Comparison of the *longissimus dorsi* muscle tone in Thoroughbred racehorses before and after training

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Abstract

The *longissimus dorsi* is the largest back muscle of the horse and has the potential to contribute movement to the horse's back. Damage to the *longissimus dorsi* is very common to cause back injuries, which is also a major cause of poor performance and gait abnormalities in horses. The muscle indenter is a tool that allows measuring the stiffness of the back muscles. We hypothesized that the *longissimus dorsi* muscle tone after training would be stiffer than at rest. One sound mare and three gelding Thoroughbred racehorses were used in this study. The muscle tone was measured using a muscle indenter along both sides of the T14, T16, T18 and L2 *longissimus dorsi* muscle. Blood sample were collected to measure the blood lactate concentration before and after training. Heart rate was measured at rest and at 0, 5, 10, 15 and 20 minutes after training. We found a significant increase in muscle tone after training at T14, T16 and T18. The blood lactate concentration of studied horses significantly increased after training, although the values were still within the normal range. The recovery heart rates for all horses are tended to decrease (< 70 bpm) after 5 minutes of stopping exercise. We confirmed that the *longissimus dorsi* is a key muscle in horse movement that can be sensitive to relatively small training sessions; that is why this muscle is prone to get injured. Generally, the muscle intender was a successful tool of objectively measuring this muscle tone.

Keywords: Horse, Thoroughbred, *longissimus dorsi*, muscle indenter, muscle tone

การศึกษาเปรียบเทียบแรงตึงของกล้ามเนื้อ *longissimus dorsi* ในม้ากลุ่มโทโรเบรดก่อนและหลังการฝึกซ้อม

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บทคัดย่อ

กล้ามเนื้อ *Longissimus dorsi* เป็นกล้ามเนื้อหลังที่มีขนาดใหญ่ที่สุดของม้า ซึ่งช่วยในการเคลื่อนที่ของหลังม้า การบาดเจ็บที่กล้ามเนื้อส่วนนี้มักเป็นสาเหตุหลักของอาการเจ็บหลังในม้า โดยปัญหาดังกล่าวจะส่งผลให้ม้ากีฬาหรือม้าแข่งมีศักยภาพลดลงและมีการก้าวย่างที่ผิดปกติไป เครื่องมือวัดแรงตึงของกล้ามเนื้อเป็นเครื่องมือชนิดหนึ่งที่สามารถวัดแรงตึงกล้ามเนื้อหลังของม้าได้ ในการทดลองนี้ต้องการพิสูจน์สมมติฐานว่าแรงตึงของกล้ามเนื้อ *longissimus dorsi* หลังจากการฝึกซ้อมมีค่ามากกว่าแรงตึงขณะพัก โดยได้ทำการทดลองในม้าแข่งพันธุ์โทโรเบรด ได้แก่ ม้าเพศเมีย 1 ตัว และม้าเพศผู้ตอน 3 ตัว ซึ่งทั้งก่อนและหลังการฝึกซ้อมติดต่อกัน 10 วันจะทำการทดสอบวัดแรงตึงของกล้ามเนื้อ *longissimus dorsi* ด้วยเครื่องวัดแรงตึงที่ตำแหน่ง T14 T16 T18 และ L2 ทั้งสองข้าง พร้อมทั้งทำการเก็บตัวอย่างเลือดเพื่อหาความเข้มข้นของระดับเลคเตท อีกทั้งทำการวัดอัตราการเต้นของหัวใจขณะพักที่คอกและหลังจากฝึกซ้อม โดยจะทำการวัดอัตราการเต้นของหัวใจในนาทีที่ 0 5 10 15 และ 20 หลังการฝึกซ้อม ซึ่งผลการทดลองพบว่าแรงตึงของกล้ามเนื้อหลังฝึกซ้อมมีค่าเพิ่มขึ้นอย่างมีนัยสำคัญทางสถิติ รวมทั้งระดับความเข้มข้นของเลคเตทในเลือดหลังฝึกซ้อมของม้าทุกตัวมีค่าเพิ่มขึ้นอย่างมีนัยสำคัญทางสิถิติ อย่างไรก็ตามอัตราการเต้นของหัวใจภายหลังจากการออกกำลังกายของม้าทุกตัวมีแนวโน้มลดลงต่ำกว่า 70 ครั้งต่อนาทีภายใน 5 นาทีหลังจากฝึกซ้อม จากการศึกษาครั้งนี้เป็นการยืนยันว่ากล้ามเนื้อ *Longissimus dorsi* เป็นกล้ามเนื้อหลักที่ทำให้หลังม้าเคลือนที่และมีความอ่อนไหวต่อการฝึกแม้ว่าจะเป็นการฝึกซ้อมที่ไม่หนักมากก็สามารถทำให้แรงตึงของกล้ามเนื้อเปลี่ยนแปลงได้ ซึ่งมักเป็นสาเหตุหนึ่งที่ทำให้ม้ามีอาการเจ็บหลังได้ง่าย จากผลการศึกษาครั้งนี้เราสามารถใช้เครื่องวัดแรงตึงเป็นเครื่องมือในการวัดแรงตึงของกล้ามเนื้อหลังม้าได้อย่างไม่มีอคติ

คำสำคัญ : ม้า พันธุ์โทโรเบรท *longissimus dorsi* เครื่องวัดแรงตึง แรงตึงของกล้ามเนื้อ

Introduction

Various conditions can affect the movement of horse resulting in muscles stiffness or pain. The types of work of the horses such as racing, eventing and showjumping are predisposed to cause injury to the horse's back being damage to the *longissimus dorsi* muscles. The *longissimus dorsi* muscles are the widest muscles of the horse back, which lie on transverse processes of spine, the main extensor of the back and loins of the horse and also raises the hind limbs for bucking and the forelimbs for rearing (Kidd, 2009). Thus, any injuries to the *longissimus dorsi* can affect the movement efficiency of the horse.

Back pain in horses could happen from many causes that can be wounded directly at the back or as a result from other factors such as nervous system abnormalities, mismanagement; poorly fitting saddler will limit movement of the back and cause injuries (Munroe, 2009). Damage to the epaxial muscles is a common cause of back injuries with 38.8% incidence of cases reported with back problem (Jeffcott, 1980). Back problems are a major cause of poor performance and gait abnormalities in sport and racing horses. The physical examination to demonstrate a suspected back problem and the diagnosis of the cause of the pain are real challenges for the equine practitioner. Earlier substantial improvements in back problem have been achieved due to the use of radiographic and ultrasonographic evaluation of the thoracolumbar and sacral areas (Denoix 1998). However, the horse still needs to be referred a diagnostic centre with good facilities and an experienced veterinary surgeon in order to make a precise identification of the pain lesion. In order to assess the horse vertebrae column, a powerful x-ray machine is needed so, to radiograph the mid and caudal regions of the thoracolumbar spine (Jeffcott, 1981). Assessment of the back pain is also possible by using blood biochemistry test, for instance, Aspartate aminotransferase (AST), Creatine kinase (CK) or blood lactate concentrations. Lactate is a product of muscular metabolism and accumulates in muscle and blood at higher intensities of exercise (Hogdson, Rose, 1994). Blood lactate is also regularly used to assess the level of fitness in the athletic horse (Piccione et al., 2010) or to help the trainer evaluate the fitness of the horses before the competition (Evans, 2004). Blood lactate response and the velocity at which its concentration changes as a result of exercise are widely used to measures determine fitness (Lindner et al., 2009).

Heart rate monitoring can be used as a fitness indicator. One of the advantages of using heart rate is that allows to observe heart function over the time. The changing of the heart rate assists in decisions to alter the intensity, duration or type of training to improve the fitness level of the horse. It also allows to study individual horseís progress on successive workouts as well as comparison among different individuals (Freeman et al., 1991).

Back problems accounted for 3.3% of wastage in a study of thoroughbred racehorses (Wennerstrand et al., 2004) and are seen in horses of all breeds and in all types of work. Hence, an effective diagnosis is of importance to both the welfare and the performance of horses. However, at present the diagnosis of back pain or stiffness remains depend on the experience and observation skills of the examiner, which allows him palpate and check the muscle tone. This is quite a subjective examination, which rather is indescribable. In a recent study, the muscle tone was measured by the muscle indenter and showed that the muscle tone decreased after spinal manipulation treatment (Wakeling et al., 2006).

The muscle indenter is a tool that allows measuring the stiffness (tone) of a muscle. It has been developed as a diagnostic aid that helps in the identification of the stiffness and painful muscles. The muscle intender has been proposed as a means of diagnosis of soft tissue injuries as muscle that is practical, non-invasive and inexpensive. Thus, it helps the examiner to be more objective (Phutthachalee, Wattanachai et al., 2015). The objective of this study was to quantify the *longissimus dorsi* muscle tone at rest and after training of the horse using an objective method: i.e. using a muscle intender. We hypothesized that the *longissimus dorsi* muscle tone after training would be stiffer than at rest.

Materials and Methods

Horses

One sound mare and three geldings Thorough bred racehorses were used in this study (mean ± SD of age, height at withers and body mass were 4.25 ± 0.96 years, 163 ± 6.27 cm and 466 ± 27.90 kg, respectively). All horses were healthy and have no clinical signs of back pain. They were initially assessed by a veterinarian surgeon. The horses were fed with the same feeding and supplements and were housed in the same farm.

Muscle indenter calibration

Muscle tone was measured using a custom-made muscle indenter. A 14 mm diameter nylon bead was glued to the end of a linear variable displacement transducer (LVDT; ULSC25-10, Monitran, Penn, Bucks, UK). A spring was mounted between the bead and LVDT and metal collar (29 mm external diameter) constructed to protect these parts. The indenter was calibrated against a weighing apparatus and LVDT calibration equipment, then converted its voltage output to force and length of the bead (Force : r2 = 0.9924; Length: r2 = 0.9994; n = 12) (Figure 1)

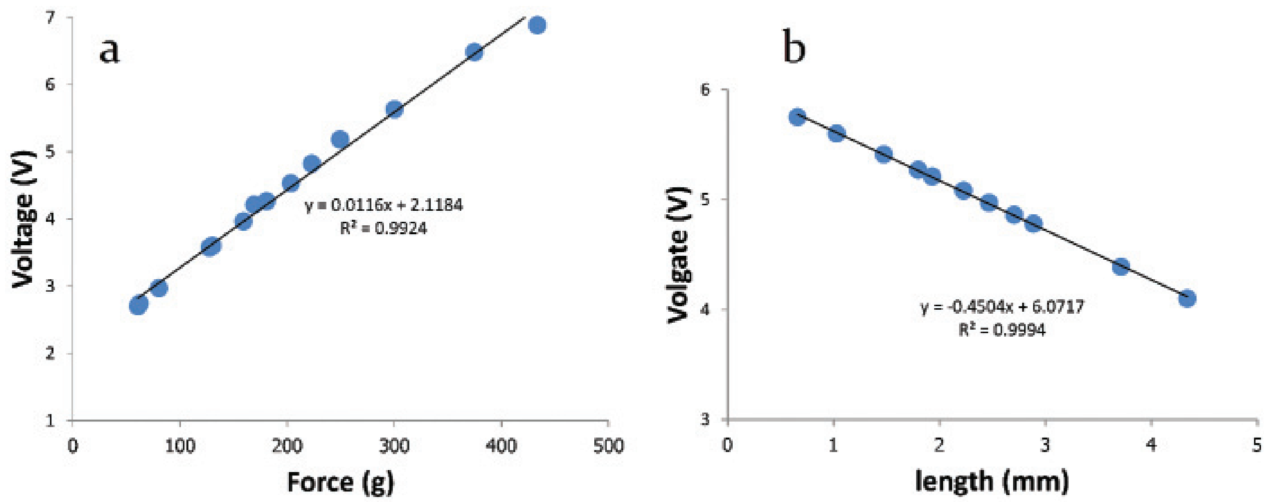

Figure 1. The relation between voltage against force (a) and length (b). The best fitting line and corresponding equations of linear regressions are shown for each figure.

Relating stiffness to voltage

$$\text{Stiffness} = \frac{\text{Force}}{\text{Length}}$$

Linear equation: $y = mx + c$

From graph A: $\text{Voltage} = 0.011 \times \text{Force} + 2.118$

$$\text{Force (g)} = \frac{\text{Voltage} - 2.118}{0.011}$$

$$\text{Force (N)} = \frac{\text{Voltage} - 2.118}{1.1217} \quad (1\ \text{N} = 101.971\ \text{g}) \qquad (1)$$

From graph B: $\text{Voltage} = -0.450 \times \text{Length} + 6.071$

$$\text{Length} = \frac{\text{Voltage} - 6.071}{-0.450} \qquad (2)$$

$$\text{Stiffness (N m-1)} = \frac{(1)}{(2)} = \frac{0.450\text{Voltage} - 0.9531}{6.8098 - 1.1217\text{Voltage}} \times 1000$$

Procedure

Muscle tone (stiffness) measurement

Bilateral sites on the longissimus dorsi, adjacent to dorsal spinous process of the fourteenth thoracic vertebrae (T14), sixteenth thoracic vertebrae (T16), eighteenth thoracic vertebrae (T18) and second lumbar vertebrae (L2) were identified and clipped. The muscle tone was measured at these sites. The horses were ridded by jockeys under the same conditions on the sand track for ten consecutive days (mean ± SD of the distance, time and speed were 3.53 ± 0.06 km, 25 ± 0.44 min, 8.59 ± 0.17 km h-1, respectively). We measured the muscle tone from these sites before training or when the horse is at rest quietly and standing square in the stable. The horses were trained and then returned to the stable. The muscle tones were measured again after exercises within 15 minutes. The muscle tone was measured on a quietly standing horse that was bearing weight on all four limbs. The collar of indenter was placed on the skin surface. The indenter produced a voltage output that was converted to the newton m-1, using calibration constants. The tone was measured at 5 cm lateral from the dorsal spinous processes on the left and the right sides of T14, T16, T18 and L2 spinal process which repeated 3 times per point.

Blood lactate measurement

Blood sample were collected from the study horses at the left jugular vein before training and after training immediately to measure the blood lactate concentration for ten consecutive days. Then the bloods were dropped on lactate strip test for measured by lactate test analyzer (Lactate scout®, SensLab GmbH, Leipzig, Germany).

Heart rate measurement

To assess the fitness condition, the horses were measured heart rate at rest in their stable and after training at 0, 5, 10, 15 and 20 minutes.

Statistics

It was hypothesized that there would be a significant increase in muscle tone after training. This hypothesis was tested using one-Sample Kolmogorov-Smirnov test and Pair-sample t-test.

Results

Three repeated measurements were recorded for each estimate of muscle tone and were pooled from all horses then the muscle tone were calculated as mean ± SEM for each muscle segments. The muscle tone on both left and right sides at T14 muscle segment after training showed a significant 13% and 19% increase from (532.17 ± 1.01) to (599.54 ± 3.62) and (539.33 ± 3.14) to (643.18 ± 5.01) N m-1, respectively. The muscle tone on both left and right sides at T16 muscle segment after training showed a significant 16% and 23% increase from (547.70 ± 5.31) to (632.87 ± 8.59) and (587.87 ± 6.56) to (723 ± 6.64) N m-1, respectively. The muscle tone on both left and right sides at T18 muscle segment after training showed a significant 7% and 16% increase from (507.82 ± 3.34) to (544.01 ± 3.58) and (527.23 ± 3.21) to (610.69 ± 5.26) N m-1, respectively (Table 1). The muscle tone between left and right sides was significantly different at T18 muscle segment before training. There were significantly different of muscle stiffness at T14 and T18 muscle segments between left and right sides after training (Figure 2).

The matched-pair t-test showed that the muscle stiffness on both left and right sides was significantly different between before and after training at T14, T16 and T18 ($P < 0.05$). The significant majority of muscle segments tested showed an increase in muscle tone after training. Changes in muscle tone before and after training are shown in Figure 2.

Table 1. Changes in mean (±SEM) muscle tone of the *longissimus dorsi* before and after training at T14, T16, T18 and L2 muscle segments.

Muscle segment	Muscle tone before (N m-1)		Muscle tone after (N m-1)	
	Left	Right	Left	Right
T14	532.17 ± 1.01	539.33 ± 3.14	599.54 ± 3.62	643.18 ± 5.01
T16	547.70 ± 5.31	587.87 ± 6.56	632.87 ± 8.59	723.00 ± 6.64
T18	507.82 ± 3.34	527.23 ± 3.21	544.01 ± 3.58	610.69 ± 5.26
L2	507.82 ± 1.67	472.17 ± 6.13	473.66 ± 6.20	492.78 ± 4.52

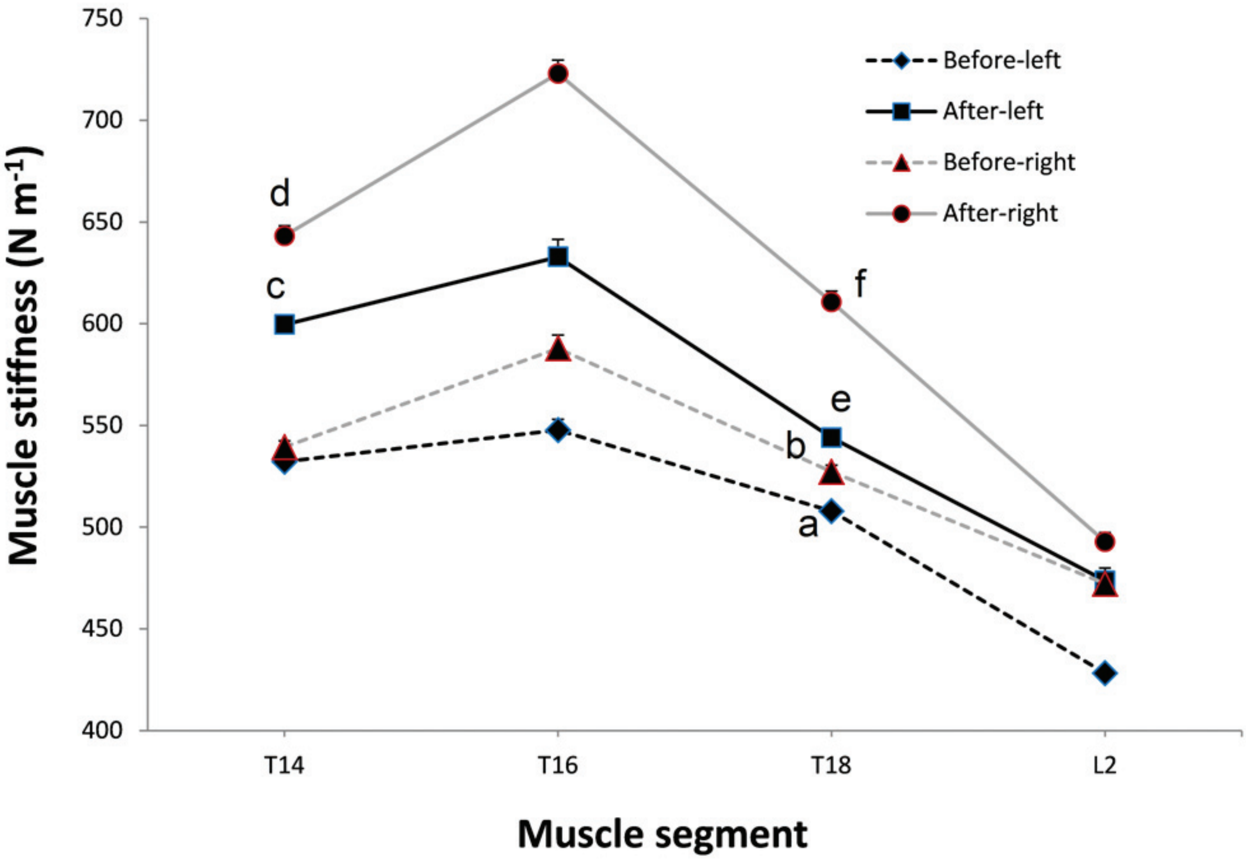

Figure 2. Mean ± SEM muscle stiffness of the *longissimus dorsi* before and after training at T14, T16, T18 and L2 segments. Letters a, b, c, d, e and f denote significant differences between conditions (P < 0.05).

The mean ± SD of the recovery heart rate for all horses at 0, 5, 10, 15 and 20 minutes were 73 ± 7.41, 61 ± 7.79, 54 ± 8.04, 50 ± 8.04 and 47 ± 6.14, respectively (Figure 3). The recovery heart rates for all horses are tended to decrease less than 70 beats per min after 5 minutes (Figure 4).

The matched-pair t-test was used to analyses blood lactate data. Blood lactate concentration was significantly different between before and after training in horse 2 (H2) and horse 3 (H3). Pooled data from all horses were also significantly different between before and after training ($P < 0.05$) (Figure 5).

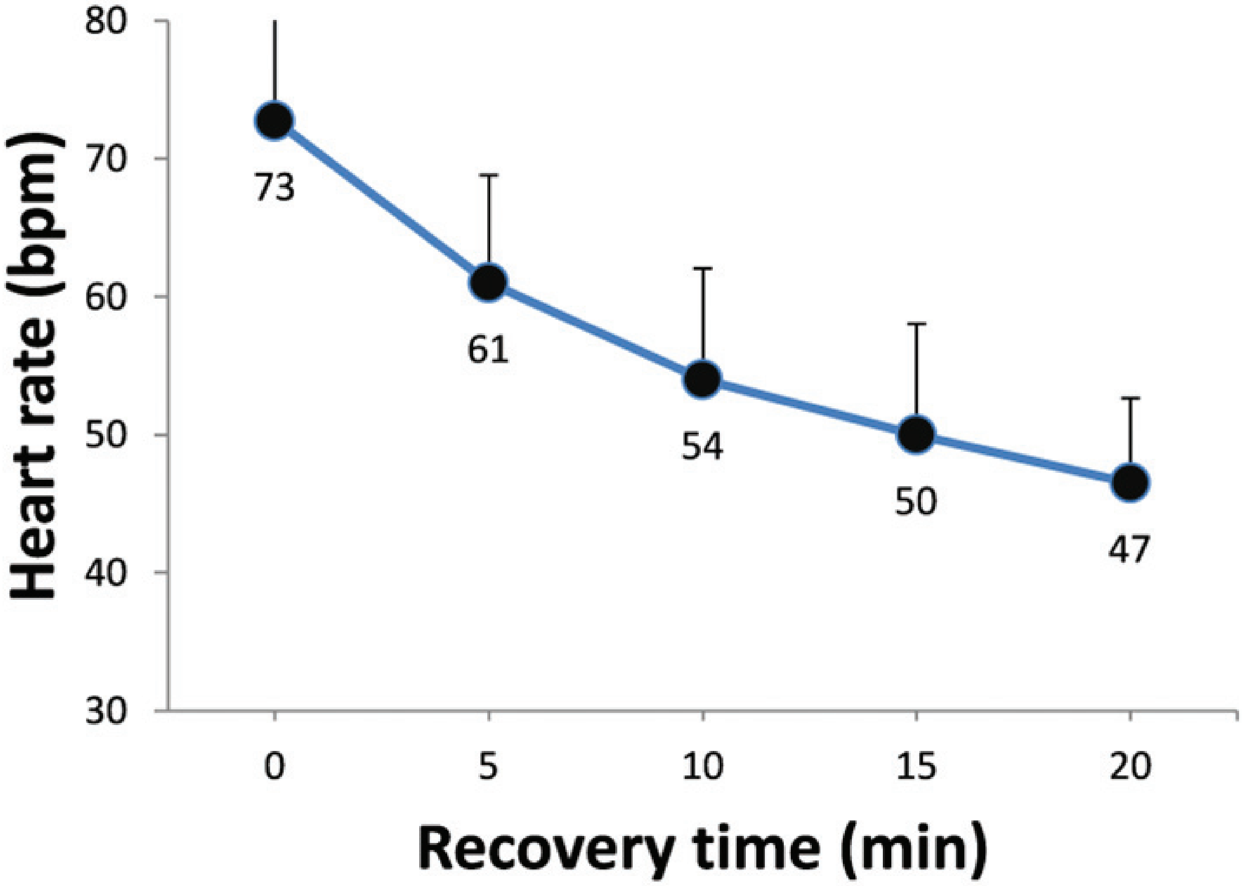

Figure 3. Mean recovery heart rate for all horses pooled together after training.

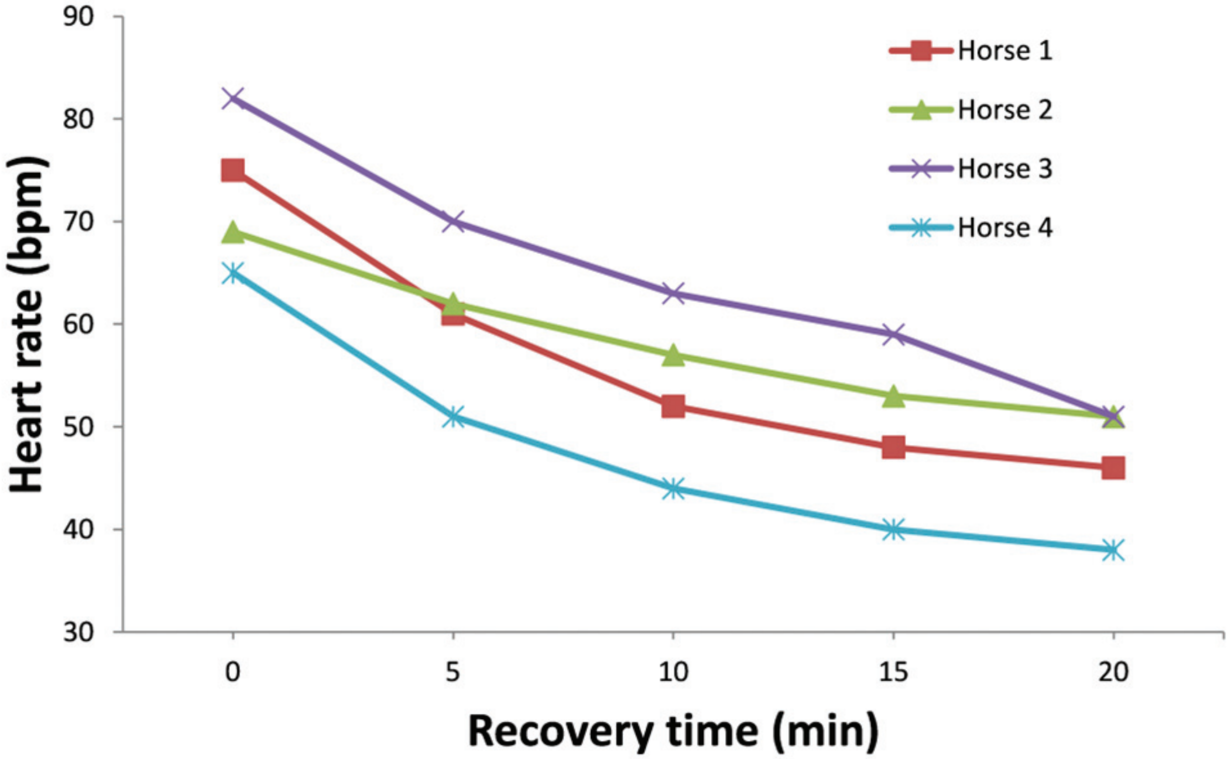

Figure 4. Recovery heart rate of each study horse after training.

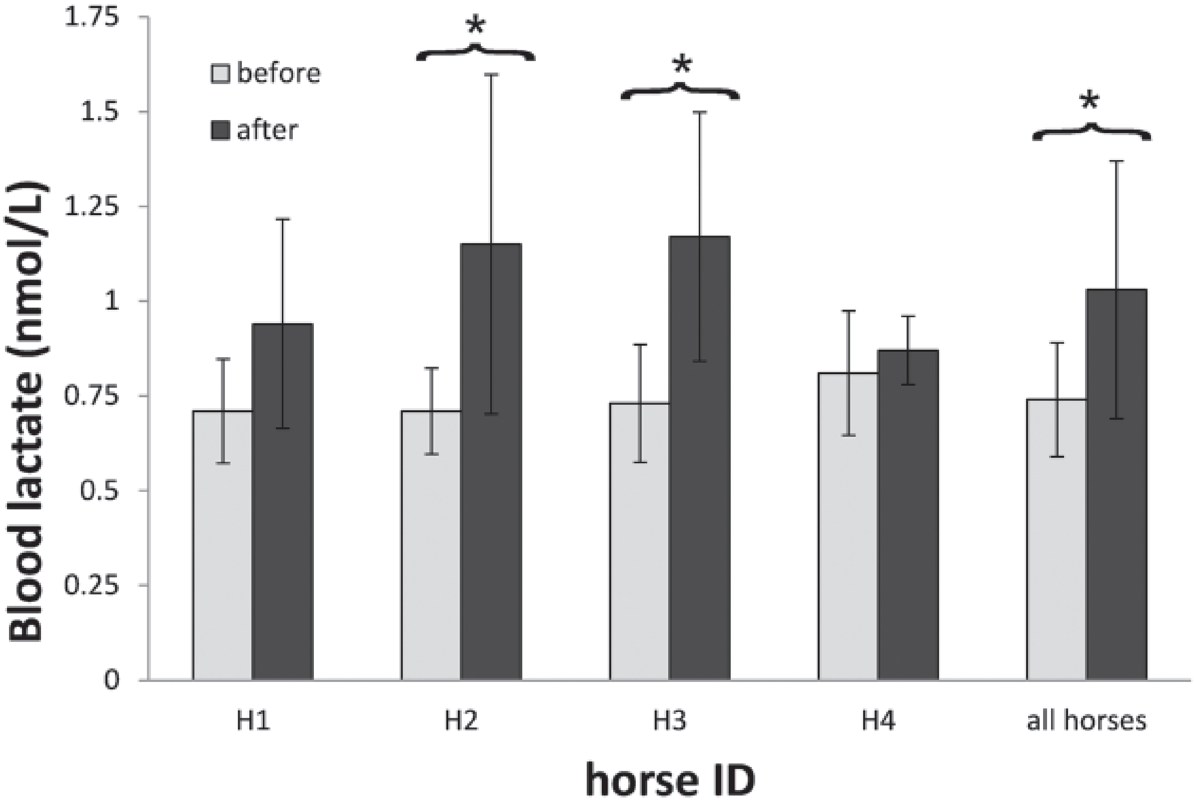

Figure 5. Blood lactate data before and after training for H1, H2, H3 and H4. Bars show the mean ± SD of blood lactate; Significant increases ($P < 0.05$) after training are indicated by the asterisks.

Discussion

This study shows that the majority of muscle segments showed an increase in muscle tone after training. However, the muscle stiffness tended to decrease along spine in the caudal direction, shown by decrease between T16, T18 to L2 during trotting on the track. Similar to one recent study, the muscle activity tends to decrease along spine in the caudal direction during trotting on the treadmill (Ritruechai, 2009). This would imply that the muscle stiffness depends on the muscle activity of the horse during dynamic movement and the muscle tone seems to decrease at T18 and L2. The studies in vivo at walk and trot have showed that the amplitude of measured EMG was highest at T12 and decreased caudally (Licka et al., 2004; Licka et al., 2009). This is related to an in vitro study in which the range of possible movements gradually decreased cranio-caudally from T10 to L2 (Jeffcott and Dalin, 1980). Another study in vitro study revealed that the muscle fascicle architecture predisposes the *longissimus dorsi* to different functions both along its length and between different regions (Ritruechai et al., 2008).

According to our results, the muscle stiffness is greatest at T16. This implies that the horse has more muscle tension on this area probably because the weight of the jockey during training is normally bearing at T16. The role of the saddle during riding has also been concern for back stiffness: both the weight and saddle induce an overall extension of the back which may play a role in soft tissue injuries and the kissing spine syndrome (de Cocq et al., 2004). Further factors that may increase a horse experiencing back stiffness could be due to the riderís position and experience, and also how the tack is fit to the horse back (Harman, 1999).

The muscle stiffness between left and right sides was significantly different at T18 muscle segment before training. It was also significantly different at T14 and T18 muscle segments between left and right sides after training. This would be imply that the *longissimus dorsi* both sides are responded to speed, rider's weight and his maneuver over the horse (Harman, 1999; de Cocq et al., 2004). The resistance of the horse to the riders, with lowering or lifting the head could result in flexion or extension of the thoracolumbar spine (van Weeren, 2006). One recent study showed that the correlation of muscle activity between the left and right sides changes at different sites along *longissimus dorsi* and different gaits (Wakeling et al., 2007).

Observed differences of horses' blood lactate concentration before and after training are likely explained by plasma lactate concentration increasing with the intensity of exercise (Hogdson, Rose, 1994; Lindner et al., 2009). Nevertheless, lactate values were generally less than 1.2 mmol/L, which fall within the known normal concentration scores of a resting horse (0.6-1.9 mmol/L; Knottenbelt, 2006). The reason for this could be that our trotting exercise was not intensive enough to induce larger changes in blood lactate concentration. In addition, it has been reported that during trotting, horses exhibit an average blood lactate level at 2.01 ± 0.33 mmol/L (mean ± SD) after exercise (Piccione et al., 2010). This would be imply that our experiment horses are a fit athletes

The recovery heart rates for all horses tended to decrease to less than 70 beats per minute after 5 minutes of stopping training. Recovery heart rate is accepted universally as a means to assess the ability of endurance horses to continue a competition. It is suggested that in the fittest racing horses, recovery heart rate would drop below 70 beats per minute within 5-10 minutes after stopping exercise (Freeman et al., 1991). However, because our training protocol was only to trot the horse during less than 30 minutes, the recovery heart rate did not show much difference.

Conclusions

We found that *longissimus dorsi* muscle tone was stiffer after training than at rest and that its stiffness tended to decrease along the spine in the caudal direction between T16, T18 to L2 during trotting on the track. The muscle stiffness was greatest at T16 due to the weight of the riders normally placed on its position. The muscle stiffness between left and right sides after training was different at T14 and T18 muscle segments due to the muscle from both sides responding to speed, and rider's weight and maneuvers over the horse. The blood lactate concentration of horses in this study significantly increased after training, but the values were generally within the normal range. The recovery heart rates in this study†dropped below 70 beats per minute after 5 minutes of stopping exercise. We confirmed that the longissimus dorsi is a key muscle in horse movement that can be sensitive to relatively small training sessions; that is why this muscle is prone to get injured. Generally, the muscle intender was a successful tool of objectively measuring this muscle tone.

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