorsal aspects of the thoracic walls of horses.

References