Clinical Perspectives on Equine Back Kinematics

A Biomechanical Analysis of the Equine Back at Walk and Trot

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Cover: Horse wearing reflective markers on the treadmill
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Abstract

Back pain and dysfunction are important reasons for impaired performance in sport horses. Earlier studies have developed a clinical tool, the infrared-based automated gait analysis system, to objectively evaluate the function of the equine back. The aim of this thesis was to test its ability to differentiate horses with back pain from clinically sound horses. Additional aims were to evaluate the effect of local anaesthesia and weighted boots, respectively, on the movement of the back in asymptomatic horses. In all studies, the kinematics of the back were recorded at 240 Hz at walk and trot on a treadmill. Range of movement and symmetry of movement were derived from angular movement pattern data in Backkin®.

In Study I, the back kinematics of twelve horses with clinical back pain and dysfunction were measured and compared to the same parameters in 33 clinically sound horses in regular training and competition.

In Study II, a crossing-over study, ten clinically sound horses were measured before and after injections with mepivacaine and injections with sodium chloride around the interspinous spaces between T16 and L2.

In Study III, a lactic acid solution was injected into the left *m. longissimus dorsi* of eight clinically sound horses. The movement of the back was measured before the injections and on five occasions during the week subsequent to the injections.

In Study IV, a crossing-over study, eight clinically sound horses in regular training and competition were measured with and without weighted boots on the forelimbs and hind limbs, respectively.

In conclusion, the results show that the infrared-based automated gait analysis technique can differentiate horses with back dysfunction from horses with normal back movements, and that this technique can be used to evaluate a specific, localized change in movement in a patient with clinical back pain. It has also been shown that local anaesthesia affects the back movement in asymptomatic horses, and that weighted boots on the limbs affect the movement of the back in clinically sound horses. Suggestions for future items to be studied are bilateral back pain and long-term follow-ups of back patients after treatment.

Keywords: equine, horse, back movement, back pain, kinematic evaluation, biomechanics, local anaesthesia, induced back pain, lactic acid, weighted boots

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Contents

List of publications 7

Abbreviations 8

Introduction 11

Diagnosing back problems in horses 11

Background 13

History 13
- *Back problems over the centuries* 13

Anatomy of the back 15
- *The vertebral column* 15
- *Spinal ligaments* 17
- *Muscles affecting the movement of the back* 17

Movement of the back 19
- *Biomechanical research* 19
- *The movements of the equine back* 21
- *The movement of the back at trot* 23
- *A comparison of the movement of the back at walk and trot* 23

Back problems 29
- *Kissing spines and injuries of the supraspinal ligament* 29
- *Degenerative changes related to the articular processes* 30
- *Congenital and degenerative changes associated with the vertebral bodies and transverse processes* 31
- *Sacroiliac dysfunction* 32
- *Fractured spinal processes or vertebral bodies* 33
- *Pelvic fractures* 33
- *Spinal muscle pathology* 34

Aims of the investigations 37

Materials and methods 39

Horses (Studies I, II, III and IV) 39

Clinical examination (Studies I, II, III and IV) 41

Experimental set-up and data collection (Studies I, II, III and IV) 41
- *Training* 41
- *Measurements* 41

Calculation of back kinematics *42*
Back patients versus asymptomatic controls *43*
Local anaesthesia *43*
Induced reversible back pain *44*
Weighted limbs *44*
Statistical analysis 45
Ethical review 45

Results **47**

Back patients versus asymptomatic controls 47
Local anaesthesia 49
Induced reversible back pain 52
Back examinations *52*
Back kinematics - Range of movement (ROM) *55*
Back kinematics - The instantaneous vertebral angles throughout the stride cycle *57*
Stride parameters *65*
Weighted limbs 65
Additional results 67
A *clinical case* *67*

General discussion **71**

The movement of the back in horses with back pain and dysfuntion 71
Local anaesthesia as a diagnostic aid 73
The effect of weighted boots on the movement of the back 74
The infrared-based automated gait analysis technique 75
Kinematic analysis as a tool to evaluate back dysfunction 76

Conclusions **77**

Future studies 78

Manufacturers' addresses **79**

References **81**

Acknowledgements **89**

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Wennerstrand, J., Johnston, C., Roethlisberger-Holm, K., Erichsen, C., Eksell, P. and Drevemo, S. 2004. Kinematic evaluation of the back in the sport horse with back pain. *Equine vet. J., Suppl.* **36**, 707-711.

II Roethlisberger Holm, K., Wennerstrand, J., Lagerquist, U., Eksell, P. and Johnston, C. 2006. Effect of Local Analgesia on the Movement of the Equine Back. *Equine Vet. J.* **38**, 65-69.

III Wennerstrand, J., Gómez Álvarez, C.B., Meulenbelt, R., Johnston, C., van Weeren, P.R., Roethlisberger-Holm, K. and Drevemo, S. Spinal kinematics in horses with induced back pain (*manuscript*).

IV Wennerstrand, J., Johnston, C., Rhodin, M., Roethlisberger-Holm, K. and S. Drevemo. 2006. The effect of weighted boots on the movement of the back in the asymptomatic riding horse. *Equine and Comparative Exercise Physiology* **3**, 13-18.

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Abbreviations

AMP	Angular movement pattern
cm	Centimetre
D	Dressage
Dri.	Driving
E	Three-day-eventing
ER	Exertional rhabdomyolysis
G	General purpose
Hz	Hertz
i.m.	Intramuscular
Int. I	Intermediare I
J	Show jumping
kg	Kilogram
L	Lumbar
LF	Left front
LH	Left hind
m	Metre
m.	Muscle
M.	Muscle
mg	Milligram
RF	Right front
RH	Right hind
ROM	Range of movement
S	Sacral
s.d.	Standard deviance
SI	Sacroiliac
Stb.	Standardbred trotter
T	Thoracic

T/L-junction	Thoracic/Lumbar-junction
Wbl.	Warmblood

Introduction

Diagnosing back problems in horses

More than a hundred years ago, Lupton stated that back pain is one of the most common, yet least understood problems in sport horses (Jeffcott, 1999). Today, back problems are still a common reason for impaired performance in riding horses (Jeffcott, 1980a; Jeffcott, 1999), and diagnosing a patient with dysfunction of the back is usually time-consuming. The findings may also be difficult to interpret (Jeffcott, 1979; Martin and Klide, 1999; Erichsen *et al.*, 2003a), especially since decreased performance is often the only symptom.

Different injuries may affect back movement patterns in various ways, and movement tests are valuable and may give crucial information. Back pain and dysfunction may appear as symptoms such as tail swishing, resentment at mounting, poor jumping, or failure to bend or yield to aids, but commonly it is beyond the perceptive ability of the human eye to detect a change in back movement. While the eye can detect changes in movement only above a certain amplitude, automated gait analysis systems have proven to be a valuable and adequate tool to document even minor movements and changes therein in both humans and animals (Faber *et al.* 2001c; Licka *et al.*, 2001; van Weeren, 2005; van Heel *et al.*, 2006a; Gradner *et al.*, 2007; Meyer *et al.*, 2007; van Dillen *et al.,* 2007). Present-day technology will thus help uncover changes in movement due to pain or dysfunction earlier than would be possible by a traditional clinical observation alone.

Background

History

Back problems over the centuries

Primary and secondary back problems have most likely caused pain and abnormal movements in working horses for as long as they have been used by man, but only recently has the equine back become more closely investigated. Compared to colic or laminitis for example, the symptoms generally develop more gradually in horses with back problems. This, together with the initially less affected work capacity and insufficient diagnostic techniques, may explain why it took so long before we started evaluate the equine back more closely.

The literature suggests that the type of work performed by the horse has influenced the prevalence of different kinds of back problems. Riders on the steppes in Asia (about 600 B.C. – 200 A.D.) rode long distances at gallop (Furugren, 1990). Over time, this made the horses incredibly enduring. The training process of the young horses started very early and their backs became robust and rigid. This did not affect the riders particularly, since they rode at walk and gallop only.

The horse has gradually become bigger over the centuries. It is assumed that the average height at the withers was approximately 135 cm during the Bronze Age, while a regular horse was about 150 cm during the Roman Era (Furugren, 1990). The habit to *ride* the horse had then become much more common and the horse was used frequently at war. Heavy suits of armour used to protect the horses could sometimes weigh more than 50 kg. This additional weight required strong and enduring backs. As a consequence, the biggest horses became very valuable. In the Nordic countries and on the British islands, horses fulfilling these criteria were scarce for a long time, and both Gustav Wasa and Henry VIII forbade the export of high horses.

A common problem in heavy draft horses was the so-called "strain of the back" or "sway'd back" (Jeffcott, 1999). Typically this meant strained back muscles, but could also include an injured spinal cord and discolouring of the skeleton. In more serious cases the horses had both an aching back and a lame limb. Such horses were called "chinked". It has also been reported that ankylosis of the back vertebrae were common among older and hard working horses. They were then called ”broken-backed" or ”chinked in the chine", which is believed to have been osteoarthritis.

In older literature you can find descriptions of how horses with strained ligaments showed pain and reluctance on mounting and then kicked and reared (Jeffcott, 1999). Presumably this was what we nowadays call "cold back". These symptoms were also thought to arise as a consequence of a certain temper.

Injuries caused by saddles and harnesses have a long-known history (Biengräber, 1916). This type of tack has been used for a long time and the pressure injuries are easy to relate to the anamnesis. A special form called "saddle galls" was more common among horses ridden by ladies (Jeffcott, 1999), probably because of the side-saddles.

Spinal fractures were in the beginning of the 20th century thought to make up for 4-5 % of the equine fractures (Vennerholm, 1914). The anamnesis and prognosis differed depending on whether the fracture was located to the dorsal spinal processes or to the vertebral bodies. Horses working in the forests were sometimes hit by falling trees, which in unfortunate cases resulted in fractured dorsal spinal processes, transverse processes or pelvic wings.

Field surgery is nowadays generally performed on horses standing, but for a long time the casting harness was a commonly used aid, for example at castration and this procedure resulted frequently in fractures of the spinal column (Vennerholm, 1914). Attempts to escape or heavy movements in the recovery during the excitation phase, often result in great strain on the spinal vertebrae. When the horse flexes its back to the maximum, and at the same time contracts the *m. longissimus dorsi* and the psoas muscles, the vertebral bodies in the thoracic and lumbar back are compressed. The forces may be considerable and enough to result in a comminute fracture. Fractures in the vertebral column were seen mainly at the thoracolumbar junction (Vennerholm, 1914), one of the regions that modern research has shown to be exposed to both injuries and movement alterations (Denoix, 1999; Jeffcott, 1999; Denoix, 2004; Wennerstrand *et al.*, 2004).

The conformation of the horse has been a debated topic since long. Peter Hernquist wrote that the thoracic back is more enduring if it is short and not too wide (Hernquist, 1793). A long back was considered to give a more comfortable gait and a beautiful appearance of the neck, but at the same time a weaker back. The same was believed for the lumbar back; "a short lumbar back gives strength, but also a less comfortable gait. A horse with a long lumbar region is easier to ride, but a disadvantage is lost muscular and ligament strength." The English Youatt had a similar opinion and he said that a short back indicates strength and endurance, while a long back favours a high speed (Jeffcott, 1999).

Occasionally horses develop abnormally. When we nowadays notice that a young horse grows in an abnormal way, we try to stop or prevent this by altering the feeding, trimming of the hooves and the exercise, and we consider the facts very carefully before recommending more radical methods. Few decades ago, extreme methods were used more regularly (Vennerholm, 1914). When, for instance, a horse showed signs of kyfosis, the owner was advised to place the manger high, break the horse early, and use the reins to raise its head.

In relation to their anatomical and physiological capability, the performance horses of today are trained and competed at high levels, and minor differences in movement pattern, strength and speed may make the difference between winning and loosing.

Anatomy of the back

The vertebral column

The equine vertebral column consists of 7 cervical (C), 18 thoracic (T), 6 (occasionally 5) lumbar (L), 5 sacral (S), and approximately 20 caudal vertebrae. Different types of movement arise between two adjacent vertebrae. The type and degree of movement depend on the appearance of the vertebrae, which varies along the vertebral column. Each vertebra consists of a body, from which several processes arise. There are one dorsal, two transverse and four articular processes.

The vertebral column has several functions. Its rigidity constitutes an excellent protection to the spinal cord and associated nerve roots, and it also supports the horse's whole body. The division of the vertebral column into several small segments, gives the neck and back flexibility, and allows for greater movements than would else have been possible.

The vertebrae are linked to each other by long and short ligaments, which together with muscles and tendons stabilize the vertebral column. The size, shape and angles of the muscles and vertebral processes vary along the spine, since each vertebra is uniquely designed to best serve the functional purposes.

The dorsal spinous processes are long and caudally inclined in the cranial thoracic region. Under the saddle they become more vertical and are reduced in length. The last thoracic vertebrae and those in the lumbar back, have even shorter spinous processes, pointing slightly cranially.

The transverse processes are wide and large in the cervical region, and provide good attachments for muscles and ligaments. In the thoracic region, costotransverse articulations are formed by the ribs and articular surfaces on the short transverse processes of the thoracic vertebrae. The transverse processes in the lumbar back are long, wide and flat, and the important sublumbar muscles are attached to the ventral side of these processes. The transverse processes of L4 and L5 are sometimes united by intertransverse synovial joints, equally to the synovial articulations between the transverse processes of L5 and L6, and L6 and S1 (Stecher, 1962; Townsend and Leach, 1984). Finally, the sacrum, has fused transverse processes, forming the cranial wings and the lateral crests.

Four articular processes arise from the vertebral arch, two pointing cranially and two caudally. The caudal articular processes form, together with the two cranial processes on the following vertebra, bilateral synovial joints. These additional articulations interlock adjacent vertebrae, forming one long vertebral chain, the vertebral column. The joint capsule is reinforced dorsally by the *m. multifidi*, and ventrally by the ligamentum flavum.

The joints between adjacent vertebral bodies are fibrocartilaginous articulations with an intervertebral disc inserted between the bodies. The disc has an outer annulus fibrosus with concentrical layers of fibers, and an inner, gelatinous nucleus pulposus, which in horses is rudimentary in the thoracic region compared to in the cervical and lumbar regions. Thicker discs provide more mobility. Consequently, the disc in the lumbosacral joint is thicker than the average thoracic or lumbar disc to meet the functional requirements at the lumbosacral junction. The overall relative thickness of the discs is less in horses than in humans or dogs (Dyce *et al.*, 1987).

The vertebral column is articulated to the pelvis by the sacroiliac (SI) joints. The cranial wings on the sacrum are positioned against the medial side of the wings on the ilium. Strong ligaments are needed to support the sacroiliac joint and the caudal vertebral column. There are three bilateral sets of ligaments, connecting the ilium to the sacrum; the dorsal sacroiliac ligaments, the interosseous sacroiliac ligaments and the ventral sacroiliac ligaments. To further enhance the stability, there are also ligaments running between the sciatic bone and the sacrum, the sacrosciatic ligaments.

Spinal ligaments

Three longitudinal ligaments run along the vertebral column providing stability. The nuchal ligament starts at the external occipital protuberance of the cranium. As it runs over the first and second cervical vertebrae, and when it passes over the top of the third thoracic vertebra, the ligament is protected by three bursae. At the withers, the nuchal ligament is continued by the less elastic supraspinous ligament, which ends on the sacrum. This ligament joins the summits of the thoracic and lumbar spinous processes. The dorsal longitudinal ligament runs dorsally on the vertebral bodies, at the bottom of the vertebral canal, and the ventral longitudinal ligament runs ventrally on the vertebral bodies. These ligaments give stability to the back, and reinforce the discs (Haussler, 1999).

Between adjacent vertebrae, short ligaments provide stability to each back segment. The interspinous ligaments connect adjacent dorsal spinous processes, while intertransverse ligaments connect adjoining lumbar vertebrae. The spaces between contiguous vertebral lamina of the respective vertebra are bridged by ligamenta flava.

Muscles affecting the movement of the back

Spinal muscles are grouped as epaxial and hypaxial muscles (Budras and Sack, 1994; Haussler, 1999). The muscles dorsal to the transverse processes, the epaxial muscles, extend the back, while the hypaxial muscles ventral to the transverse processes flex the spine. Unilateral activity of the spinal muscles bends the back laterally.

Generally, the deep muscles are shorter than the superficial. The *m. multifidi* is a series of short units close to the spine, each spanning only two to four vertebrae. These short muscles have a high percentage of type 1 muscle fibers and therefore a static function (Haussler, 1999). If they are injured, it will affect stabilization, proprioception and posture negatively.

The spinalis, longissimus and iliocostalis muscles fill the space between the spinous and transverse processes. *M. spinalis* is located closest to the spinous processes (Budras and Sack, 1994). It is more prominent at the withers, where it can be injured by a narrow saddle, and decreases in diameter further caudally in the thoracic region.

M. longissimus is the greatest and longest of the spinal muscles. It has its origin on the spinous processes of the sacrum, lumbar and thoracic vertebrae, on the transverse processes of the thoracic and cervical vertebrae and on the wings of the ilium bones, and it inserts on the transverse processes, the tubercles of the ribs, on the atlas and on the temporal bone (Budras and Sack, 1994). It is a muscle of great functional importance as it stabilizes and extends the vertebral column, and also elevates and bends the head and neck laterally.

M. iliocostalis runs along the lateral border of the transverse processes of the lumbar vertebrae to the ribs. It also bridges the transverse processes of the caudal cervical region. As the other epaxial muscles, it extends the back or bend it laterally (Budras and Sack, 1994). It also stabilizes the lumbar region and the ribs. The larger epaxial back muscles have a high percentage of type II muscle fibers, and they are all important for dynamic functions; movement, posture and flexibility (Haussler, 1999).

The shoulder and pelvis girdle muscles have attachments on both the axial skeleton and the proximal limb segments. Their general function depends on whether the vertebral column or the limbs are held stationary in relation to the other (Haussler, 1999). When the limb is loaded, muscle activity results in movement of the back, and inversely; when the back is held stabilized, these muscles induce movements of the proximal limbs. *M. brachiocephalicus, m. trapezius, m. rhomboideus and m. latissimus dorsi* suspend the forelimbs from the neck and trunk, while the pectoral muscles and *m. serratus ventralis* suspend the neck and trunk from the forelimbs.

The muscles in the pelvic girdle affect the pro- and retraction of the hind limbs, and the flexion and extension of the hip joint. *M. sartorius, m. iliopsoas, m. tensor fascia lata* and *m. rectus femoris* are located cranially to the hip joint (Budras and Sack, 1994). They protract the hind limb, and flex the hip joint. Their antagonists, *m. biceps femoris, m. semitendinosus and m. semimembranosus*, retract the hind limb and extend the hip joint. The great *m. gluteus medius* assists in transmitting the force forward from the hind limb to the spine, and is connected to the longissimus muscle by an aponeurosis. This muscle assists in extending the hip joint, and also abducts the limb, while adduction of the limb is induced by *m. gracilis, m. adductor* and *m. pectineus*.

The sublumbar psoas muscles and the iliacus muscle are antagonists to the epaxial muscles. *M. psoas minor* has its origin on the ventral side of the bodies of the last few thoracic and first few lumbar vertebrae, and *m. psoas major* starts in the same region of the back, ventrally on the transverse processes (Budras and Sack, 1994). *M. psoas minor* inserts on the psoas minor tubercle of ilium, and flexes pelvis on the loins, while *m. psoas major* fuses with *m. iliacus* as it passes ilium, and inserts on the lesser trochanter of femur. The iliopsoas muscle protracts the hind limb and flexes the hip joint. When the limb is loaded, this muscle stabilizes the back.

The abdominal muscles also influence the movement of the back, and *m. rectus abdominis* in particular is of great importance in gaits with a suspension phase, where it helps prevent overextension of the lumbar back (Denoix and Audigié, 2001). *M. rectus abdominis* runs from the lateral surface of the cartilages of the last true ribs to the prepubic tendon and head of femur (Budras and Sack, 1994). The rectus abdominis muscle limits the extension of the thoracolumbar back and flexes the lumbar region and the lumbosacral joint when active.

The movement of the back

To understand how the equine back moves, and how the movements change when the back is influenced by external factors, we study the biomechanics, which gives information on the equilibrium and movements of different body segments. While the clinical examination is always fundamental and the initial step when diagnosing back problems, the biomechanics give additional, objective information about the movements, and alterations of the movements, that are too small for the human eye to detect.

Biomechanical research

Biomechanical work has been performed for centuries. Galileo (1564-1642) studied solids and William Harvey (1578-1657) fluids, and later the Italian mathematician, physicist, astronomer and physiologist Giovanni Borelli made several studies on the subject (Vogel, 2007). Borelli wrote the physiological work *De Motu Animalium,* in which he explains the movements of living beings (Borelli, 1680).

In the 19th century the Irish scientist Samuel Haughton wrote the extensive book *On Some Elementary Principles in Animal Mechanics*, which have been appreciated still during the 20th century (Hildebrand, 1962).

The Dutch scientist E.J. Slijper, described in 1946 a biomechanical model on the relationship between the vertebral column and the ventral part of the trunk (Slijper, 1946). This "bow and string" theory is generally accepted even today, and the concept illustrates an interaction between the thoracolumbar spine, the pelvis, the limbs, the sternum and the abdominal muscles. The spinal column is held under tension like a bow by the abdominal wall (the string). Activity in the epaxial muscles stretch the back and relax the bow, while contraction of the hypaxial sublumbar muscles and the abdominal muscles flex the back and tense the bow. The weight of the viscera also promotes stretching of the back (relaxing of the bow), as do protraction of the forelimbs and retraction of the hind limbs.

Since an animal has to move in slow motion for the human eye to observe its true movement pattern, the advent of photography was a great breakthrough in biomechanical research. In the late 1800s, Eadweard Muybridge, "The Father of Motion Picture" was challenged to set a bet between Leland Stanford, railroad baron and future founder of the Stanford University, and a friend of his over whether or not all four feet of a galloping horse are ever simultaneously suspended off the ground. To solve this challenge, Muybridge invented a method to take continous photographs in a series. In 1887 he published an extensive series of studies on human and animal locomotion (Muybridge, 1887).

When photography was combined with computer techniques during the second half of the 20th century, it increased the possibilities to obtain much more detailed information on the movements of humans and animals. Biomechanical researchers started use high-speed cinematography to record the movements of horses (Fredricsson *et al.*, 1980), which improved quality and efficiency. When the horses later were put on a treadmill, with cameras placed around the treadmill (Jeffcott *et al.*, 1982; Fredricson *et al.*, 1983), it gave the possibility to study the equine movements with less interference from external factors.

Several *in vitro* studies have been made to better understand the movements of the equine back. Jeffcott and Dalin (1980b) studied post mortem specimens from Thoroughbreds to evaluate the natural rigidity of the thoracolumbar spine. Denoix investigated the amount of vertebral thoracolumbar flexion and extension movements (Denoix, 1999), and Townsend *et al.* (1983) studied the different types of movement of the equine spine; flexion-extension, lateral bending and axial rotation.

Data is today often captured at a sampling rate of 240 Hz, which should be compared to Muybridge's 4 pictures per second. Studies evaluating the equine movements have, during the last decade, given us a lot of new information on the movements of the back in normal, asymptomatic horses (Faber *et al.*, 2000; Denoix and Audigié, 2001; Faber *et al.,* 2001c; Licka *et al.* 2001; Johnston *et al.,* 2004). The influence of conformation and equipment has also been studied (Johnston *et al.,* 2002; de Cocq *et al.*, 2004; Licka *et al.,* 2004b), as has the interaction between movements of the limbs and the back (Faber *et al.,* 2001b; Álvarez *et al.,* 2007a), and recently, a few studies have evaluated the influence of back pain on the movements of the back (Faber *et al.*, 2003; Wennerstrand *et al.*, 2004; Gómez Álvarez *et al.*, 2008b).

The movements of the equine back

Several types of movement contribute to the versatile overall movement of the equine back. Dorsoventral flexion and extension, lateral bending (sometimes referred to as lateroflexion) and axial rotation are the three major movements (Figure 1). The vertebrae are also displaced vertically and horizontally when the horse moves.

- Flexion and extension movements occur around a transverse axis. **Flexion** of the vertebral column bends the back ventrally, making it dorsally convex, while **extension** creates a concave dorsal aspect. Flexion is biomechanically defined as a change in movement that creates a more positive angular movement pattern (AMP), while extension makes the AMP more negative.
- Movement of the vertebral column around a vertical axis is called **lateral bending**. Lateral bending to the left results in a more positive AMP, and bending to the right in a more negative one.
- When the vertebrae rotate around the longitudinal axis, it is referred to as **axial rotation**. If the dorsal spinous process rotates to the left, that is, counter-clockwise, seen from behind, it will generate a more negative AMP, while clockwise rotation of the spine makes the AMP more positive.

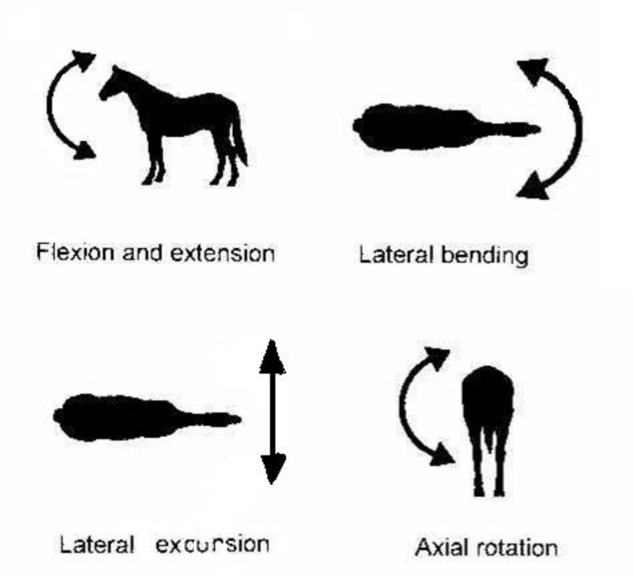

Figure 1. The three main movement types of the spine; flexion-extension, lateral bending, and axial rotation. Shown is also the lateral displacement movement, the lateral excursion.

- **Dorsoventral translation** displaces a vertebra vertically, up- or downwards, compared to its original position. This occurs when the particular region of the back is flexed or extended.
- **Lateral excursion** is associated with the lateral bending and axial rotation movements and is defined as the displacement to the left or right of the median plane.

The horse is designed to move a great deal, and in its natural habitat, as well as in most equestrian disciplines, rapid movements and changes in movement are included. The equine back has to provide flexibility and stability, both of great importance. The range of movement (ROM) between adjacent back vertebrae is generally small, but the whole vertebral column also acts as a complex functional unit with great cumulative flexibility .

The back is the connection between the force generating hindquarters and the neck and forelimbs, and stability of the back is required to adequately transmit the propulsive forces forward. The sacroiliac and intertransverse joints contribute in this process, and the latter joints also provide resistance to lateral bending and axial rotation movements (Haussler, 1999).

The movement of the back at trot

The suspension phase at trot requires an increased muscle activity to maintain the stability of the back, compared to at walk (Robert *et al.*, 1998).

The trunk starts its downward rotation at ground contact of the left (or right) hind limb (Denoix and Audigié, 2001). The vertebral column extends during stance as a consequence of visceral mass inertia, and the *mm. recti abdominis* are active at landing to limit this passive extension of the back (Audigié *et al.*, 1999). The hip joint starts to extend at the middle part of stance, followed by extension of the stifle and hock joints. At the end of the stance phase of the left hind limb, the vertebral column is convex to the left.

The lateral bending of the trunk is limited by the *m. longissimus lumborum* during symmetrical gaits (Denoix and Audigié, 2001). During the later part of stance, the trunk starts its upward rotation, which continues until the end of the swing phase. The *m. longissimus dorsi* is active at the end of each diagonal stance phase and early swing phase (Denoix and Audigié, 2001; Licka *et al.*, 2004a). First it induces an extension of the lumbosacral spine and facilitates the propulsion, followed by a stabilization of the thoracic and lumbar spine undergoing flexion (Denoix, 1999). Another muscle contributing before and after lift off is the *M. multifidous lumborum* (Denoix and Audigié, 2001).

At the propulsion, the stifle and hock joints are extended, as is also the lumbosacral spine. The moment after propulsion, the stifle and hock start to flex, which moves the limb slightly further caudally. The hip joint is extended to its maximum and the limb is maximally retracted. The back, which at the end of the stance phase is ventrally translated, starts to rise when the horse has just left the ground.

During the first suspension phase, the stance phase of the right hind limb and the second suspension phase, the left hind limb is protracted and the hip joint becomes more and more flexed. The vertebral column flexes during the suspension phases as a result of hind limb protraction.

A comparison of the movement of the back at walk and trot

The inter-limb coordination and footfall sequence differ between gaits, and consequently the movement of the back and the activity of its muscles differs too (Denoix and Audigié, 2001, Licka *et al.*, 2004a; Licka *et al.,* 2008). While the walk is a four beat, symmetric, right or left bipedal gait with no period of suspension, the trot is a two beat, symmetric, diagonal gait with two periods of suspension per stride cycle (Figures 2a and b).

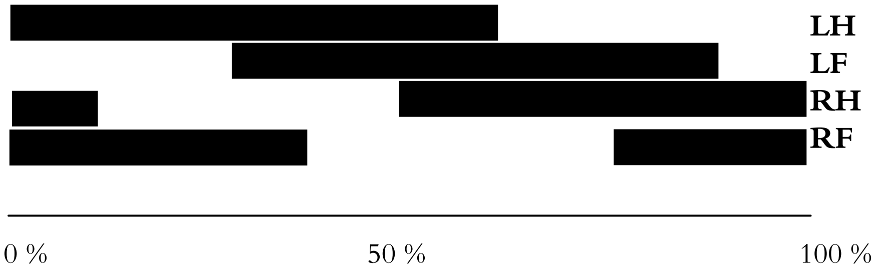

Figure 2a Walk

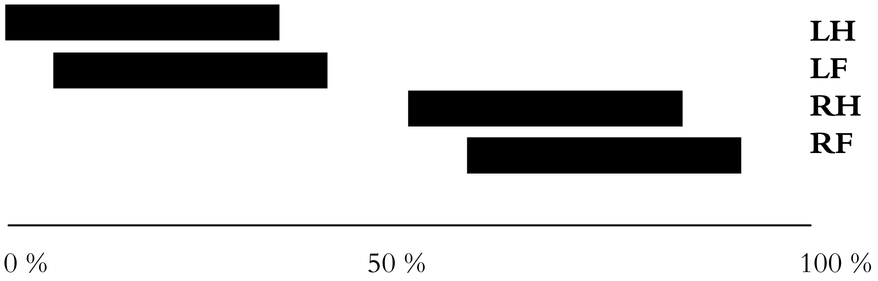

Figure 2b Trot

Figures 2a and b show the stance phase for each limb at walk and trot. LH=left hind; LF=left front; RH=right hind; RF=right front

- Since there is no suspension phase at walk, the antagonistic help of the abdominal muscles is not required, and *m. rectus abdominis* shows no electromyographic activity at this gait (Robert *et al.*, 1998).
- At walk, the back is extended at ground contact when the stride cycle starts, while it is very flexed at this moment at trot.
- At walk, the flexion and extension movements start in the caudal back. The movement then proceeds in cranial direction with a time shift, that is, flexion (and extension) of the caudal lumbar back proceeds flexion (and extension) of the thoracolumbar junction, which in turn proceeds flexion (and extension) of the thoracic back (Figure 3a). At trot, there is not a corresponding time shift, but instead a more simultaneous flexion/extension of the back. When the

gravitation force acts on the visceral mass at ground contact of the respective hind limb, it causes a passive extension of the back. The vertebrae at the withers are then rotated in the opposite direction compared to the vertebrae in the caudal lumbar back, which is illustrated in the graphs below (Figure 3b).

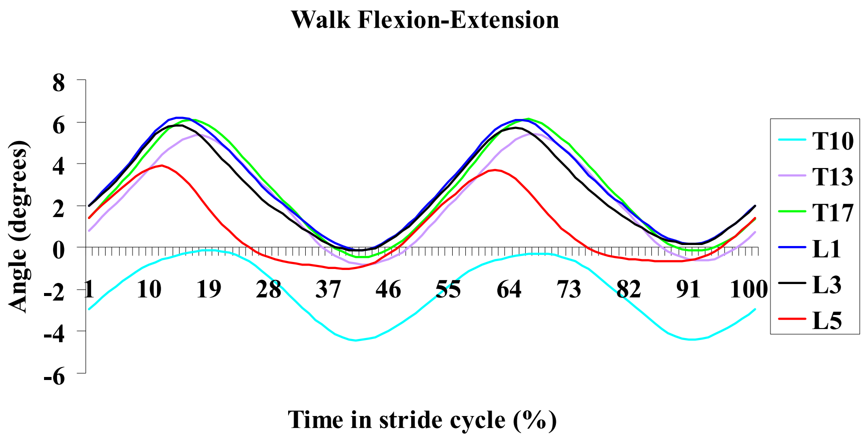

Figure 3a

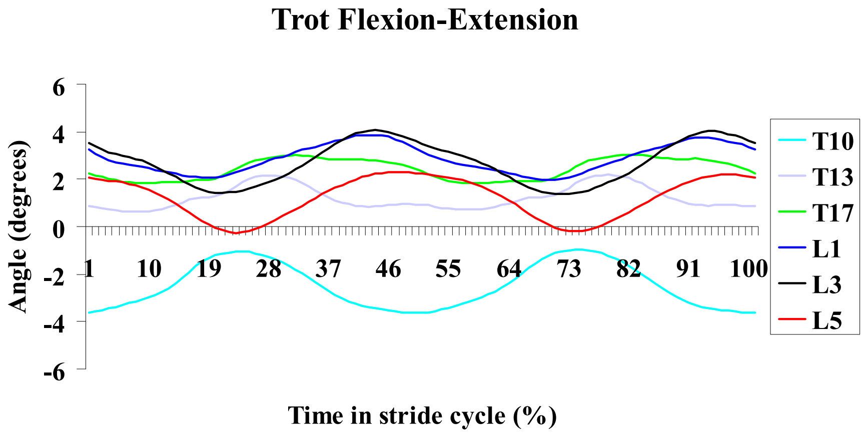

Figure 3b

Figures 3a and b show the flexion and extension movement of six back vertebrae during a stride cycle at walk and trot.

The amplitudes of the equine back movements generally become higher at walk than at trot (Figures 4a-c). The muscle activity is normally great at trot, while the movements, especially the lateral bending, are more passive at walk (Robert *et al.*, 1998).

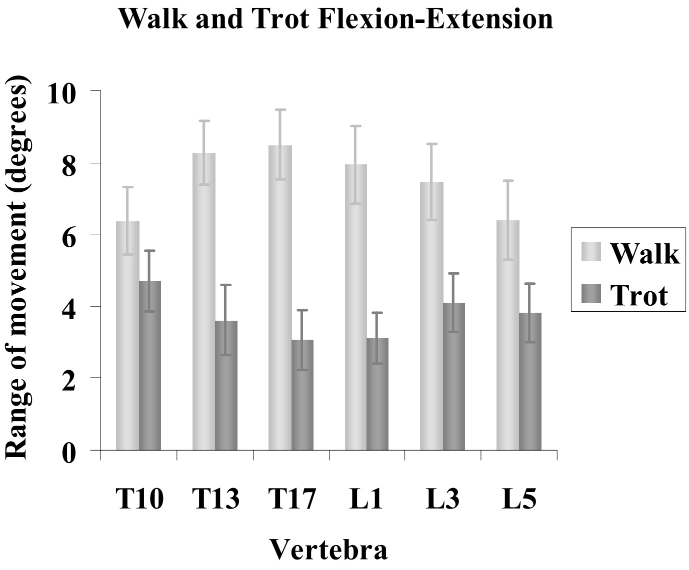

Figure 4a

Figure 4a shows the mean ROMs ±s.d. for the flexion-extension movement of six back vertebrae in clinically sound horses at walk and trot.

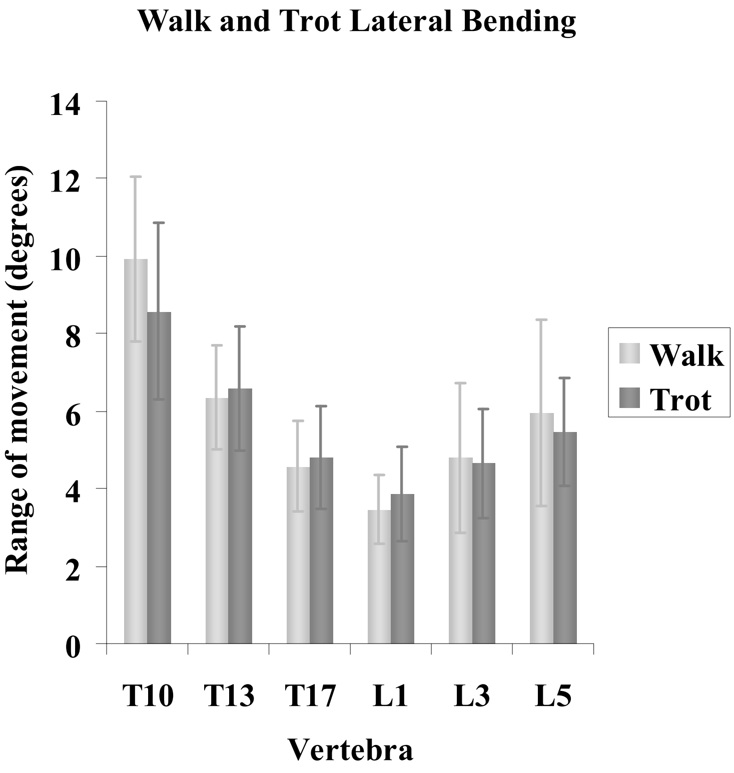

Figure 4b

Figure 4b shows the mean ROMs ± s.d. for the lateral bending movement of six back vertebrae in clinically sound horses at walk and trot

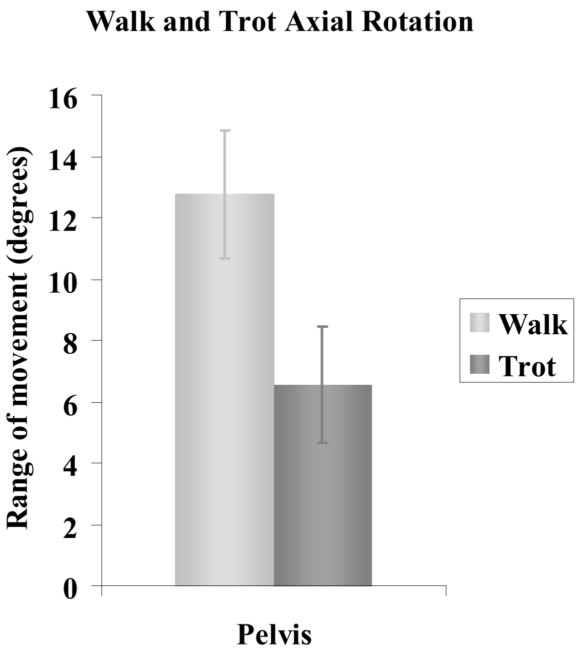

Figure 4c

Figure 4c shows the mean ROM ± s.d. for the axial rotation movement of the pelvis in clinically sound horses at walk and trot.

Back problems

When diagnosing a horse with a suspected back problem, the first challenge is to decide whether there *is* a back problem or not. If the clinical examination indicates a painful back, the next step is to evaluate which part of the back is injured, and finally, if possible, to find the underlying cause of the pain.

A horse with an apparent or suspected back problem can have poorly fitting tack, temperamental issues or simply lack the ability its rider desires, or it can have an actual back problem. A horse may react on palpation simply because of sensitive, thin skin, or it can be guarding because of earlier injure or for temperamental reasons.

Back disorders can be primary or secondary. Secondary back pain can arise e.g. as a consequence of lameness. Various factors like breed, gender, age, size or discipline for which the horse is used, affect the likelihood of developing a certain disorder. For instance, horses with short backs are more prone to vertebral lesions, while horses with long backs are more inclined to demonstrate muscular and ligamentous injuries (Jeffcott, 1999).

The clinical examination should include palpation of the neck, back and limbs. Palpation of the neck and back is preferably repeated a few times to see changes in reaction. However, it is important to remember that the palpation gives information on the pain on palpation, but it does not give information on the function, which is best evaluated by movement tests.

Kissing spines and injuries of the supraspinal ligament

Kissing spines, or overriding dorsal spinous processes, is commonly seen both in horses with back problems, and in fully functioning asymptomatic riding horses (Jeffcott, 1979; Townsend *et al.*, 1986; Erichsen *et al.*, 2004). The condition is most commonly seen in the caudal thoracic back (T10-T18), but can also occur in the lumbar back (Townsend *et al.*, 1986; Denoix, 1998; Jeffcott, 1999; Wennerstrand *et al.*, 2004). The prevalence has been reported to be higher in show-jumping performance horses, but also in high level dressage horses, compared to other horses (Jeffcott, 1980a). This is likely due to the great flexion-extension movements and demanding spinal maneuvers.

Overriding dorsal spinous processes can be graded into four categories (Jeffcott, 1980a). Grade 1 includes narrow interspinal spaces with mild sclerosis of the cortical margins. In grade 2, there is no interspinal space left. The sclerosis of the cortical borders is classified as moderate in patients with grade 2, and severe in grade 3 or 4 cases. In grade 3 there is also a transverse thickening and/or radiolucent areas. In the most severe type of kissing spines, the spinous processes have a changed shape and osteolytic areas may occur.

The functional perspective is important since a horse may have kissing spines without accompanying pain. Infiltration of a local anaesthetic between and around affected spinous processes may indicate if the overriding processes causes pain in a back patient or not (Stashak, 1987). Kissing spines is most consistently accompanied by pain if there is a simultaneous and relatively recent insertion desmopathy in the supraspinal ligament at the affected site (Denoix, 2004). When injured, the supraspinal ligament becomes thicker and painful. The initial symptoms are pain, heat and swelling, while an increased, palpable thickening is suggestive of a chronic injury. Commonly, the lesions arise over a spinous process, which results in a changed surface of the top of the process. The increased thickness of the supraspinal ligament induces a local deformation of the dorsal profile of the thoracolumbar region. The deformation, bump, is typically seen over the caudal part of the involved spinous processes.

Degenerative changes related to the articular processes

An abnormal appearance of one or more articular processes is not uncommon (Haussler *et al.*, 1997; Haussler *et al.*, 1999). If the change in morphology is accompanied by clinical symptoms depends on the degree and location of the change, and also the type of work requested from the horse. It is clear though, that in humans as well as in horses, the articular, i.e. zygapophyseal, joint complex has been reported as a common site for the origin of back pain (Bogduk, 1995; Denoix, 1998). In humans, painful cervical articular joints accounts for more than 50% of chronic neck pain after whiplash, and zygapophyseal joint pain is one of the three most common causes of chronic low back pain (Bogduk, 1995). Pathological changes at the zygapophyseal articulations at the thoracolumbar junction and in the lumbar spine, have also been reported to be one of the most common spinal disorders associated with back pain in horses (Denoix, 1998). If the pathological changes cause pain, the lateral bending movement pattern may appear different from the normal condition, and bending towards the affected side generates discomfort or even pain (Marks, 1999).

Several types of abnormal findings associated with osteoarthritis have been observed at the articular joint complexes (Haussler *et al.*, 1997). Asymmetry was found in at least one site in 83% of the horses in this study. Another study on the same horses showed degenerative changes in the thoracolumbar articular processes in 97 % of the individuals (Haussler, 1999). The pathological findings in this study were observed mainly at the thoracolumbar junction and in the lumbar region.

Abnormalities in the articular joint complexes have been found not only in young racehorses (Haussler *et al.*, 1997; Haussler *et al.*, 1999), but also in adult riding horses (Denoix, 2004). Abnormal findings in the articular joint complexes include both radiolucent areas in the subchondral bone and subchondral sclerosis, and periarticular proliferations can be seen dorsally and/or ventrally. Other pathological findings associated with the articular processes are ankylosis and fractures.

Congenital and degenerative changes associated with the vertebral bodies and transverse processes

Developmental differences are common in the equine spine. In a study on the functional anatomy in 120 horses, sacralisation of the last lumbar vertebra (L6) was found in every third horse (Stubbs *et al.*, 2006). Lumbosacral variations were generally common in ridden horses, but absent in Standardbreds. Another study on spinal specimens from a group of racehorses, reported that almost 40 % of the individuals did not have the expected 6 lumbar and 5 sacral vertebrae (Haussler *et al.*, 1997). It seems however, that if the number of vertebrae in one region is decreased or increased, it is frequently compensated for by an additional or excluded vertebra in an adjacent region. Occasionally, a transitional vertebra may occur. This may be of clinical importance, but thoracolumbar and lumbosacral vertebrae are known to occur sporadically as a random finding.

Spondylosis is a degenerative and initially subclinical condition of the vertebral joints, with remodelling and osteophyte formation on the vertebral bodies (Haussler, 1999). If an osteophyte grows near an intervertebral foramen, it may compress a nerve root with subsequent pain, and sometimes the osteophytes become large enough to span the intervertebral disc. Abnormal articular loading induces bony proliferations that bridge the intervertebral space laterally. Prolonged osteophyte formation and inflammation can eventually lead to complete ankylosis. Ankylosis can be painless, but the ankylosed vertebral bodies are susceptible to fracture due to the reduced load absorbing capacity of the joint.

Sacroiliac dysfunction

Stability, not movement, is the essence of the sacroiliac (SI) joint. The joint capsule is close-fitting and the narrow joint space is often bridged by fibrous bands. Dorsal and ventral sets of sacroiliac ligaments further reinforce the joint. Stresses that result in movement, may induce subluxation (Stashak, 1987). Displacement and instability may cause chronic pain, and until sufficient scar tissue has formed and the injury is healed, the horse may have reflex muscle spasms.

Recent research has indicated two clinical forms of SI dysfunction (Dyson and Murray, 2003). The typical patient is either a performance horse that is still in work, but with pain and impaired performance, or a horse with rather poor performance and obvious gait changes. The latter has also been reported to have muscle asymmetries and chronic pathological joint changes.

Affected horses can be reluctant to jump because of the pain it causes, and they are commonly stiff and painful in the hindquarters (Stashak, 1987). The joint instability and muscle spasm induce inflammation, which can lead to lameness. Gait changes include prolonged stance duration and delayed subprotraction of the hind limb. As a result, the front hoofs impact the ground before the hind hoofs, and the stride is shortened. The tuber sacrale on the affected side has been reported to often become higher than the unaffected one, and since jumping hunter horses are among those suffering from this problem, the visible tuber sacrale is referred to as a hunter's bump (Marks, 1999). However, in a recent study on 74 horses with clinical signs suggestive of SI joint pain, the tubera sacrale appeared grossly symmetrical in 95% of the horses (Dyson and Murray, 2003).

Instability of the SI joints may lead to remodelling of the ventromedial joint surfaces (Jeffcott *et al.*, 1985). Pathological changes may be subclinical, but are reported to be a common finding in performance horses (Haussler, 1999). Proliferative changes as osteophytes and lipping of the articular surfaces are frequent findings in these cases. Reportedly, the findings tend to be bilateral and symmetrical in horses without a history of back pain (Haussler, 1999), while asymmetrical findings have been considered a criterion of abnormality (Tucker *et al.*, 1998; Erichsen *et al.*, 2003b; Goff *et al.*, 2007).

Fractured spinal processes or vertebral bodies

When the spinous processes fracture, it usually happens at the withers (T2–T9) (Haussler, 1999). For instance, the horse falls over backwards when rearing or takes a nasty fall during steeplechase. If the fractures are not too complicated, they usually heel conservatively with a fibrous union in a few months (Marks, 1999).

Physical trauma, like a severe fall, may result in fractured bodies of thoracic or lumbar vertebrae. More unusual etiologies as lightning strike or electric shock have also been reported to cause vertebral body compression fractures (Haussler, 1999). Fractures or subluxation of the back vertebrae can result in acute, strong pain with rapid atrophy of the epaxial muscles. Decreased performance capacity is common, and there may be neurological abnormalities.

In a study on horses that died at racetracks because of injuries unrelated to the back, a large proportion (61%) showed evidence of stress fractures in the caudal thoracic back, lumbosacral spinal region and pelvis (Haussler and Stover, 1998). Fifty percent of these horses had vertebral lamina stress fractures that were positively associated with the severity of kissing spines and degenerative changes of the articular processes. The articular processes are tightly interlocking at the thoracolumbar junction and in the lumbar region, and great axial rotation is thought to increase the risk of fracture (Townsend *et al.*, 1986). The design of the articular processes may also contribute to vertebral lamina stress fractures.

Pelvic fractures

Pelvic fractures are not uncommon (Stashak, 1987). Normally they result from a fall. Ridden horses may fracture their iliac wings as a consequence of a jumping accident at high speed, and young horses sometimes slip and split when they play. Slippery and icy ground in the winter increases the risk and may lead to a fractured acetabulum or pubic bone.

The symptoms are dependent on the location of the fracture, but hind limb lameness is common. Muscle atrophy may exist if the fracture is old. If the iliac bone is fractured with overriding fragments, the horse is in severe pain and often refuses to place the hoof on the ground. If the acetabulum is afflicted, the cranial phase of the stride is short and loading of the limb is painful. If the pubic symphysis is involved, the horse may appear bilaterally lame.

Pelvic fractures also occur as stress fractures. This type of fracture is known to arise spontaneously during performance. A group of Thoroughbred race horses were diagnosed with iliac wing fractures (Pilsworth *et al.*, 1994). None of these patients had a history of inciting trauma.

Spinal muscle pathology

Although a decreased performance capacity is often the only initial clinical symptom of a back problem, painful back muscles are common in horses with back dysfunction. The horse may not be painful on palpation in the early stages, but may only show the *effects* of the discomfort or pain, like tail swishing, resentment at mounting, poor jumping or failure to bend or yield to aids. A change in muscle compliance may precede actual pain on palpation of the back.

Insufficient training, exercise exceeding the capacity of the horse, pre-existing lameness and inadequate warm-up are factors that may predispose a horse to muscle strains, and local muscle strain is a common injury in performance horses. Depending on the discipline, different muscles are more or less prone to be affected. Riding horses as dressage horses or show-jumpers more frequently injure their back muscles, while the hamstring muscles are more exposed in Quarter horses.

Back muscle myositis can be caused by a number of factors. One of the most common may be pain due to another source of pain. Spinal osseous or ligamentous pain commonly lead to injured back muscles. Nerve root compression, abscesses and articular process joint disease may also induce secondary muscle pain.

Many horses with back problems have coexisting lameness. In a study on 805 horses with orthopaedic problems, the prevalence of coexisting back problems and lameness was evaluated (Landman *et al.*, 2004). The horses, (70% dressage horses, 20% show jumpers and the remaining trotters), were examined for back problems and lameness irrespective of their initial problem. It was found that the prevalence of back problems was 32% among the lame horses, while the prevalence of lameness in the group with back problems was 74 %. As mentioned earlier, muscle spasm may arise as a consequence of SI dysfunction (Stashak, 1987). Spasms in the longissimus muscle may then result in altered hind limb gait.

Fatigue of the abdominal and iliopsoas muscles results in an extension of the back. If the horse is kept in work, the epaxial muscles may become sore (Marks, 1999). If the horse is exercised at high speed on a slippery surface, like wet mud or dry wood chips, the slipping at propulsion may result in painful back muscles. Strained longissimus dorsi muscles can also be caused by splinted abdominal muscles due to iliopsoas myositis.

Traumatic back muscle injuries are rather common in the horse. Mild injuries occur frequently, while severe traumatic injuries are less common. Mild skin lesions as well as deep muscle damage may be caused by the rider or the saddle, while severe acute soreness in the back muscles often is associated with falling.

Exertional rhabdomyolysis (ER) with muscle pain and cramping associated with exercise, is a well-known syndrome (Quiroz-Rothe, *et al.*, 2002; McCue *et al.*, 2006; Singer *et al.*, 2008). The acute form of ER usually occurs shortly after the onset of exercise, and the symptoms include sweating, pain, increased heart and respiratory rate, lameness and myoglobinuria due to liberation of myoglobin from damaged muscle tissue. Palpation of the lumbar and gluteal muscles often reveals firm, painful and sometimes warm muscles, and traumatic myopathy is one differential diagnoses to acute ER.

If the horse has not previously shown signs of ER, and suddenly gets sore, cramping and stiff muscles associated with exercise, and the blood values for CK and ASAT increase, the condition is called sporadic tying-up. Some horses, predominantly fillies, get recurrent rhabdomyolysis when exercising (Valberg, 2003). Muscle biopsies have helped identify two types of chronic rhabdomyolysis (Quiroz-Rothe, *et al.*, 2002), polysaccharide storage myopathy (PSSM) in Warmbloods, Quarter horse-related breeds and heavy draft horses, and recurrent exertional rhabdomyolysis in Thoroughbreds and possibly also Standardbreds and Arabians.

Aims of the investigations

The general aim of the present series of investigations was to evaluate a present-day gait analysis system as an objective and quantitative diagnostic tool in evaluating the back movement of horses. The main hypothesis of the studies was that the movement of the back in horses with clinical back pain differs from that of asymptomatic horses, and that a modern gait analysis system can differentiate horses with back dysfunction from asymptomatic, fully functioning horses.

The specific aims were:

- to establish a kinematic database on sport horses with clinical back pain and dysfunction
- to compare the back kinematics of horses with established back problems to the same parameters in asymptomatic, fully functioning horses at walk and trot
- to evaluate the effect of local anaesthesia on the back movements in horses without clinical signs of back pain
- to evaluate if induction of back pain in a well-defined site may cause consistent changes in back movement
- to evaluate the usefulness of a modern gait analysis system as a clinical tool to help diagnose equine back dysfunction
- to evaluate the effect of weighted boots on the back movement

Material and Methods

Horses (Studies I, II, III and IV)

A summary of the data of the horses used in each study is shown in Table 1. Studies II-IV were randomised crossing-over studies, and all horses in these studies participated in both the control group and the test group. Study I included two different groups, one with asymptomatic, fully functioning horses, and one with horses with back problems.

The horses in Studies I (control group), III and IV were in regular training for dressage, show jumping or eventing, and by their owners/riders considered sound and fully functioning. Two of the horses in Study III were also sometimes used for driving.

The horses with back problems in Study I had been in regular training prior to the onset of their back problems, while the horses in Study III were used for teaching purposes at the University Clinic in Uppsala and were neither regularly ridden nor driven.

Thirty-four horses were included in the control group in Study I, but one of them had to be excluded before the measurements due to being unsafe on the treadmill. Due to technical reasons, four additional horses had to be excluded from the measurements at walk. Finally, the control group in Study I included 29 horses at walk and 33 horses at trot.

Study	**I**		**II**	**III**	**IV**
Group	Control	Back problem	Control / Test	Control / Test	Control / Test
Total Number of Horses	Walk: 29 Trot: 33	12	10	8	8
Number of Stallions	3	-	-	-	1
Number of Mares	15	4	7	8	3
Number of Geldings	15	8	3	-	4
Age (years)	5-15	5-13	3-14	7-12	6-14
Weight (kg)	495-685	503-665	426-541	528-604	530-640
Height-at-the-Withers (cm)	158-174	157-174	-	156-167	158-176
Breed	Wbl.	Wbl.	Stb. / Wbl.	Dutch Wbl.	Wbl.
Disciplin and Level	D (n = 14) /J (n = 16) /E (n = 3)	D (n = 5) /J (n = 4) /E (n = 1) /G (n = 2)	Trotting / All-round Riding	D / J / Dri.	D (n = 4) /J (n = 3) /G (n = 1)

Wbl. = Warmblood; Stb. = Standardbred trotter; Int. I = Intermediare I; D = dressage; J = show jumping; E = three-day-eventing; G = General Purpose; Dri. = Driving

Table 1 shows an overview of the horses included in the respective studies.

All horses in Study IV were also participants of the control group in Study I. The owners of the control horses in Study I were either contacted personally or responded to an invitation in a Swedish equestrian journal. The back patients in Study I either came to the University Clinic in Uppsala directly, or were referred to the clinic by private practitioners or other clinics. The horses in Study II, all Standardbred trotters except for one, were owned by the University Clinic in Uppsala, and the horses in Study III belonged to the Utrecht University.

Clinical examination (Studies I, II, III and IV)

Prior to the measurements, all horses underwent a clinical examination in order to assure that they fulfilled the physical inclusion criteria. All horses were examined at a squared stance and in hand at walk and trot on a hard surface. They were also lunged at walk and trot on both reins. No abnormalities of clinical importance were found in the conformation or on palpation of the extremities. If lameness was detected in a horse in any of the above mentioned examinations, the horse was excluded.

In all studies, the back was thoroughly examined, including visual inspection of the muscle symmetry of the back, and palpation of the dorsal spinal processes of thoracic and lumbar vertebrae and the sacrum, as well as the back muscles. In Studies II, III and IV, and in the control group in Study I, a horse was excluded if an abnormality of clinical importance was found in the conformation or on palpation of the back, while the horses in the back patient group in Study I had to demonstrate clinical back pain on palpation and impaired performance to be allowed to participate (Ranner *et al.*, 2002).

Experimental set-up and data collection (Studies I, II, III and IV)

Training

Before the first recording, all horses were trained 4 times on the treadmill at walk and trot (Fredricson *et al.*, 1983; Buchner *et al.*, 1994). A coir mat treadmill was used in studies I and IV, while the horses were recorded on a SÄTO[1] treadmill in Study II, and on a Mustang 2200©[2] treadmill in Study III. When a horse was trained in a new study for the first time, it was sedated with a low dose (0.03 mg/kg) of Plegicil®[3] vet. (acepromazinmaleate) i.m.

Measurements

Spherical, reflective markers, 19 mm in diameter, were glued onto the skin over the dorsal spinous processes of thoracic, lumbar and sacral vertebrae: T6, T10, T13, T17, L1, L3, L5 and S3. Markers were also placed on both left and right tubera coxae and proximally on the lateral part of the hoof wall of one hind hoof. The landmarks were identified by palpation in the square standing horse. The positions of the markers (spatial resolution less than 1.5 mm) were captured by six infrared cameras (ProReflex®)4, which were positioned around the treadmill in a way that each marker was always covered by at least two cameras.

Measurements were made relative to a right-handed orthogonal laboratory coordinate system with the positive y-axis oriented in the line of progression, the positive z-axis oriented upward and the x-axis oriented perpendicular to the direction of the y- and z-axes. Calibration was done dynamically, using a calibration frame which defined the orientation of the laboratory coordinate system and a wand with an exactly defined length. Data was captured at a sampling rate of 240 Hz for 5 seconds at a squared stance, and for 10 seconds when the horses were walking and trotting at a steady state.

Calculation of back kinematics

The reconstruction of the 3-dimensional position of each marker is based on a direct linear algorithm (QTrack™)[5]. The raw x-, y- and z-coordinates were exported into MatLab®[6] and Backkin®[7] programme packages for further data processing. The beginning of each stride cycle was defined as the moment of first ground contact of the left hind hoof.

The x-, y-, and z-coordinates were used in accordance to Faber *et al.* (1999) to calculate the flexion-extension and lateral bending movements of the back, and the axial rotation of the pelvis. The instantaneous orientation of a vertebra, say V2, was calculated from the position of the vertebrae located cranial (V1) and caudal (V3) to it. The orientation of V2 was then assumed to be represented by the orientation of the line connecting V1 and V3.

Coordinates were extracted for the walk and trot from approximately 8 and 10 representative strides, respectively. Angular motion patterns (AMPs) were calculated for each vertebral angle and the pelvis. In order to allow averaging of the AMPs over strides, each stride was normalised to 101 data points.

Stride length and duration were calculated from the marker on the left hind hoof. The total ROM and the mean movement were derived from the AMPs.

Back patients versus asymptomatic controls

The back movements at walk and trot were compared between two groups of horses in Study I. Prior to the measurements, the clinical cases of back pain and the horses in the control group underwent a clinical examination to establish they matched the inclusion criteria. The control horses should be clinically sound and not treated for a back related problem for at least one year prior to the examination The horses in the clinical case group, on the other hand, had to show clear signs of clinical back pain and impaired performance to be included in the study. They should demonstrate pain on palpation and the reaction should not decrease at repeated palpation. The horses with back pain commonly reacted to palpation by adverse reactions like tail swishing, unruliness or rapid caudal movement of the ears.

A riding test was included in the clinical examination for all horses in both groups. The test was performed by the horses' regular riders and designed individually for each horse to match its normal level of performance. The control horses were found to perform satisfactorily during the riding test, while the horses with back problem expressed various degrees of resentment, like refuse to bend or yield to aids, protest when jumping, or even not let their rider mount at all.

All back patients had chronic back pain. Their respective history of back pain went back 6 months or more for all horses except 2, which had had their problems for about 2 months. According to the inclusion criteria, the horses should not have been treated for their back problem, or any other back related problem, for at least three months prior to the examination.

Diagnostic aids such as radiological and scintigraphic examination, ultrasound and regional anesthesia were used to diagnose the horses. In cases when recovery was not considered possible for a horse and it had to be euthanatized, an autopsy was carried out to verify the diagnosis.

Local anaesthesia

The horses in Study II were measured twice on two occasions at walk and trot on the treadmill. After the first measurement, the back of each horse was injected with either a local anaesthetic solution or sodium chloride. The dorsal spinous processes of T16, T17, T18, L1 and L2 were identified by palpation. Ten ml of mepivacaine hydrochloride (Carbocain 20 mg/ml)[8] or physiologic sodium chloride were injected on each side of the interspinous space between T16-17, T17-18, T18-L1 and L1-2, approximately 20 mm lateral to the midline, with the needle pointing towards the midline. For further details see paper II.

A second measurement was done 25 minutes after injections. Seven days later, the movement of the back was measured a third time. The horses which had earlier been injected with local anaesthetics were now injected with sodium chloride and vice versa. A last measurement was carried out 25 minutes after the second injection.

Induced reversible back pain

In the horses in Study III, the back was clipped and aseptically prepared. The dorsal spinous processes of T13, T14, T15, T16, T17, T18 and L1 were identified by palpation. To induce back pain, two ml of 85 % lactic acid solution was injected into the left *m. longissimus dorsi* at the height of the caudal edges of T13, T14, T15, T16, T17 and T18, approximately 10 cm left of the midline using a 40 mm long, 21 gauge needle. Total volume injected was thus 12 ml.

Back kinematics were measured at walk and trot on the treadmill prior to and at 1 hour, 1 day, 2 days, 3 days and 7 days after the pain induction. The back was examined after each session on the treadmill except for the first. The tips of the spinal processes and the muscles were palpated and any swellings were noted. Back pain was considered present if the horse showed signs of pain/discomfort on palpation of the back.

Weighted limbs

In the weighted limbs study, the horses were accustomed to walk and trot with weighted boots on the fore- and hind limbs, respectively. The boots were made of terylene and artificial leather and had vertical pockets intended for weights and in the study each boot weighed 700 g. They were fastened around the metacarpal or metatarsal regions and did not seem to distract the horses once they had acclimated to them.

The horses were measured three times at both walk and trot; once without boots, once with the weighted boots on the forelimbs and once with the boots on the hind limbs. The measurement sequence of the three conditions was chosen randomly for every horse and separately within each gait.

Statistical analysis

The results are presented as means ± s.d. Students' t-test and one-way ANOVA were used to analyse possible kinematic differences in Study I. In Studies II and IV, Wilcoxon matched pairs test was used to analyse possible differences. The data in Study III were tested for normality of distribution. The variations in the back vertebral angles throughout the stride were normally distributed and further analysed with Students' t-test, in which each individual percentage of the stride post injection was compared to the corresponding percentage prior to the injections. Wilcoxon matched pairs test was used to analyse possible ROM and AMP differences. The minimum level of statistical significance was set to $p<0.05$. The statistical analyses were performed with an acknowledged statistical software package (Statistica©)[9].

Ethical Review

Studies I, II and IV were approved by the local ethical committee for the Swedish National Board for Laboratory Animals and Study III was approved by the Animal Experimentation Committee of the Utrecht University, in compliance with the Dutch Act on Animal Experimentation.

Results

Back patients versus asymptomatic controls

The overall flexion-extension movement was significantly smaller in the patients at both walk and trot compared to the asymptomatic horses (Figure 5a). The differences were seen in the caudal thoracic back at walk, and at the T/L-junction at trot.

The lateral movements were different in the horses with back dysfunction only at walk (Figure 5b). The lateral bending ROM was significantly increased at T13, and numerically at T10 and T17, in the painful horses compared to the fully functioning horses.

The rotation of the pelvis around the longitudinal axis of the spine showed a decrease in the horses with back pain at walk compared to the asymptomatic horses (Paper I).

In addition to the changes in the ROMs, the horses with back pain had less symmetric movements of the back than the asymptomatic horses (Paper I). A significantly decreased symmetry was observed for the flexion-extension at the T/L-junction, and for the lateral bending in the caudal lumbar back at walk. No symmetrical difference was observed in the symmetry of the back between the two groups at trot.

A shorter stride length was observed for the back patients compared to the control group at walk. The stride length was 1.74 ± 0.13 m for the horses with back dysfunction and 1.86 ± 0.09 m for the sound horses. At trot, there was no significant difference between the stride length for the patients (2.72 ± 0.24 m) and the controls (2.83 ± 0.13 m).

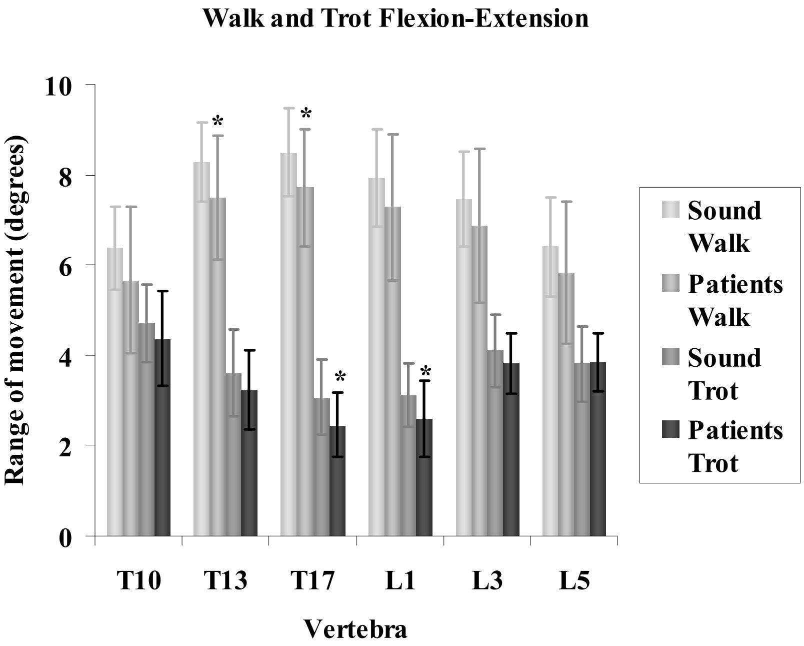

Figure 5a

Figure 5a shows the total ROM for the flexion-extension movement of the back at walk and trot for the back patients as compared to the sound horses. * = Movement in back patient significantly different to movement in sound horse.

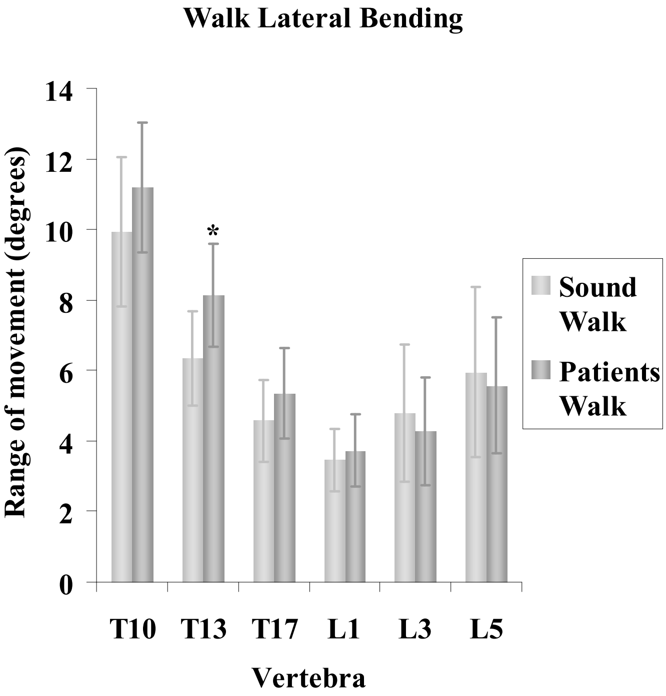

Figure 5b

Figure 5b shows the total ROM for the lateral bending movement of the back at walk for the back patients as compared to the sound horses.
* = Movement in back patient significantly different to movement in sound horse.

Local anaesthesia

Injections with local anaesthetics resulted in a greater movement of the back at walk, while the movement at trot was only affected by the injections to a minor degree. At walk, the flexion-extension as well as the lateral movements, bending and excursion, increased within half an hour after mepivacaine had been injected. The total ROM for flexion and extension became greater at all measured segments except T10 (Figure 6a). The lateral bending increased at the withers and in the lumbar back (Figure 6b), and the side-to-side movement of the back, the lateral excursion, showed a statistically significant increase at all measured segments except one, where the increase was numerical only (Figure 6c).

The ROM for flexion and extension decreased in one segment at trot after the local anaesthetic had been injected (Paper II). No other kinematic changes were observed at this gait subsequent to the injections of the anaesthetics, but there was an increased ROM for the lateral bending in the lumbar back after the horses had been injected with the sodium chloride (Paper II). The sodium chloride also led to an increased flexion-extension of the back at walk (Paper II). The changes were small, but similar to those seen after the administration of local anaesthetics.

In addition to the above mentioned analyses, the movement of the back before the injections of mepivacaine was compared to the movement before the injections of sodium chloride. No differences were seen at the walk or trot, except for a smaller lateral bending at L5 and a corresponding lateral excursion at L3 and L5 at walk before the infiltration of mepivacaine. Changes in the stride parameters (stride length, stride velocity and protraction and retraction of the right hind limb) were not seen in either walk or trot.

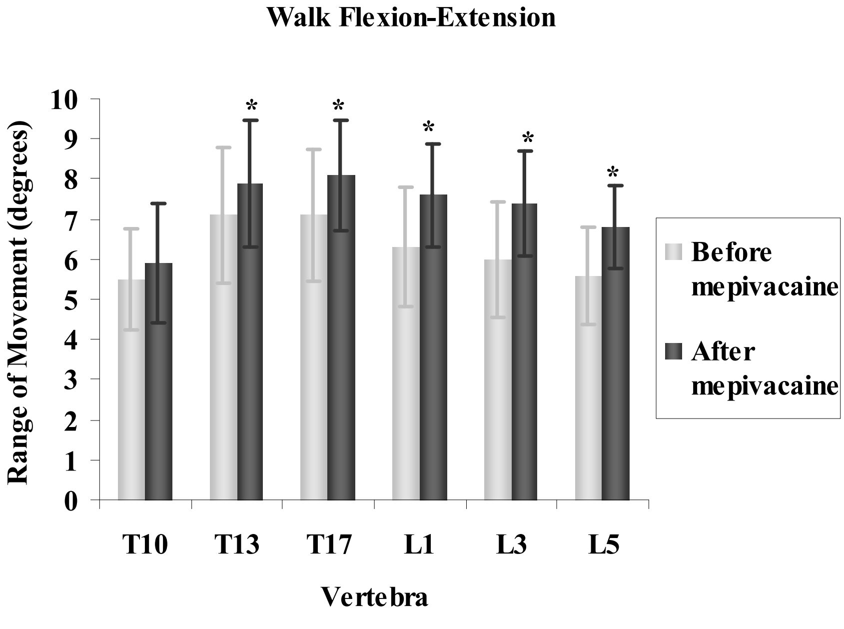

Figure 6a

Figure 6a shows the total ROM for the flexion-extension movement of the back at walk before and after local anaesthetic injections. * = Movement significantly different after injection with mepivacaine as compared to before.

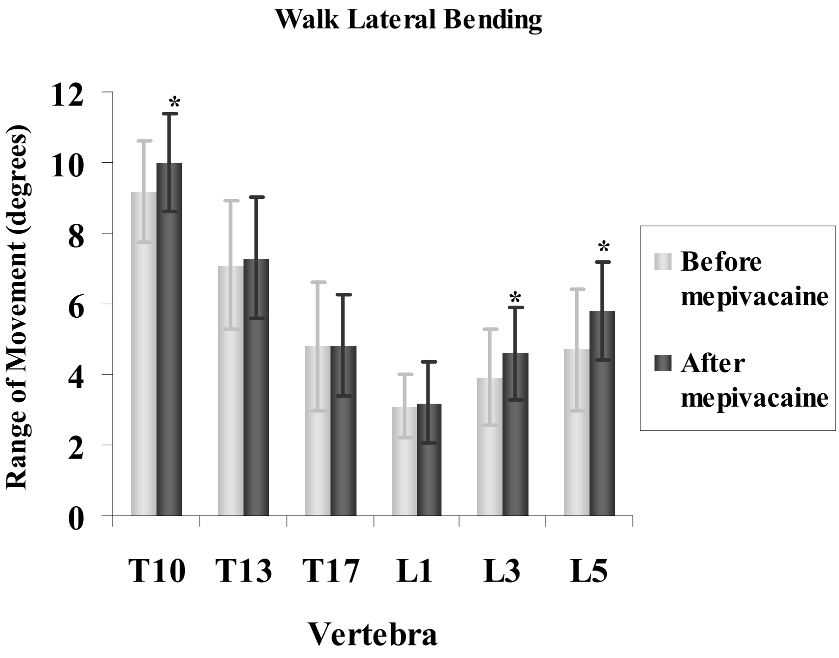

Figure 6b

Figure 6b shows the total ROM for the lateral bending movement of the back at walk before and after local anaesthetic injections. * = Movement significantly different after injection with mepivacaine as compared to before.

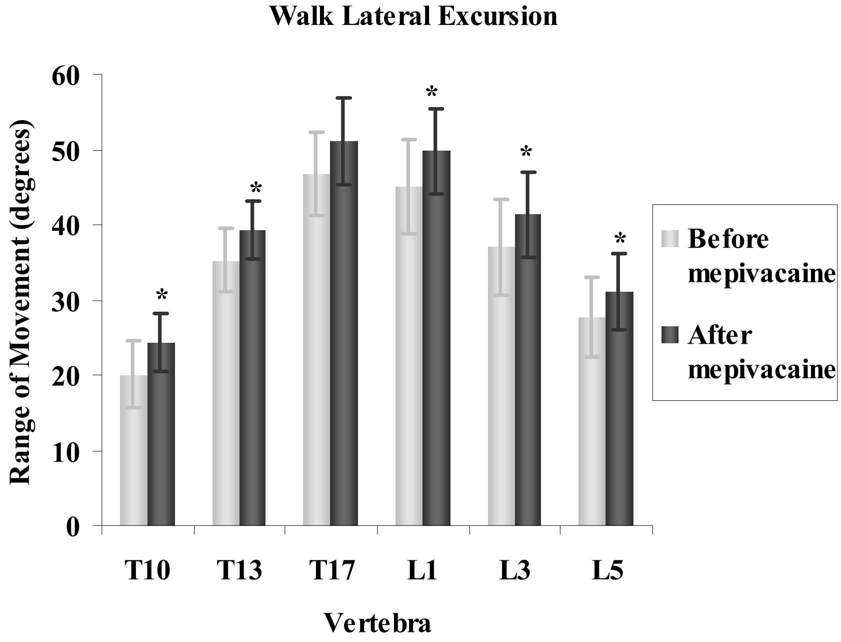

Figure 6c

Figure 6c shows the total ROM for the lateral excursion movement of the back at walk before and after local anaesthetic injections. * = Movement significantly different after injection with mepivacaine as compared to before.

Induced reversible back pain

Back examinations

The clinical findings during the week subsequent to the lactic acid injections are summarized in table 2.

1 hour post injection

Horse	Palpation		
	Spinal processes	*M.longissimus dorsi*	
		Left	Right
1	No remarks	T15-L2 moderate pain L2-L6 mild pain	No remarks
2	No remarks	T13-T16 mild pain T16-L4 moderate pain	No remarks
3	No remarks	T15-T18 moderate pain	No remarks
4	No remarks	Mild tension	Mild tension
5	No remarks	Mild tension	Mild tension
6	No remarks	T15-L3 moderate pain	No remarks
7	No remarks	Moderate tension, but no pain	Moderate tension, but no pain
8	No remarks	Mild tension	No remarks

1 day post injection

Horse	Palpation		
	Spinal processes	*M.longissimus dorsi*	
		Left	Right
1	No remarks	T12-L5 tension T13-T15 mild pain	T13-L3 mild tension
2	No remarks	T10-L4 tension T14-T18 mild pain	T15-L5 mild tension
3			
4			
5	No remarks	T11-L4 tension T13-T18 mild pain	T11-T17 mild tension
6	No remarks	T10-L3 tension T13-T18 mild pain	T12-L3 tension
7			
8			

2 days post injection

Horse	Palpation		
	Spinal processes	*M.longissimus dorsi*	
		Left	Right
1	No remarks	T10-L3 tension T13-T18 moderate pain	T14-L4 mild tension
2	T15-T16 + L/S-junct. mild pain	T6-L4 tension T13-T18 mild-moderate pain	T13-L4 mild-moderate tension
3	No remarks	T10-L1 mild pain	No remarks
4	No remarks	T13-T18 mild pain	No remarks
5	No remarks	T12-L3 tension T13-T17 mild pain	No remarks
6	T16-T18 mild pain	T10-L4 tension T13-T18 mild pain	T14-L1 mild-moderate tension
7	No remarks	T10-L3 mild pain	Withers mildly tensed, T13-L3 mod. tension
8	No remarks	T11-L4 mild pain	No remarks

3 days post injection

Horse	Palpation		
	Spinal processes	*M.longissimus dorsi*	
		Left	Right
1	No remarks	T13-L5 tension T16-L2 moderate pain	T10-L3 mild-moderate tension
2	No remarks	T13-L3 mild tension	No remarks
3	No remarks	T13-T18 mild tension	No remarks
4	No remarks	T13-T18 mild pain T18-L1 moderate pain	No remarks
5	No remarks	T10-L3 mild-moderate tension	No remarks
6	No remarks	T10-L5 tension T13-T15 mild pain L/S-joint mild pain	T16-L1 mild tension, L/S-joint mild pain
7	No remarks	T10-L/S-joint tension T13-L2 mild pain	T13-T18 mild-moderate tension
8	No remarks	T13-L1 mild tension L3 mild pain	No remarks

7 days post injection

Horse	Palpation		
	Spinal processes	*M.longissimus dorsi*	
		Left	Right
1	No remarks	T12-T14 moderate pain T12-L1 mild tension	T12-T17 mild tension
2	No remarks	T14-L2 mild tension	No remarks
3	No remarks	T15-L2 mildly stiff dermis	No remarks
4	No remarks	T13-L3 mildly stiff dermis	No remarks
5	No remarks	T14-T18 mild tension	T14-T18 mild tension
6	No remarks	No remarks	No remarks
7	No remarks	T13-L1 moderately stiff dermis	T15-T18 mild tension
8	No remarks	No remarks	No remarks

Table 2 shows the results of the back examinations during the week subsequent to the injections.

Back kinematics - Range of movement (ROM)

As expected, the back kinematics altered after the lactic acid injections. The first changes were observed merely an hour subsequent to the injections, while others developed during the following days. Most changes gradually faded towards the end of the week, and at the last measurement, 7 days after the lactic acid was injected, only a few remained.

The total ROM for the flexion-extension movement did not change significantly at walk, except for one segment on one occasion. At the trot on the other hand, the flexion-extension increased both in the thoracic and lumbar back during the week of the Study (Paper III). Several measurements demonstrated a statistically significant increase, mainly in the caudal thoracic back.

A few changes were seen for the ROM of the LB movement during the week subsequent to the injections (Paper III).

Similar changes in lateral excursion ROM were observed in the caudal thoracic back and in the lumbar back at both walk and trot (Figures 7a and b). The changes were most evident at walk, but at both gaits the general difference was a decreased ROM after the injections. During the following week, the ROMs gradually approached their pre-injection levels again.

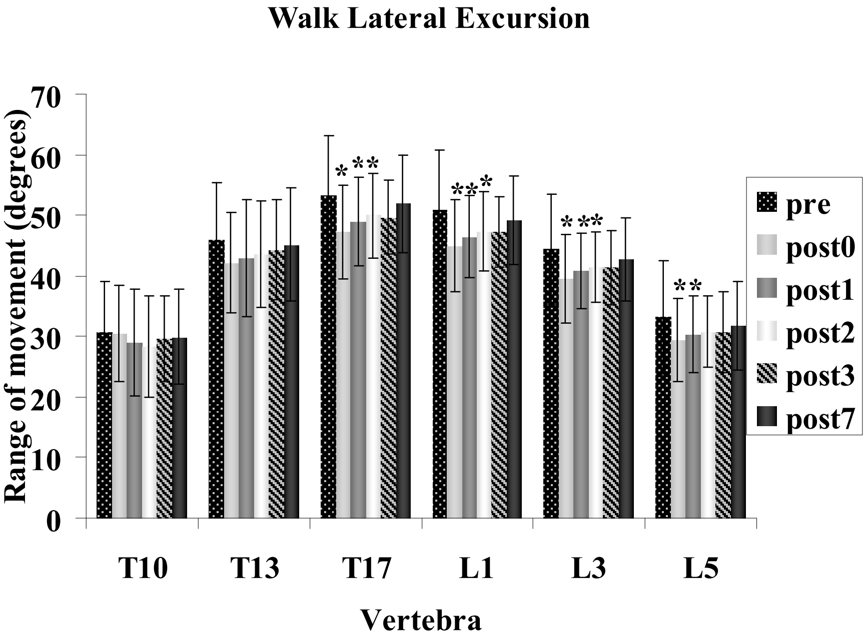

Figure 7a

Figure 7a shows the total ROM for the lateral excursion movement of the back at walk before and during the week subsequent to the lactic acid injections. * = Movement significantly different after injection with lactic acid as compared to before.

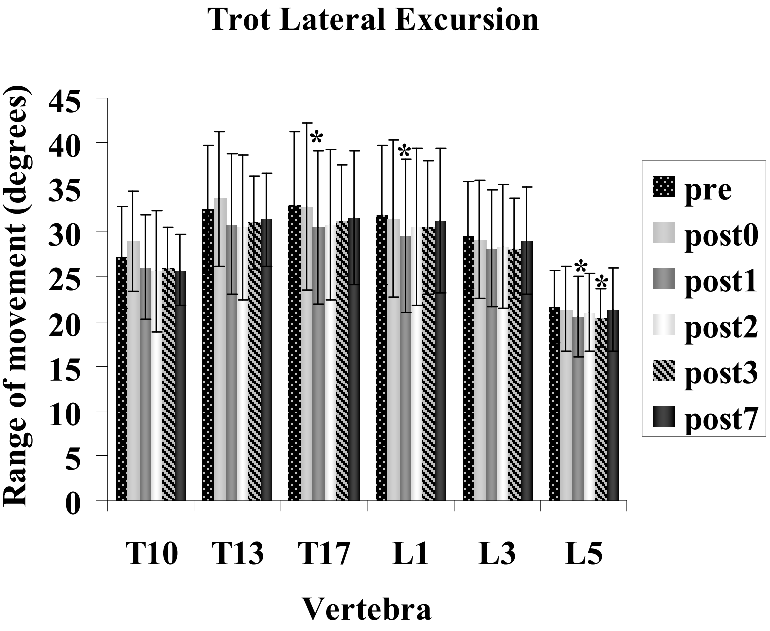

Figure 7b

Figure 7b shows the total ROM for the lateral excursion movement of the back at trot before and during the week subsequent to the lactic acid injections. * = Movement significantly different after injection with lactic acid as compared to before.

Back kinematics – The instantaneous vertebral angles throughout the stride cycle

The movement pattern of the back changed for the flexion-extension and lateral bending movement of the back, and for the axial rotation movement of the pelvis, when the horses had been injected with lactic acid. Differences were observed at both walk and trot (Figures 8-10), and the mean angles of the back movement were also influenced.

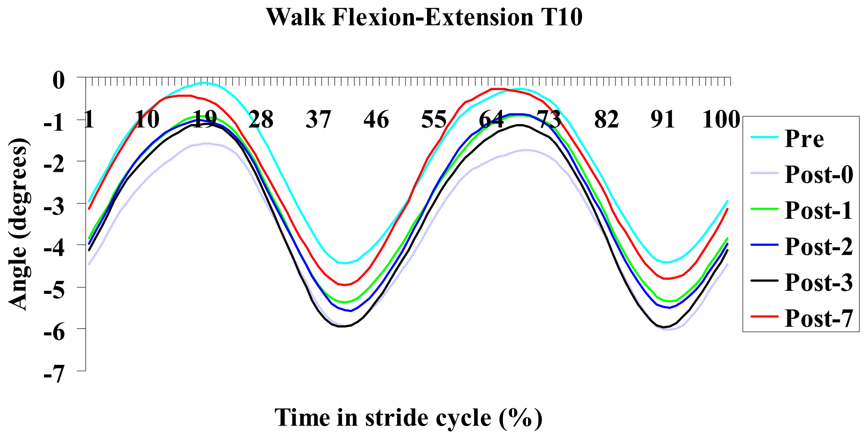

Figure 8a

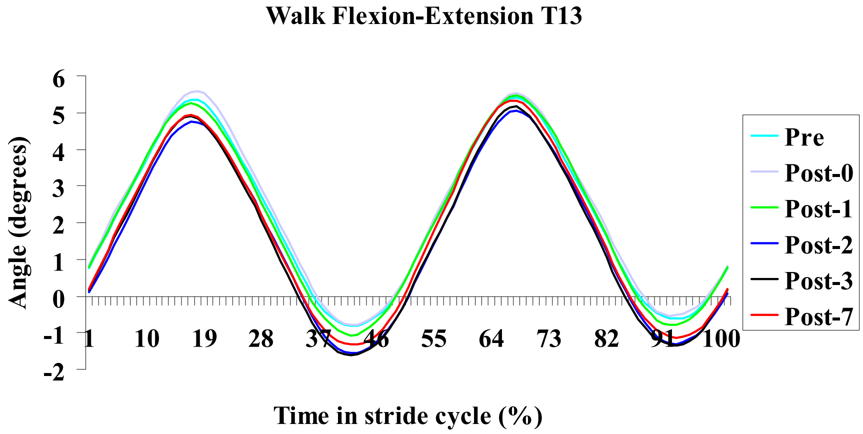

Figure 8b

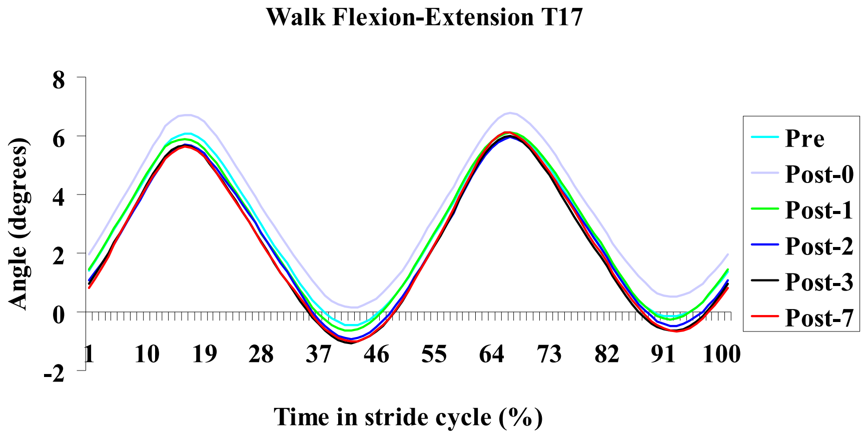

Figure 8c

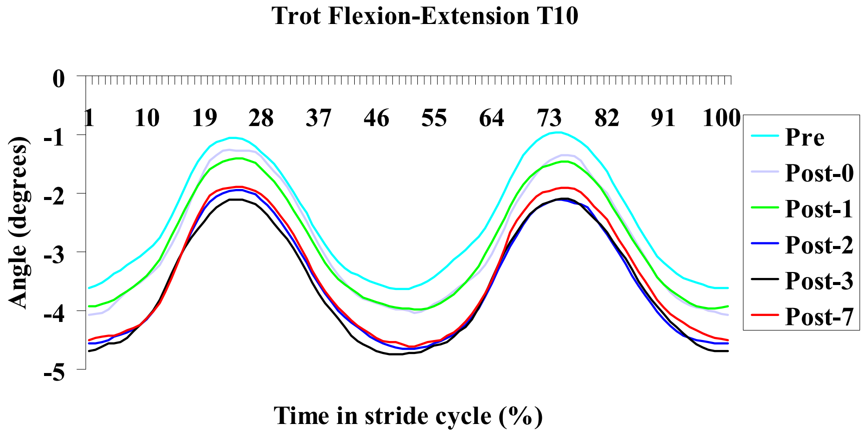

Figure 8d

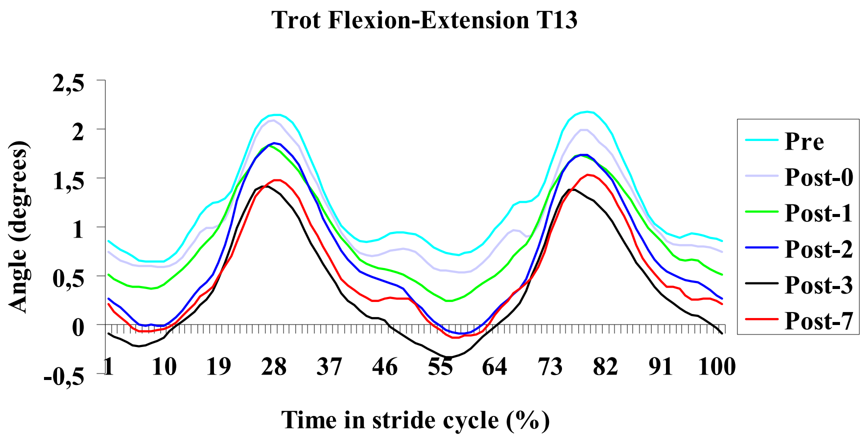

Figure 8e

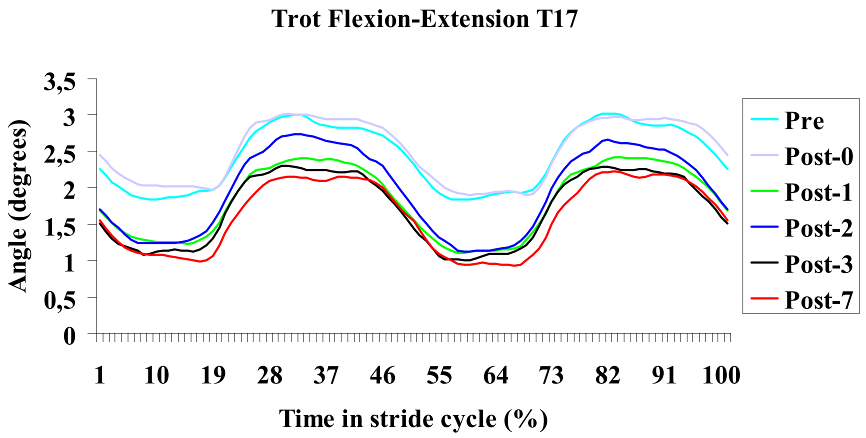

Figure 8f

Figures 8a-f show the flexion-extension movement of T10, T13 and T17 during a stride cycle at walk and trot before the lactic acid injections and on five occasions during the week subsequent to the injections.
Pre=before the injections; Post-0= 1 hour after the injections;
Post-1= 1 day after the injections; Post-2= 2 days after the injections;
Post-3= 3 days after the injections; Post-7= 7 days after the injections.

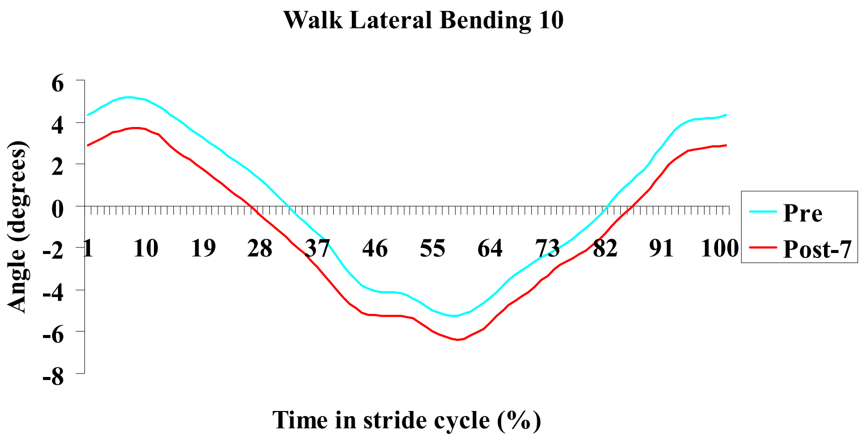

Figure 9a

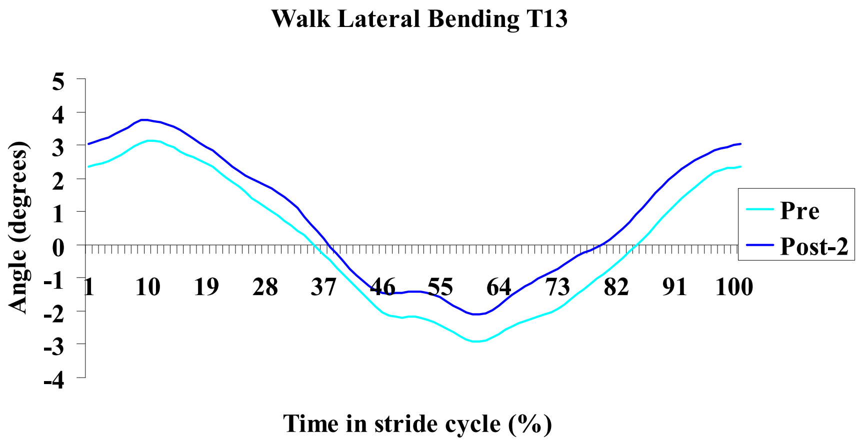

Figure 9b

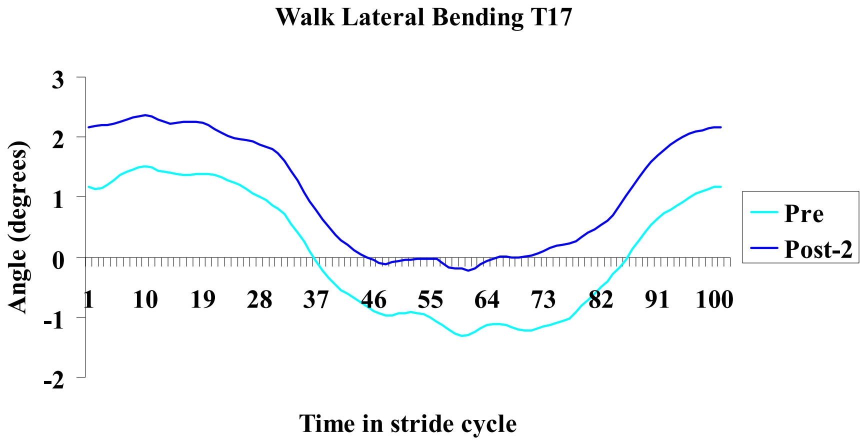

Figure 9c

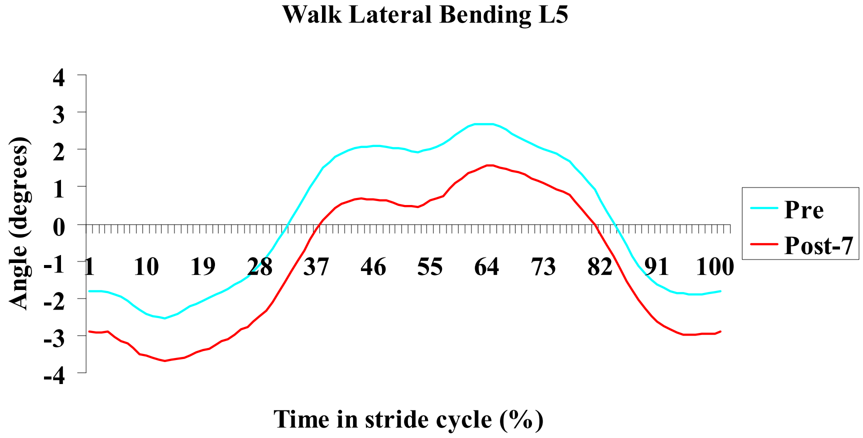

Figure 9d

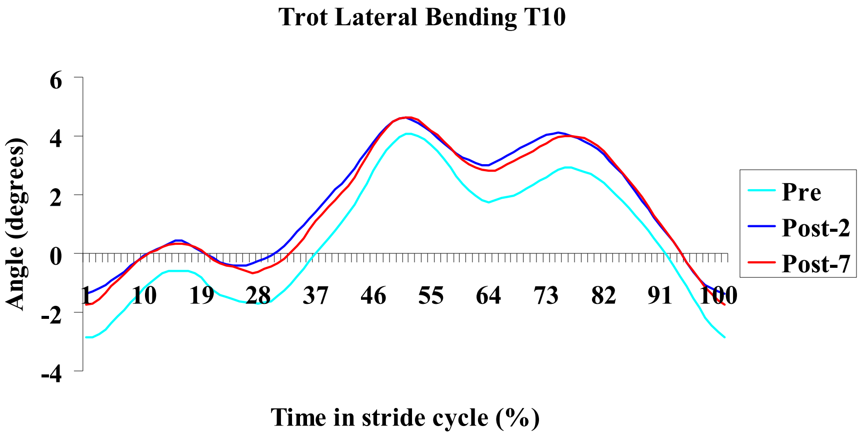

Figure 9e

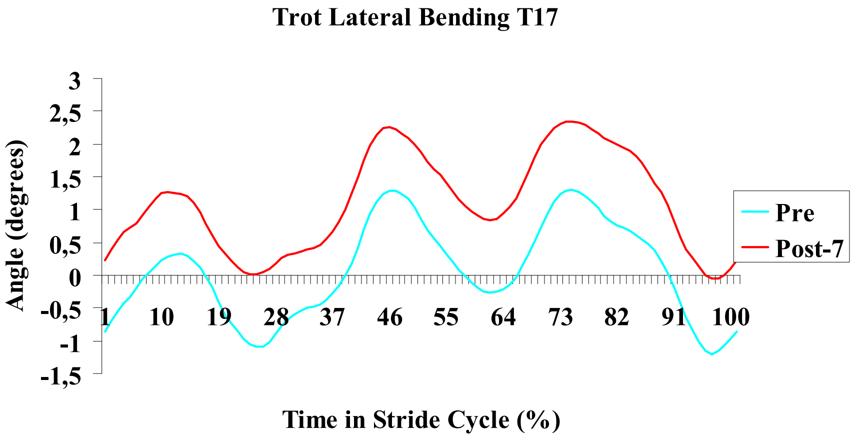

Figure 9f

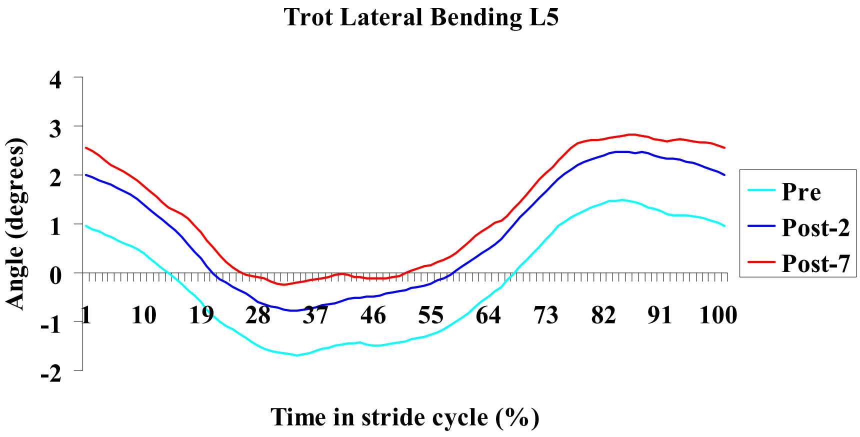

Figure 9g

Figures 9a-g show the lateral bending movement of T10, T13 and T17 and L5 during a stride cycle at walk and T10, T17 and L5 during a stride cycle at trot before the lactic acid injections and on two occasions during the week subsequent to the injections.
Pre=before the injections; Post-2= 2 days after the injections;
Post-7= 7 days after the injections.

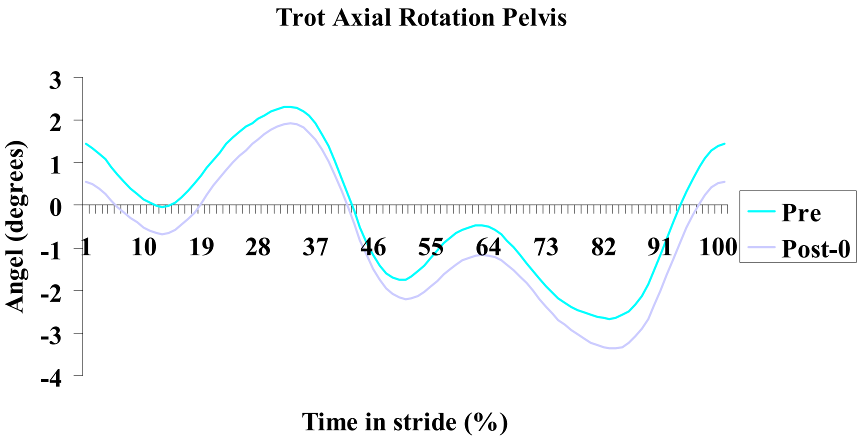

Figure 10

Figure 10 shows the axial rotation of the pelvis at trot before and one hour after the lactic acid injections. Pre=before the injections; Post-0= 1 hour after the injections.

Stride parameters

The linear and temporal gait parameters did not change subsequent to the lactic acid injections. The stride length was 2.6±0.1 m at all measurements at trot, and 1.7±0.1 m at all measurements at walk, except for on the seventh day after the pain induction, when the stride length was 1.7±0.0 m. The stride duration was 0.7±0.0 s during the whole study at trot, and 1.1±0.1 s at every measurement at walk, except for the seventh day after pain induction, when it was 1.1±0.0 s.

Weighted limbs

Essentially, when weighted boots were put on the forelimbs, they affected the movement of the thoracic back. When put on the hind limbs, they changed the movement of the lumbar back. The weighted hind limb boots increased the flexion-extension movement of the lumbar back at walk (Figure 11a), compared to when the horses did not wear boots. Further, the lateral bending ROM was decreased at the thoracolumbar junction at trot. Weighting the hind limbs did not affect the lateral bending ROM at walk, nor the ROM for flexion-extension at trot.

Weighted boots on the forelimbs did not influence the ROM of the back at walk, while the lateral bending movement decreased significantly at the withers at trot (Figure 11b). The movement altered at the withers at trot when the horses wore the boots on the forelimbs. There was also an increase in the lateral movement at L3.

The boots did not change the ROM for the axial rotation of the pelvis at walk or trot. At trot, the weighted hind limb boots decreased the protraction and retraction of the hind limb. The means and s.d. for the stride duration and stride velocity were calculated for the three conditions at the walk and trot. No significant difference was found for any of these parameters.

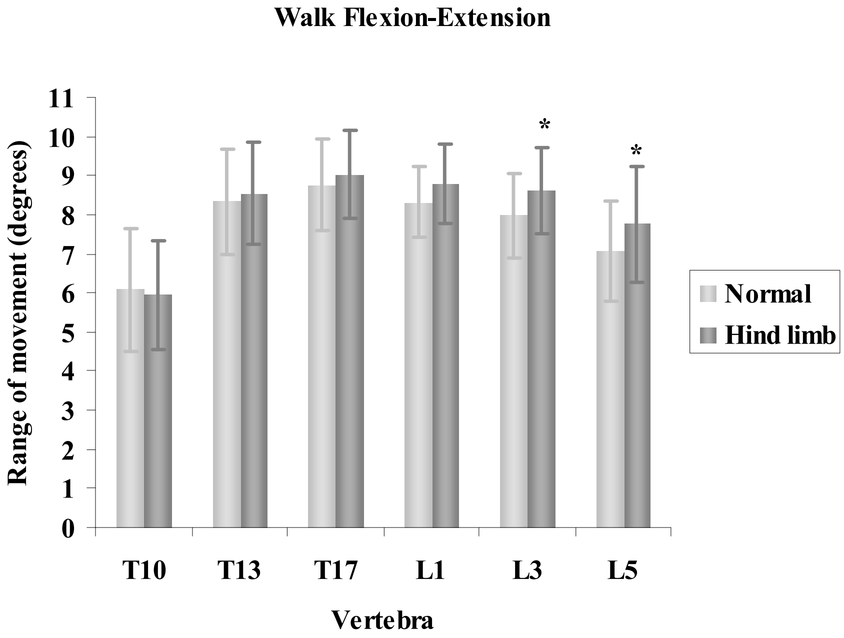

Figure 11a

Figure 11a shows the total ROM for the flexion-extension movement at walk with and without weighted hind limb boots. * = Movement significantly different with hind limb boots as compared to without.

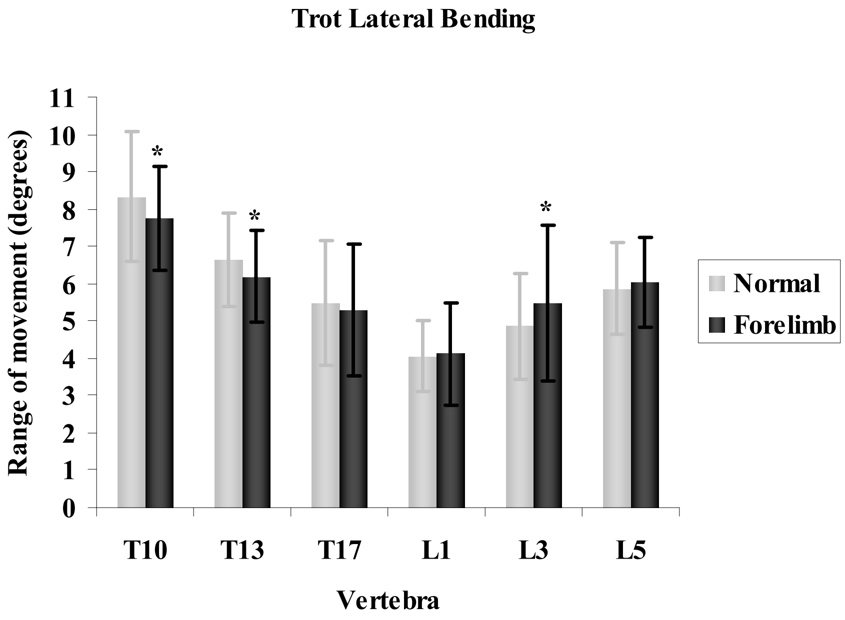

Figure 11b

Figure 11b shows the total ROM for the lateral bending movement at trot with and without weighted forelimb boots. * = Movement significantly different with forelimb boots as compared to without.

Additional results

A clinical case

A patient was presented to the biomechanical research group in Uppsala. Four months earlier, the horse, a 5-year-old Swedish Warmblood mare, had started light work after a longer period on pasture with her foal. The owner noted stiff movements when the horse was lunged and long-reined, and after 20 minutes with a rider, a small swelling was noted in the thoracic back. A clinical examination at that point showed asymmetrical back muscles, an underdeveloped right trapezius muscle and difficulties to bend the neck laterally. An ultrasound after riding revealed that the swelling under the saddle was a subcutaneous edema. During the following months, the horse was lunged, long-reined and ridden without a saddle. Improved movements were observed, but a stiffness on lateral movements remained, as did a certain degree of muscle asymmetry in the cranial thoracic region.

When the horse came to the University Clinic in Uppsala she had no remarks on palpation of the limbs, movement in hand or on flexion tests. No appreciable muscle asymmetries were noted, but the mare showed mild pain on palpation of the dorsal spinous processes at the withers, mainly at T12-T14. She was not sore on palpation of the back muscles, but slightly tensed in the saddle region. No significant scintigraphic or radiological abnormalities of the cervical or thoracic spine were detected.

The horse was trained and measured on the treadmill according to the principles followed in studies I-IV. The kinematic analysis showed that she had a smaller ROM for flexion-extension at the withers (T10) at trot, compared to the control group in Study I (Figure 12). She had also a decreased symmetry of movement for the lateral bending (T10) and lateral excursion (T10 and T13) movements at trot. The abnormal movements were thus observed in the region where the horse had had muscle asymmetry and a repeated reaction to saddle pressure, while none of the other analyzed back segments showed any remark at all.

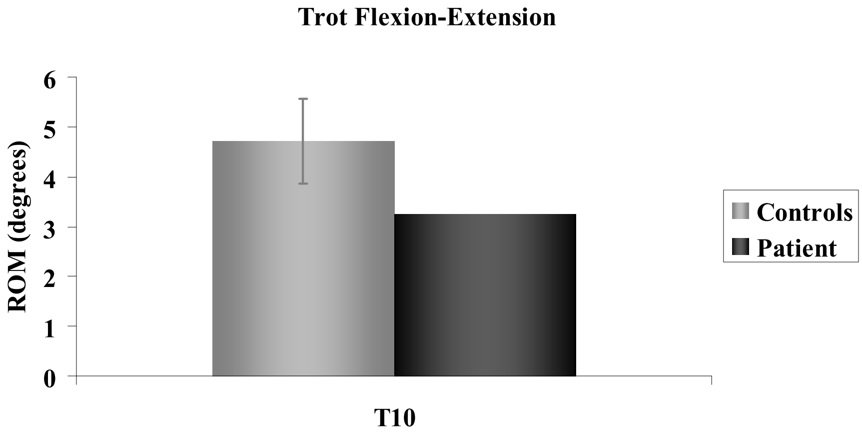

Figure 12 shows the ROM for the flexion-extension movement at T10. Mean ± s.d. are shown for the control group and the numerical value is shown for the patient.

General discussion

The movement of the back in horses with back pain and dysfunction

The results of Studies I and III confirm the two general hypotheses of this thesis; that the movement of the back in horses with clinical back pain differs from that of asymptomatic horses, and that present-day gait analysis systems can differentiate horses with back dysfunction from asymptomatic, fully functioning horses.

The back patients in Study I were a heterogeneous group of clinical cases presented to the University Clinic. The group demonstrated decreased flexion-extension ROM in the caudal thoracic spine and at the thoracolumbar junction at walk and trot. There was also a decreased axial rotation of the pelvis at walk. The greater amplitude of the lateral and twisting movements in asymptomatic horses at walk may be the cause of the decreased axial rotation ROM at this gait, while the decreased flexion-extension ROMs may result from an attempt to alleviate the pain by reduced reflection of the back. An altered neuromuscular control to ease the pain may have induced excessive muscle activity leading to spasms. It is also possible that acquired pathological limitations may be the initial cause of the problem, and as a consequence, the decreased ROMs.

The shorter stride length observed in the horses with back pain at the walk, and the coinciding decrease in flexion-extension ROM is in agreement with the positive relationship between the pro- and retraction of the hind limbs and the flexion-extension movement of the back at walk (Faber *et al.,* 2000) and trot (Faber *et al.*, 2001c).

The increased extension of the caudal back at both walk and trot in Study III may have been induced by a shortened and hypertonic *m. longissimus* *dorsi* not able to adequately control the vertebral column. However, while the horses in Study I showed a decreased ROM for flexion-extension at the caudal thoracic back and T/L-junction, the opposite findings were observed in Study III. This may be due to the differences in the anatomical origin of the pain between naturally occurring back pain in the patients in Study I and the artificially induced back pain in Study III. In addition, the back pain was unilaterally induced in Study III, and the compensatory mechanisms can be assumed to differ between unilateral and bilateral back pain. Bilateral back pain is likely to cause a more general restriction of the back movement.

Due to the unilaterally induced back pain, the back demonstrated a transient accentuated lateral bending subsequent to the lactic acid injections. The increased lateral bending was most likely a consequence of an impaired muscle function at the painful side. Loss of normal activity in the left epaxial musculature may have affected the naturally existing left/right balance and lead to a scoliosis of the back with, in this case, right convexity as a result. In a study by Faber *et al.* (2003), the back movements of a horse were evaluated before and after manipulative treatment. The horse in that study showed decreased performance, was often rearing and reacted on palpation of the back. Clinically, a right-convex bending from T10 to L2 was diagnosed, and the kinematic analysis demonstrated a smaller lateral bending ROM than normal for the T10 segment of the back. After treatment, the lateral bending ROM increased, which is in accordance with the results in Study III.

In Study III, the horses showed a reversed pattern at the withers and in the caudal lumbar back 7 days after the injections at walk, that is, bending to the unaffected side. This may have been caused by a decreased contraction capacity in the injected muscle. This biphasic response was also observed in the earlier study in trotters with induced back pain (Jeffcott, 2007, personal communication).

The lactic acid injections resulted in an immediate onset of back pain while most changes in movement appeared 48-72 hours after the injections. As the lactic acid produced naturally in situations with intensive, rapidly increased, or changed exercise, the injected lactic acid induced acute muscle soreness, followed by changes in movement after a couple of days. The second, more severe peak of soreness induced by natural lactic acid production, is called delayed onset muscle soreness (DOMS) in human medicine (Marlin and Nankervis, 2002). It appears that a similar phenomenon occurred in study III, where the changes in movement may represent the second peak of muscle pain.

With only small differences, back movement changed in a similar way at walk and trot in Study III. An increased extension of the back was observed at both gaits, but remained manifest for a longer period of time at trot. This, and the more obvious lateral bending asymmetry at trot, may be explained by the greater back muscle activity at this gait.

Similar AMP results were observed in a study on ten Warmblood horses demonstrating bilateral thoracolumbar pain on palpation (Gómez Álvarez *et al.*, 2008b). Chiropractic treatment increased the flexion of the caudal thoracic back in those horses at both walk and trot, which is in accordance with the findings in Study III.

A lactic acid solution, equal to the one used in Study III, was used to induce back pain in a group of horses (Jeffcott *et al.*, 1982). This resulted in a reversible pain reaction on palpation of *m. longissimus dorsi*, which was confirmed in Study III. No changes were observed in the linear or temporal stride parameters in either study, but a decreased work capacity was noted in the study done by Jeffcott *et al.* (1982), and consistent changes in the vertebral kinematics were observed during the week following the injections in Study III.

Local anesthesia as a diagnostic aid

Local anaesthesia is commonly used to substantiate the location of pain in the back (Walmsley *et al.*, 2002; Dyson and Murray, 2003). To our knowledge, no other study has been published on the effect of local anesthesia on the movement of the back. Local anaesthetics seem to affect the stability of the back. In Study II, this was probably due to the fact that the injections were made in the multifidus muscle, which affect stabilization, proprioception and posture. The differences in muscle activity between walk and trot are probably the reason why changes in back movement were observed mainly at the walk, in which the movement of the back is largely passive. The results in Study III indicate that evaluation of the back movement after local anesthesia is probably best done at trot, since the local anaesthetics affect back movement only to a minor extent at this gait.

The effect of weighted boots on the movement of the back

Several studies have evaluated limb kinematics (Clayton *et al.*, 2002; Back *et al.*, 2003; Bobbert *et al.*, 2005; Dutto *et al.*, 2006; van Heel *et al.*, 2006b), but only a few have studied the influence of limb kinematics on the movement of the back (Faber, 2001a; Faber *et al.*, 2001c; Wennerstrand *et al.*, 2006; Gómez Álvarez *et al.*, 2007; Gómez Álvarez *et al.*, 2008a). Since it has been shown that different parts of the body are synchronized, and that one body segment may induce or inhibit the movement of another (Faber *et al.*, 2000; Denoix and Audigié, 2001; Faber *et al.*, 2001c; Rhodin *et al.*, 2005), it is important to know how external influences may affect these relationships.

The use of weighted boots has been suggested as a method to rehabilitate horses with back pain (Persson, 1999, personal communication). The aim of Study IV in this thesis was therefore to evaluate the effect of weighted boots on the movement of the back. Earlier studies have shown that non-weighted boots as well as loading of the distal hind limbs affect the three-dimensional movement pattern of the limbs (Kicker *et al.*, 2004; Wickler *et al.*, 2004), and our hypothesis was that weighting the distal limbs would also influence the back movements. This turned out to be true; weighted boots on the hind limbs increased the flexion-extension of the lumbar spine at walk, and weighted boots on the forelimbs decreased the lateral bending of the thoracic spine at trot.

It seems that the movement of the back is less susceptible to external influences at trot compared to at walk. Hind limb boots did not induce changes in protraction and retraction of the hind limbs at walk, even when the flexion-extension ROM at the lumbar back was increased. At trot, on the other hand, there was a decreased protraction and retraction of the hind limb, but no significant change in the ROM for the flexion-extension of the lumbar back. These differences could possible be due to the difference in muscle activity between the two gaits. While there are suspension phases and only a diagonal support during the support phases at trot, the four-beat walk has no suspension phase, and a greater activity of the back and abdominal muscles is required to maintain the stability of the back and the horse in balance at trot (Robert *et al.*, 1998).

Similar to the flexion-extension, the lateral bending of the back is correlated to the protraction and retraction of the hind limbs (Faber *et al.*, 2001c), and the decreased lateral bending at the thoracolumbar junction at trot may have been a consequence of the significantly decreased protraction and retraction induced by the hind limb boots. Correspondingly, the forelimb boots may have influenced the lateral bending of the thoracic back at trot. Additional loading increases the muscular output in humans (Martin and Cavanagh, 1990), and the added forelimb weights may likewise have increased the muscle activity in the horses, possibly resulting in more stable and balanced movements.

Exercises to increase the flexion-extension flexibility of the lumbar back in a controlled way can sometimes be desirable in training and rehabilitation of sport horses. Weighted boots may be one possibility to achieve this. Weighting the hind limbs probably induces strengthening of the hypaxial lumbar muscles, which favours a controlled, increased mobility of the lumbar back. The risk for overstraining or accidental injuries is likely to be low at walk.

The infrared-based automated gait analysis technique

The infrared-based automated gait analysis technique has been used in many studies on back movements in humans, dogs and horses during the last decade (Licka *et al.*, 2001; Johnston *et al.*, 2004; Wennerstrand *et al.*, 2006; Gradner *et al.*, 2007; van Dillen *et al.*, 2007). Biomechanical research on humans, have used this technique to study a wide range of topics as the effect of hyperpronation on the lower extremities (Khamis and Yizhar, 2007), the position of the lumbar spine during steady state movement on flat and angled surfaces (Levine *et al.*, 2007), the timing of hip and lumbopelvic rotation in people with low back pain (van Dillen *et al.*, 2007) and shoulder alignment in bowlers (Roca *et al.*, 2006).

The wide-ranging spectrum and large number of studies, including the present thesis, have established present-day technology as a valuable and adequate tool to document movements and alterations of the movements. A high degree of repeatability was seen between the two measurements before the respective injections of either mepivacaine or sodium chloride in Study II, which further supports the use of modern technology for kinematic analyses. This is also in accordance with the conclusion of Faber *et al.* (2002), that analysis of back kinematics in the horse can provide highly repeatable data, which makes it suitable for clinical use.

Kinematic analysis as a tool to evaluate back dysfunction

All patients in Study I showed muscle soreness on palpation of the back, and more than half of them had pathological skeletal changes, which makes it reasonable to assume that the back pain was the main reason for the changes in back movement. In Study III, back pain was clearly evident in all horses subsequent to the lactic acid injections. Whereas no abnormal back movements could be detected by clinical observation, the kinematic analysis technique revealed several changes in movement. The kinematic changes remained manifest and detectable for a longer period of time than the clinically palpable back pain, which can be compared to the early stages of a typical back problem. While the function of the back and the performance capacity of the horse are decreased, the horse is commonly not initially painful on palpation. The infrared-based automated gait analysis technique may detect and measure dysfunctions, which makes it possible to early on discover the problems and later on do follow-up-measurements during rehabilitation. When the patient in the case study in the "additional results" above was evaluated at the University Clinic, the clinical symptoms had improved and no appreciable muscle asymmetries were noted. However, the owner considered the horse to have a decreased performance, and the kinematic analysis revealed kinematic changes in ROM and symmetry of movement, where the patient had earlier showed symptoms. This reflects the difference between a traditional clinical examination on the stationary horse and movement analysis. While palpation gives information on the pain on palpation, movement analysis gives information on the function.

In conclusion the results show that the infrared-based automated gait analysis technique can differentiate horses with back dysfunction from horses with normal back movements, and that this technique can be used to evaluate a specific, localized change in movement in a patient with clinical back pain. It has also been shown that local anaesthesia affect the back movement in clinically sound horses, and that weighted boots on the limbs affect the movement of the back in asymptomatic horses in regular training and competition.

Conclusions

- Horses with naturally occurring back pain and dysfunction
    - Data from a group of riding horses with naturally occurring spinal and back muscle pain and dysfunction have been gathered.
    - These data show that the movement of the back in a horse with back pain and dysfunction differs from that of the asymptomatic horse.

- Regional anaesthesia
    - Diagnostic infiltration of local anaesthetic solution affects the movement of the back in clinically sound horses.
    - When interpreting the use of this clinical aid in assessing clinical cases of back dysfunction, its effects on asymptomatic horses have to be considered.

- Induced back pain
    - Horses with identical back injuries appear to show similar changes in their back kinematics, as compared to the asymptomatic condition.
    - Unilateral back pain seems to result in an increased extension of the back, as well as compensatory lateral movements.

- Weighted boots
    - Weighted boots on the hind limbs affect the movement of the lumbar back.
    - Weighted boots on the forelimbs affect the movement of the mid-thoracic back.
    - Knowledge of the effect of weighted boots on the back movement is useful in training and rehabilitation of sport horses.

  - Weighted boots on the hind limbs at the walk may induce strengthening of the flexors of the lumbar back and increase the flexion–extension of the lumbar back under controlled conditions.

- Automated gait analysis systems
  - Present-day gait analysis systems can identify changes in the back movement, and will help to clinically describe and, most important, classify, horses with back pain and dysfunction.
  - Knowledge of the relationship between changes in the back movement and the site of injury will be of help in better localizing and diagnosing disorders of the equine back.
  - Kinematics can objectively evaluate the effect of local anaesthesia of the back.
  - Kinematics can objectively evaluate improvements of the back movement.

Future studies

Automated gait analysis systems have proven to be able to differentiate horses with back dysfunction from horses with normal back movements, and it has been shown that this technique can be used to evaluate a specific, localized change in movement in a patient with clinical back pain.

Suggestions for future items to be studied are bilateral back pain and long-term follow-ups of back patients after treatment. Kinematic analysis could also be used to further evaluate the non-scientific therapies that are sometimes used to treat back problems.

Further studies are required before the full effects of weighted boots can be evaluated, and studies over a longer period of time, perhaps with the use of electromyography, are suggested.

Manufacturers' addresses

[1]SÄTO, SÄTO AB, Knivsta, Sweden
[2]Mustang 2200©, Kagra corporation, Fahrwangen, Switzerland
[3] Plegicil® vet., Pharmaxim, Helsingborg, Sweden
[4]ProReflex®, Qualysis Medical AB, Gothenburg, Sweden
[5]QTrack™, Qualysis Medical AB, Gothenburg, Sweden
[6]MatLab®, The Math Works Inc., Natick, USA
[7]Backkin®, Qualysis Medical AB, Gothenburg, Sweden
[8]Carbocain®, AstraZeneca, Södertälje, Sweden
[9]Statistica©, StatSoft Inc., Tulsa, USA

References

Audigié, F., Pourcelot, P., Degueurce, C., Denoix, J.-M. and Geiger, D. (1999) Kinematic of the equine back: flexion-extension movements in sound trotting horses. *Equine Vet. J. Suppl.* **30**, 210-213.

Back, W., Remmen, J.L., Knaap, J. and de Koning, J.J. (2003) Effect of lateral heel wedges on sagittal and transverse plane kinematics of trotting Shetland ponies and the influence of feeding and training regimes. *Equine Vet. J.* **35**, 606-612.

Biengräber, M. (1916) Hästens yttre åkommor. Stockholm, Wilhelmssons boktryckeri A-B.

Bobbert, M.F., Santamaría, S., van Weeren, P.R., Back, W. and Barneveld, A. (2005) Can jumping capacity of adult show jumping horses be predicted on the basis of submaximal free jumps at foal age? A longitudinal study. *Vet. J.* **170**, 212-221.

Bogduk, N. (1995) The anatomical basis for spinal pain syndromes. *J. Manipulative Physiol. Ther.* **18**, 603-605.

Borelli, G. A. (1685) De motu animalium. Second edition. Leiden: Petrum Vander Aa.

Buchner, H.H.F., Savelberg, H.H.C.M., Schamhardt, H.C., Merkens, H.W. and Barneveld, A. (1994) Habituation of horses to treadmill locomotion. *Equine vet. J., Suppl.* **17**, 13-15.

Budras, K.-D. and Sack, W.O. (1994) Selected body systems in tabular form; muscles. *In:* Anatomy of the horse, an illustrated text. Eds: K.-D. Budras and W.O. Sack, Schlütersche verlagsanstalt und druckerei GmbH & Co., Hannover. pp. 81-93.

Clayton, H.M., Hoyt, D.F., Wickler, S.J., Cogger, E.A. and Lanovaz, J.L. (2002) Hindlimb net joint energies during swing phase as a function of trotting velocity. *Equine Vet. J., Suppl.* **34**, 363-367.

De Cocq, P., van Weeren, P.R. and Back, W. (2004) Effects of girth, saddle and weight on movements of the horse. *Equine Vet. J.* **3**, 758-763.

Denoix, J.-M. (1998) Diagnosis of the cause of back pain in horses. *In:* Proceedings of the Conference on Equine Sports Medicine and Science, Cordoba, 1998, pp. 97-110.

Denoix, J.-M. (1999) Spinal biomechanics and functional anatomy. *In:* *Vet. Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia. pp. 27-60.

Denoix, J.-M. and Audigié, F. (2001) The neck and back. *In:* Equine Locomotion. Eds: W. Back and H. Clayton, W.B. Saunders Co, London. pp. 167-191.

Denoix, J.-M. (2004) Diagnostic imaging of thoracolumbar lesions in horses, The thoracolumbar spine: lesions, and Ultrasonographic evaluation of back lesions. *In:* The equine back, pelvis and neck. Le Cirale, Dozulé, France, July, 2004, pp. 58-95.

Dutto, D.J., Hoyt, D.F., Clayton, H.M., Cogger, E.A. and Wickler, S.J. (2006) Joint work and power for both the forelimb and hindlimb during trotting in the horse. *J. Exp. Biol.* **209**, 3990-3999.

Dyce, K.M., Sack, W.O. and Wensing, C.J.G. (1996) The locomotor apparatus. *In:* Textbook of veterinary anatomy. Eds: K.M. Dyce, W.O. Sack and C.J.G. Wensing, W.B. Saunders Co., Philadelphia. pp. 31-98.

Dyson, S. and Murray, R. (2003) Pain associated with the sacroiliac joint region: a clinical study of 74 horses. *Equine Vet. J.* **35**, 240-245.

Erichsen, C., Eksell, P., Roethlisberger-Holm, K., Lord, P. and Johnston, C. (2003a) Scintigraphic evaluation of the thoracic spine in the asymptomatic riding horse. *Vet. Radiol. Ultrasound* **3**, 330-338.

Erichsen, C., Eksell, P., Widström, C., Berger, M., Holm, K.R. and Johnston, C. (2003b) Scintigraphy of the sacroiliac joint region in asymptomatic riding horses: scintigraphic appearance and evaluation of method. *Vet. Radiol. Ultrasound* **44**, 699-706.

Erichsen, C., Eksell, P., Roethlisberger-Holm, K., Lord, P. and Johnston, C. (2004) Relationship between scintigraphic and radiographic evaluations of spinous processes in the thoracolumbar spine in riding horses without clinical signs of back problems. *Equine Vet. J.* **36**, 458-465.

Faber, M., Schamhardt, H. and van Weeren, R. (1999) Determination of 3D spinal kinematics without defining a local vertebral co-ordinate system. *J. Biomech.* **32**, 1355-1358.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2000) Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *Am. J. Vet. Res.* **61**, 399-406.

Faber, M. (2001a). Kinematics of the equine back during locomotion. *In:*

Kinematics of the equine back during locomotion, PhD thesis by Marjan Faber, Utrecht University, The Netherlands, pp. 91–110.

Faber, M., Schamhardt, H., van Weeren, R. and Barneveld, A. (2001b) Methodology and validity of assessing kinematics of the thoracolumbar vertebral column in horses based on skin-fixated markers. *In:* Kinematics of the equine back during locomotion, PhD thesis by Marjan Faber, Utrecht University, The Netherlands, pp. 65-75.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2001c) Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *Am. J. Vet. Res.* **62**, 757-764.

Faber, M., Johnston, C., van Weeren, P.R. and Barneveld, A. (2002) Repeatability of back kinematics in horses during treadmill locomotion. *Equine vet. J.* **34**, 235-241.

Faber, M., van Weeren, R., Schepers, M. and Barneveld, A. (2003) Long-term follow-up of manipulative treatment in a horse with back problems. *J. Vet. Med. A.* **50**, 241-245.

Fredricson I, Drevemo S, Dalin G, Hjertën G, Björne K. (1980) The application of high-speed cinematography for the quantitative analysis of equine locomotion. *Equine Vet. J.* **12**, 54-59.

Fredricson, I., Drevemo, S., Dalin, G., Hjertén, G., Björne, K., Rynde, R., Franzén G. (1983) Treadmill for equine locomotion analysis. *Equine Vet. J.* **15**, 111-115.

Furugren, B. (1990) Från vildhäst till sporthäst – om hästens historia från istid till nutid. Hästens historia. Hippologiska högskoleutbildningen, Sveriges Lantbruksuniversitet.

Goff, L.M., Jeffcott, L.B., Jasiewiczc, J. and McGowan, C.M. (2007) Structural and biomechanical aspects of equine sacroiliacjoint function and their relationship to clinical disease. *Vet. J.*(*Accepted.*)

Gómez Álvarez, C.B., Wennerstrand, J., Bobbert, M.F., Lamers, L., Johnston, C., Back, W. and van Weeren, P.R. (2007) The effect of induced forelimb lameness on thoracolumbar kinematics during treadmill locomotion. *Equine Vet. J.* **39**, 197-201.

Gómez Álvarez, C.B., Bobbert, M.F., Lamers, L., Johnston, C., Back, W. and van Weeren, P.R. (2008a) The effect of induced hindlimb lameness on thoracolumbar kinematics during treadmill locomotion. *Equine Vet. J.* **40**, 147-152.

Gómez Álvarez, C.B., L'ami, J.J., Moffat, D., Back, W. and van Weeren, P.R. (2008b) Effect of chiropractic manipulations on the kinematics of back and limbs in horses with clinically diagnosed back problems. *Equine Vet. J.* **40**, 153-159.

Gradner, G., Bockstahler, B., Peham, C., Henninger, W. and Podbregar, I. (2007) Kinematic study of back movement in clinically sound malinois dogs with consideration of the effect of radiographic changes in the lumbosacral junction. *Vet. Surg.* **36**, 472-481.

Haussler, K.K., Stover, S.M. and Willits N.H. (1997) Developmental variation in lumbosacropelvic anatomy of thoroughbred racehorses. *Am. J. Vet. Res.*, **58**, 1083-1091.

Haussler, K.K. and Stover, S.M. (1998) Stress fractures of the vertebral lamina and pelvis in Thoroughbred racehorses. *Equine Vet. J.*, **30**, 374-381.

Haussler, K.K. (1999) Anatomy of the thoracolumbar vertebral region, pp. 13-26, and Osseous spinal pathology, pp. 103-112. *In: Vet.Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia.

Haussler, K.K., Stover, S.M. and Willits N.H. (1999) Pathologic changes in the lumbosacral vertebrae and pelvis in Thoroughbred racehorses. *Am. J. Vet. Res.*, **60**, 143-153.

Hernquist, P. (1793) Yttre kjänneteken på en väl eller illa skapad hästkropp samt bästa sättet at sko en häst. Skara.

Hildebrand, M. (1962) Walking, running and jumping. *Am. Zoologist,* 2, 151-155.

Jeffcott, L.B. (1979) Radiographic features of the normal equine thoracolumbar spine. *Vet. Radiol.* **20**, 140-147.

Jeffcott, L.B. (1980a) Disorders of the thoracolumbar spine of the horse – a survey of 443 cases. *Equine Vet. J.* **12**, 197-210.

Jeffcott, L.B. and Dalin, G. (1980b) Natural rigidity of the horse's backbone. *Equine Vet. J.* **12**, 101-108.

Jeffcott, L.B., Dalin, G., Drevemo, S., Fredriccson, I., Björne, K. and Bergquist, A. (1982) Effect of induced back pain on gait and performance of trotting horses. *Equine Vet. J.* **14**, 129-133.

Jeffcott, L.B., Dalin, G., Ekman, S. and Olsson, S.E. (1985) Sacroiliac lesions as a cause of chronic poor performance in competitive horses. *Equine Vet. J.* **17**, 111-118.

Jeffcott, L.B. (1999) Historical perspective and clinical indications. In: *Vet. Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia. pp 1-12.

Johnston, C., Holm, K., Faber, M., Erichsen, C., Eksell, P. and Drevemo, S. (2002) Effect of conformational aspects on the movement of the equine back. *Equine Vet. J., Suppl.,* **34**, 314-318.

Johnston, C., Holm, K., Erichsen, C., Eksell, P. and Drevemo, S. (2004) Kinematic evaluation of the back in the asymptomatic riding horse.

Equine Vet. J. **6**, pp. 495-498.

Khamis, S. and Yizhar, Z. (2007) Effect of feet hyperpronation on pelvic alignment in a standing position. *Gait Posture* **25**, 127-134.

Kicker, C.J., Peham, C., Girtler, D., Licka, T. (2004) Influence of support Boots on fetlock joint angle of the forelimb of the horse at walk and trot. *Equine Vet. J.* **36**, 769-771.

Landman, M.A., de Blaauw, J.A., van Weeren, P.R. and Hafland, L.J. (2004) Field study of the prevalence of lameness in horses with back problems. *Vet. Rec.* **155**, 165-168.

Levine, D., Colston, M.A., Whittle, M.W., Pharo, E.C. and Marcellin-Little, D.J. (2007) Sagittal lumbar spine position during standing, walking, and running at various gradients. *J. Athl. Train.* **42**, 29-34.

Licka, T., Peham, C. and Zohmann, E. (2001) Range of back movement at trot in horses without back pain. *Equine Vet. J., Suppl.* **33**, 150-153.

Licka TF, Peham C, Frey A. (2004a) Electromyographic activity of the longissimus dorsi muscles in horses during trotting on a treadmill. *Am. J. Vet. Res.* **65**, 155-158.

Licka, T., Kicker, C., Peham, C. and Girtler, D. (2004b). Evaluation and comparison of the effect of support boots on the fetlock joint angle during the stance phase at walk and trot. *Equine and Comparative Exercise Physiology* **2**, A17.

Licka T, Frey A, Peham C. (2008) Electromyographic activity of the longissimus dorsi muscles in horses when walking on a treadmill. *Vet J.(Accepted.)*

Marlin, D. and Nankervis, K. (2002) Part II, Exercise and training responses: Muscular responses. In: *Equine exercise physiology*. Eds: D. Marlin and K. Nankervis, Blackwell Science Ltd, Malden. pp. 75-85.

Marks, D. (1999) Medical management of back pain. In: *Vet. Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia. pp. 179-194.

Martin, B.B. and Klide, A.M. (1999) Physical examination of horses with back pain. In: *Vet. Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia. pp 61-70.

Martin, P.E. and Cavanagh, P.R. (1990). Segment interactions within the swing leg during unloaded and loaded running. *J. Biomech.* **23**, 529–536.

McCue, M.E., Ribeiro, W.P. and Valberg, S.J. (2006) Prevalence of polysaccharide storage myopathy in horses with neuromuscular disorders. *Equine Vet. J.* **36**, 340-344.

Meyer, S.W., Weishaupt, M. and Nuss, K.A. (2007) Gait pattern of heifers before and after claw trimming: a high-speed cinematographic study on a treadmill. *J. Dairy Sci.* **90**, 670-676.

Muybridge, E. (1887) Animal locomotion. Philadelphia.

Pilsworth, R.C., Shepherd, M.C., Herinckx, B.M. and Holmes, M.A. (1994) Fracture of the wing of the ilium, adjacent to the sacroiliac joint, in thoroughbred racehorses. *Equine Vet. J.* **26**, 94-99.

Quiroz-Rothe, E., Novales, M., Aquilera-Tejero, E. and Rivero, J.L. (2002) Polysaccharide storage myopathy in the *M. longissimus lumborum* of showjumpers and dressage horses with back pain. *Equine Vet. J.* **34**, 171-176.

Ranner, W., Gerhards, H. and Klee, W. (2002) Diagnostic validity of palpation in horses with back problems. *Berl. Munch. Tierarztl. Wochenschr.* **115**, 420-424.

Robert, C., Valette, J.P. and Denoix, J.M. (1998) Surface electromyographic analysis of the normal horse locomotion: a preliminary report. In: *Proceedings of the Conference of Equine Sports Medicine and Science*, Cordoba, Spain, pp. 80-85.

Roca, M., Elliott, B., Alderson, J. and Foster, D. (2006) The relationship between shoulder alignment and elbow joint angle in cricket fast-medium bowlers. *J. Sports Sci.* **24**, 1127-1135.

Rhodin, M., Johnston, M., Roethlisberger-Holm, K., Wennerstrand, J. and Drevemo, S. (2005). The influence of head and neck position on the kinematics of the back in riding horses at the walk and trot. *Equine Vet. J.* **37**, 7-11.

Singer, E.R., Barnes, J., Saxby, F. and Murray, J.K. (2008) Injuries in the event horse: training versus competition. *Vet. J.* **175**, 76-81.

Slijper, E.J. (1946) Comparative biologic-anatomical investigations on the vertebral column and spinal musculature of mammals. *K. Ned. Acad. Wetensch.* **42**, 1-128.

Stashak, T.S. (1987) The pelvis. The thoracolumbar spine. Muscle problems. *In:* Adams' lameness in horses, 4th ed. Ed: T.S. Stashak, Lea & Febiger, Lippincott, Williams & Wilkins, Philadelphia. pp. 752-762.

Stecher, R.M. (1962) Lateral facets and lateral joints in the lumbar spine of the horse - a descriptive and statistical study. *Am. J. Vet. Res.* **23**, 939-947.

Stubbs, N.C., Hodges, P.W., Jeffcott, L.B., Cowin, G., Hodgson, D.R. and McGowan, C.M. (2006) Functional anatomy of the caudal thoracolumbar and lumbosacral spine in the horse. *Equine Vet. J., Suppl.* **36**, 393-399.

Townsend, H.G., Leach, D.H. and Fretz P.B. (1983) Kinematics of the equine thoracolumbar spine. *Equine Vet J.* **15**, 117-122.

Townsend, H.G. and Leach, D.H. (1984) Relationship between intervertebral joint morphology and mobility in the equine thoracolumbar spine. *Equine Vet. J.* **16**, 461-465.

Townsend, H.G., Leach, D.H., Doige, C.E. and Kirkaldy-Willis, W.H. (1986) Relationship between spinal biomechanics and pathological changes in the equine thoracolumbar spine. *Equine Vet. J.*, **18**, 107-112.

Tucker, R.L., Schneider, R.K., Sondhof, A.H., Ragle, C.A. and Tyler, J.W. (1998) Bone scintigraphy in the diagnosis of sacroiliac injury in twelve horses. *Equine Vet. J.* **30**, 390-395.

Valberg, S. (2003) Recurrent exertional rhabdomyolysis. *In:* Den prestationsnedsatta hästen. Frösundavik, Stockholm, oktober, 2003. pp. 66-70.

van Dillen, L.R., Gombatto, S.P., Collins, D.R., Engsberg, J.R. and Sahrmann, S.A. (2007) Symmetry of timing of hip and lumbopelvic rotation motion in 2 different subgroups of people with low back pain. *Arch. Phys. Med. Rehabil.* **88**, 351-360.

van Heel, M.C., van Weeren, P.R. and Back, W. (2006a) Shoeing sound warmblood horses with a rolled toe optimises hoof-unrollment and lowers peak loading during breakover. *Equine Vet. J.* **38**, 258-262.

van Heel, M.C., van Weeren, P.R. and Back, W. (2006b) Compensation for changes in hoof conformation between shoeing sessions through the adaptation of angular kinematics of the distal segments of the limbs of horses. *Am. J. Vet. Res.* **67**, 1199-1203.

van Weeren, P.R. (2005) Editorial; Equine ergonomics: a new era? *Equine Vet. J.* **37**, 4-6.

Vennerholm, J. (1914) Grunddragen av hästens icke-operativa speciella kirurgi. Stockholm, Albert Bonniers förlag.

Vogel, S. (2007) The emergence of comparative biomechanics. *Integrative and Comparative Biology* **47**, 13-15.

Walmsley, J.P., Pettersson, H., Winberg, F., McEvoy, F. (2002) Impingement of the dorsal spinous processes in two hundred and fifteen horses: case selection, surgical technique and results. *Equine Vet. J.* 34, 23-28.

Wennerstrand, J., Rhodin, M., Johnston, C., Roethlisberger-Holm, K. and Drevemo, S. (2006) The effect of weighted boots on the movement of the back in the asymptomatic riding horse. *Equine and Comparative Exercise Physiology*. **3**, 13-18.

Wennerstrand, J., Johnston, C., Roethlisberger-Holm, K., Erichsen, C., Eksell, P. and Drevemo, S. (2004) Kinematic evaluation of the back in the sport horse with back pain. *Equine Vet. J., Suppl.* **36**, 707-711.

Wickler, S.J., Hoyt, D.F., Clayton, H.M., Mullineaux, D.R., Cogger, E.A., Sandoval, E., McGuire, R. and Lopez, C. (2004). The energetic and kinematic consequences of weighting the distal limb. *Equine Vet. J.* **8**, 772–777.

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I

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Kinematic evaluation of the back in the sport horse with back pain

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Keywords: horse; back movement; kinematic evaluation; back pain

Summary

Reasons for performing study: **Earlier studies have developed a clinical tool to evaluate objectively the function of the equine back. The ability to differentiate horses with back pain from asymptomatic, fully functioning horses using kinematic measures from this tool has not been evaluated.**

Objectives: **To compare the kinematics of the back at walk and trot in riding horses with back dysfunction to the same parameters in asymptomatic sport horses.**

Methods: **The kinematics of the back in 12 horses with impaired performance and back pain were studied at walk and trot on a treadmill. Data were captured for 10 secs at 240 Hz. Range of movement (ROM) and intravertebral pattern symmetry of movement for flexion and extension (FE), lateral bending (LB) and axial rotation (AR) were derived from angular motion pattern data and the results compared to an earlier established database on asymptomatic riding horses.**

Results: **At walk, horses with back dysfunction had a ROM smaller for dorsoventral FE in the caudal thoracic region (T13 = 7.50°, T17 = 7.71°; $P<0.05$), greater for LB at T13 (8.13°; $P<0.001$) and smaller for AR of the pelvis (10.97°; $P<0.05$) compared to asymptomatic horses (FE-T13 = 8.28°, FE-T17 = 8.49°, LB-T13 = 6.34°, AR-pelvis = 12.77°). At trot, dysfunctional horses had a smaller ($P<0.05$) ROM for FE at the thoracic lumbar junction (T17 = 2.46°, L1 = 2.60°) compared to asymptomatic horses (FE-T17 = 3.07°, FE-L1 = 3.12°).**

Conclusions: **The objective measurement technique can detect differences between back kinematics in riding horses with signs of back dysfunction and asymptomatic horses. The clinical manifestation of back pain results in diminished flexion/extension movement at or near the thoracic lumbar junction. However, before applying the method more extensively in practice it is necessary to evaluate it further, including measurements of patients whose diagnoses can be confirmed and long-term follow-ups of back patients after treatment.**

Potential relevance: **Since the objective measurement technique can detect small movement differences in back kinematics, it should help to clinically describe and, importantly, objectively detect horses with back pain and dysfunction.**

Introduction

Back problems are important contributors to poor performance in riding horses (Jeffcott 1980). The case history and clinical examination are fundamental, but there is often a need for supplementary diagnostic aids to properly diagnose a horse with back dysfunction. Frequently used aids are local anaesthesia, radiography, scintigraphy and ultrasound. Sometimes these aids are insufficient to detect the origin of the problem. They can also, when not specific for the location of pain, be confusing or give information of questionable value as they may result in false positive and false negative findings (Jeffcott 1979; Erichsen *et al.* 2003).

An objective tool with good accuracy and precision would be an asset when evaluating the function of the back. The movement of the back has been studied *in vivo* at different gaits (Audigié *et al.* 1999; Denoix 1999; Faber *et al.* 2000, 2001; Haussler *et al.* 2001; Licka *et al.* 2001a,b). The reliable and repeatable protocol developed by Faber *et al.* (2000) was used recently by Johnston *et al.* (2004) to establish a database on the movement of the back in asymptomatic riding horses in regular training and competition. Under standardised conditions, the kinematics of the back were measured on a treadmill at constant speeds at the walk and trot.

The aim of the present study was to establish a corresponding database on sport horses with signs of a back problem, and compare the kinematics of the back at walk and trot of those horses to the same parameters in asymptomatic horses. The hypothesis was that the movement of the back in symptomatic horses differs in angular amplitude and symmetry from that of asymptomatic horses.

Materials and methods

Horse recruitment

Riding horses with impaired performance and clinical back pain were used in the study. The horses either came to the University clinic directly or were referred to the clinic by private practitioners or other clinics. The inclusion criteria were that subjects were Warmblood riding horses, age 5–15 years, that had not been treated for back pain in the last 3 months, with the exception of rest and/or convalescence training.

At the clinic, the horses underwent a clinical examination including a visual and palpatory examination, observation of the

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TABLE 1: The appreciated location and type of injury together with competing level prior to back pain and dysfunction in 12 horses with back dysfunction

	Palpation soreness					
Horse	Degree	Localisation	Tissue involved	Diagnosis	Basis	Performance level prior to back pain
1	M	Lumbar, left and right	Muscle	Muscle soreness	Palpation	Intermediate 3-day-event
2	M	Caudal thoracic and TL junction	Muscle and spinous processes	Kissing spines T16–18 with moderate sclerosis	RS	Intermediate dressage
3	M	Caudal thoracic and TL junction	Muscle and spinous processes	Kissing spines T13–17 with mild sclerosis. Scoliosis lumbar spine	RS	Intermediate dressage
4	M	T12–18	Muscle and spinous processes	Kissing spines ventral parts of dorsal spinous processes T13–17 and spondylosis T12–17	RS	Intermediate dressage, showjumping and 3-day-event
5	MM	Thoracolumbar junction region	Spinous processes	Kissing spines T15–18, focal uptake T13	RS	Basic dressage
6	MM	T14–L3	Muscle and spinous processes	Kissing spines with mild sclerosis Chronic periostitis on lumbar transverse processes	RS	Intermediate dressage
7	MM	T17–L3	Muscle	Kissing spines T17–L3 with sclerosis and lysis	RS	Intermediate dressage
8	MM Severe	T14–15 T17–L4	Spinous processes Muscle	Kissing spines T13–14 Deformed *tuber ischii*	Scintigraphy and autopsy Autopsy	Intermediate dressage
9	MM	T15–18 T14–18	Spinous processes Muscle	Kissing spines caudal thoracic back with mild sclerosis. Kissing spines L4–6. Deformed dorsal spinous processes and asymmetrical intervertebral joints in lumbar back	RS Autopsy	Basic showjumping
10	Mild	T15–L2	Muscle and spinous processes	Kissing spines T14–L1	RS	Basic showjumping and dressage
11	Mild	Lumbar back	Muscle and spinous processes	Kissing spines T15–16 with sclerosis Active transverse processes L3	RS	Basic showjumping
12	Mild	T15–L3	Muscle	Muscle soreness	Palpation	Basic showjumping and dressage

M = moderate; MM = mild to moderate; RS = radiography and scintigraphy.

horse moving in hand on a hard surface, flexion tests of all 4 limbs, lungeing on both reins and a riding test performed by their respective regular rider at the walk, trot and canter. If lameness was detected during any of the mentioned examinations, or a response of >1 (forelimbs) or >2 (hindlimbs) degree(s) of lameness (on a scale of 0–5) was obtained on flexion test, the horse was excluded. Back pain was considered to be present if the horse showed clear signs of pain/discomfort on palpation of the back and the reaction did not decrease at repeated palpation. Commonly, horses demonstrating back pain reacted to palpation by adverse reactions, e.g. bolting or rearing, tail swishing, unruliness, rapid caudal movement of the ears or stiff, jerky movements. The appreciated locations and types of injury are given in Table 1. The selected horses (4 mares and 8 geldings) had been in regular training for dressage (n = 5), jumping (n = 4), eventing (n = 1) or general purpose (n = 2) prior to the onset of their respective back problem.

Horses in the control group were Warmblood riding horses, age 5–15 years, considered sound and fully functioning by their riders, in regular training for at least 3 months and in competitive condition (Johnston *et al.* 2004). The controls were clinically sound at the walk and trot in hand and on lungeing on both reins, and performed satisfactorily during a riding test performed by their regular rider. They demonstrated no pain reaction on palpation of the back, showed not >1° of lameness in any of the limbs on a flexion test of the limb and had not been treated for a back-related problem for at least 12 months prior to the examination. Due to technical problems, the data at the walk had to be excluded for 4 of the control horses. The control group therefore included 29 horses at walk and 33 at trot.

Experimental set-up and data collection

All horses were trained 4 times, for 10–15 mins each, on a coir mat treadmill at walk and trot prior to the recordings (Fredricson *et al.* 1983; Buchner *et al.* 1994). Spherical reflective markers, 19 mm diameter, were glued onto the skin over the dorsal spinous processes of 8 back vertebrae (T6, T10, T13, L1, L3, L5 and S3). Markers were also placed on both left and right *tubera coxae* and proximally on the lateral part of the left hind hoof wall. The landmarks were all identified by palpation. The positions of the markers (inaccuracy <1.5 mm) were collected by 6 infrared cameras (ProReflex)[1], positioned around the treadmill so that each marker was always seen by at least 2 cameras.

The measurement volume made up a laboratory coordinate system with the positive y-axis oriented in the line of progression, the positive z-axis oriented upward and the x-axis oriented perpendicular to the direction of the y- and z-axes. The calibration was performed dynamically, using a calibration frame which defined the orientation of the right-handed orthogonal laboratory coordinate system and a wand with an exactly defined length. Data were captured at a sampling rate of 240 Hz for 1 sec at a square stance and for 10 secs with the horses walking (1.6 m/sec) and trotting (3.8 m/sec).

Calculation of back kinematics in 2D

The reconstruction of the 3D position of each marker was based on a direct linear transformation algorithm (QTrack)[1]. Subsequently, the raw x-, y- and z-coordinates were exported into MatLab[2] and Backkin[1] programme packages for further data

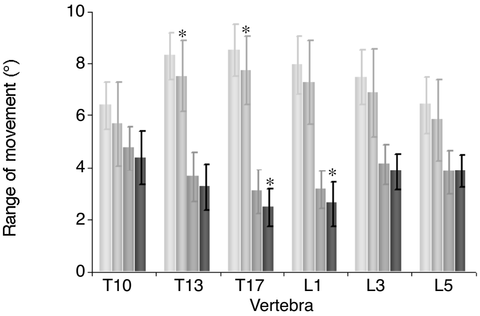

Fig 1: Mean ± s.d. range of movement for the flexion/extension movements of 6 back vertebrae at walk and trot. ░ *= asymptomatic horses at the walk;* ▒ *= horses with back dysfunction at the walk;* ▓ *= asymptomatic horses at trot;* ■ *= horses with back dysfunction at the trot. *Values for horses with back dysfunction statistically significant (P<0.05) compared with asymptomatic horses.*

processing. The individual stride cycles were determined and the beginning of each stride cycle was defined as the moment of first ground contact of the left hind hoof, determined from the velocity profile of the marker on the left hind hoof (Peham *et al.* 1999; Mickelborough *et al.* 2000). The x-, y- and z-coordinates were used to calculate the back rotations in accordance with Faber *et al.* (1999). An explanation of the principles of the instantaneous orientation of a vertebra was presented by Johnston *et al.* (2002).

Coordinate and angular motion pattern (AMP) data were extracted at the walk and trot from approximately 8 and 12 representative strides, respectively. Each stride was normalised to 101 data points, in order to allow averaging of the AMPs over strides. Stride length and velocity were calculated from the hoof marker. The range of movement (ROM) and intravertebral pattern symmetry of movement (SYM) were derived from the AMPs.

Statistical analysis

The results were presented as total ranges of movement and means ± s.d. Student's *t* test and one-way ANOVA were used to analyse possible differences in kinematics between horses with back dysfunction and asymptomatic horses (Johnston *et al.* 2004). The minimum level of statistical significance was set to P<0.05. Statistical analyses were performed with the statistical software package Statistica[3].

Ethical review

The local ethical committee for the Swedish National Board for Laboratory Animals approved this study.

Results

The affected horses had a significantly decreased ROM for the dorsoventral flexion and extension (FE) movement at T13 (7.50 ± 1.37°) and T17 (7.71 ± 1.31°) (Fig 1) at the walk, and a smaller ROM for the FE movement at T17 (2.46 ± 0.71°) and L1 (2.60 ± 0.84°) (Fig 1b) at the trot compared to the asymptomatic horses (Walk: FE-T13 = 8.28 ± 0.88°, FE-T17 = 8.49 ± 0.98°; Trot: FE-T17 = 3.07 ± 0.83°, FE-L1 = 3.12 ± 0.71°).

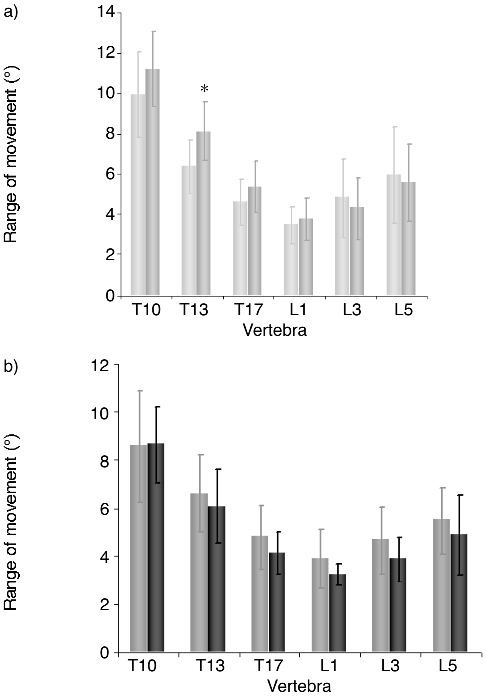

Fig 2: Mean ± s.d. range of movement for the lateral bending movements of 6 back vertebrae a) at walk and b) trot. ░ *= asymptomatic horses at walk;* ▒ *= horses with back dysfunction at walk;* ▓ *= asymptomatic horses at trot;* ■ *= horses with back dysfunction at trot. *Values for horses with back dysfunction statistically significant (P<0.001) compared with asymptomatic horses.*

The ROM for the lateral bending (LB) movement at the walk was significantly greater at T13 (8.13 ± 1.34°) (Fig 2a) in the affected than in the control horses (6.34 ± 1.47°). At the trot, no significant difference was observed between the ROMs for the LB movements of the 2 groups (Fig 2b).

The lateral excursion movement of the back did not differ significantly between the patients and the respective control group at either gait. The axial rotation (AR) movement (Fig 3) of the pelvis was less in the group with back dysfunction (10.97 ± 2.08°) than among the asymptomatic horses (12.77 ± 2.10°) at the walk, while no significant difference was observed for this parameter at the trot.

At the lumbar back, 2 significant differences in the SYM were observed between the patients and the asymptomatic horses at the walk (Table 2). The patients were less symmetrical at L1 for the FE movement and at L5 for the LB movement. At the trot, there was no difference in the SYM of the back.

At the walk, the stride length was significantly shorter for the horses with back pain (1.74 ± 0.13 m) than for the asymptomatic horses (1.86 ± 0.09 m). The stride velocity was 1.6 m/sec for both groups. At the trot, there was no significant difference between the stride length for the patients (2.72 ± 0.24 m) and the controls (2.83 ± 0.13 m). The stride velocity was slightly higher for the asymptomatic horses (3.9 ± 0.15 m/sec) than for those with back pain (3.8 ± 0.22 m/sec).

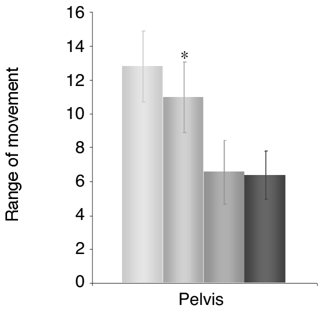

Fig 3: Mean ± s.d. range of movement for the axial rotation movement of the pelvis at walk and trot. ░ *= asymptomatic horses at walk;* ▒ *= horses with back dysfunction at the walk;* ▓ *= asymptomatic horses at the trot;* ■ *= horses with back dysfunction at the trot. *Values for horses with back dysfunction statistically significant (P<0.05) compared with asymptomatic horses.*

TABLE 2: The symmetry of movements of 6 back vertebrae and the pelvis at walk and trot for horses with back dysfunction (patients) and asymptomatic horses (controls)

	Walk (1.6 m/sec)				Trot (3.8 m/sec)			
	Controls		Patients		Controls		Patients	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
FE								
T10	0.96	0.05	0.96	0.05	0.97	0.04	0.93	0.09
T13	0.98	0.02	0.98	0.01	0.91	0.09	0.83	0.23
T17	0.98	0.02	0.98	0.01	0.86	0.16	0.76	0.31
L1	0.98	0.02	0.97*	0.03	0.91	0.11	0.86	0.14
L3	0.98	0.03	0.96	0.03	0.93	0.08	0.93	0.09
L5	0.97	0.04	0.94	0.06	0.91	0.13	0.94	0.05
LB								
T10	0.99	0.01	0.99	0.01	0.98	0.02	0.96	0.03
T13	0.98	0.02	0.99	0.01	0.97	0.02	0.92	0.15
T17	0.96	0.05	0.97	0.04	0.96	0.04	0.95	0.03
L1	0.93	0.07	0.91	0.09	0.91	0.12	0.91	0.09
L3	0.94	0.09	0.84	0.29	0.93	0.07	0.93	0.11
L5	0.98	0.02	0.93*	0.12	0.98	0.02	0.99	0.01
LE								
T10	0.99	0.01	0.99	0.01	0.96	0.08	0.96	0.04
T13	0.99	0.01	1.00	0.00	0.97	0.03	0.97	0.03
T17	0.99	0.01	1.00	0.00	0.98	0.02	0.97	0.04
L1	0.99	0.00	1.00	0.00	0.97	0.02	0.97	0.02
L3	0.99	0.01	1.00	0.00	0.97	0.03	0.98	0.02
L5	0.99	0.01	1.00	0.00	0.96	0.04	0.97	0.04
AR								
Pelvis	0.99	0.01	0.98	0.02	0.96	0.05	0.98	0.02

FE = flexion/extension; LB = lateral bending; LE = lateral excursion; AR = axial rotation. *Values for horses with back dysfunction statistically significant (P<0.05) compared with asymptomatic horses.

Discussion

The purpose of this study was to evaluate the movement of the back in sport horses with clinical signs of pain/discomfort in the back and reduced performance. A standardised protocol (with clinical examination and radiological, scintigraphic and kinematic evaluations) used previously for the control group of asymptomatic, fully functioning horses (Johnston *et al.* 2004) was used for horses with back dysfunction.

Horses with back pain show an aberrant pattern for the movement of the back, which, by the aid of the objective measurement technique, makes it possible to detect a horse with back dysfunction. It is reasonable to believe that a horse with a sore back tries to move in a way that, if possible, may alleviate the pain. Apparently this is best accomplished by a stiffening or reduction of dorsoventral movement in the caudal thoracic back and at the thoracolumbar junction, at both the walk and trot. The abnormal lateral movement seen at the withers and decreased AR of the pelvis result in a side-to-side swaying walk as seen from behind. Presumably, the symptomatic horse has altered normal neuromuscular control of the walk and trot to adjust to back pain. Acquired pathological limitations could also be an initial source of the problem and therefore crucial factors to decreased ROMs.

Apparently, flexion of the back is reduced to limit the relative displacement of the individual segments of the thoracolumbar back, perhaps due to excessive muscular activity as aggravated by nocioception (Perl 1976). The normal movement of the back is controlled by muscle activity more at the trot than at the walk, where the movement is more passive with a greater amplitude for the lateral and twisting movements. This may be the reason why the ROM for the AR of the pelvis is decreased in a horse with back pain at the walk, but not at the trot.

The reduction in ROM for the FE and AR movements has been observed in an earlier case study of one horse with increased responsiveness to palpation of the lumbar and sacral back (Faber *et al.* 2003). The shorter stride length observed in horses with back pain at the walk, coinciding with the decreased FE movement of the back, is in accordance with the findings of Jeffcott (1980) and Faber *et al.* (2003). It is also in agreement with the positive relationship between the pro- and retraction of the hindlimbs and the FE movement of the back that has been established in clinically sound horses at the walk (Faber *et al.* 2000) and trot (Faber *et al.* 2001). In the present study, the expected reduction in stride length in the horses with back dysfunction was not seen at the trot. The explanation for this is not obvious, but it is possible that the muscle activity in the hindlimbs was altered and may have influenced the stride length. The slight difference in stride velocity at the trot does not seem likely to have caused the decrease in ROM (Robert *et al.* 2001).

The present study shows significant differences between horses with back pain and asymptomatic controls at both walk and trot. The differences are most striking at the thoracolumbar junction, where the patients, in addition to the changes in the ROM, were also less symmetrical for the FE movement at the walk. These findings indicate that the thoracolumbar junction is one part of the back especially predisposed to impairment (Denoix 1998; Holm *et al.* 2002). Since all horses showed muscle soreness on palpation of the back, and more than half of them had pathological skeletal reactions, it is reasonable to believe that this was the main reason for the decreased dorsoventral FE movement at both gaits and the changed lateral movement at the walk.

This study supports the use of objective measurements of back kinematics as a valuable tool to help identify horses with back dysfunction. Before using it more extensively it is necessary to evaluate the method further including measurements of patients whose diagnoses can be confirmed and long-term follow-ups of back patients after treatment.

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Manufacturers' addresses

[1]Qualysis Medical AB, Gothenburg, Sweden.
[2]MatLab, The Math Works Inc., Natick, Massachusetts, USA.
[3]Statistica, StatSoft Inc., Tulsa, Oklahoma, USA.

References

Audigié, F., Pourcelot, P., Degueurce, C., Denoix, J.-M. and Geiger, D. (1999) Kinematics of the equine back: flexion-extension movements in sound trotting horses. *Equine vet. J., Suppl.* **30**, 210-213.

Buchner, H.H.F., Savelberg, H.H.C.M., Schamhardt, H.C., Merkens, H.W. and Barneveld, A. (1994) Habituation of horses to treadmill locomotion. *Equine vet. J., Suppl.* **17**, 13-15.

Denoix, J.-M. (1998) Diagnosis of the cause of back pain in horses. In: *Proceedings of the Conference on Equine Sports Medicine and Science*, Ed: A. Lindner, Wageningen Academic Publishers, Wageningen. pp 97-110.

Denoix, J.-M. (1999) Spinal biomechanics and functional anatomy. *Vet. Clin. N. Am.: Equine Pract.* **15**, 27-60.

Erichsen, C., Eksell, P., Roethlisberger-Holm, K., Lord, P. and Johnston, C. (2003) Scintigraphic evaluation of the thoracic spine in the asymptomatic riding horse. *Vet. Radiol. Ultrasound* **3**, 330-338.

Faber, M., Schamhardt, H. and van Weeren, R. (1999) Determination of 3D spinal kinematics without defining a local vertebral co-ordinate system. *J. Biomech.* **32**, 1355-1358.

Faber, M.J., van Weeren, P.R., Schepers, M. and Barneveld, A. (2003) Long-term follow-up of manipulative treatment in a horse with back problems. *Am. J. vet. med. Ass.* **50**, 241-245.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2000) Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *Am. J. vet. Res.* **61**, 399-406.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2001) Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *Am. J. vet. Res.* **62**, 757-764.

Fredricson, I., Drevemo, S., Dalin, G., Hjertén, G., Björne, K., Rynde, R. and Franzén, G. (1983) Treadmill for equine locomotion analysis. *Equine vet. J.* **15**, 111-115.

Haussler, K.K., Bertram, J.E.A., Gellman, K. and Hermanson, J.W. (2001) Segmental *in vivo* vertebral kinematics at the walk, trot and canter: a preliminary study. *Equine vet. J., Suppl.* **33**, 160-164.

Holm, K., Johnston, C., Faber, M., Wattle, O., Erichsen, C., Eksell, P. and Drevemo, S. (2002) Preliminary studies on the relationships between back dysfunction in riding horses and kinematics. In: *Proceedings of the Conference on Equine Sports Medicine and Science*, Ed: A. Lindner, Wageningen Academic Publishers, Wageningen. pp 141-147.

Jeffcott, L.B. (1979) Radiographic features of the normal equine thoracolumbar spine. *Vet. Radiol.* **20**, 140-147.

Jeffcott, L.B. (1980) Disorders of the thoracolumbar spine of the horse - a survey of 443 cases. *Equine vet. J.* **12**, 197-210.

Johnston, C., Holm, K., Erichsen, C., Eksell, P. and Drevemo, S. (2004) Kinematic evaluation of the back in the asymptomatic riding horse. *Equine vet. J.* **36**, 495-498.

Johnston, C., Holm, K., Faber, M., Erichsen, C., Eksell, P. and Drevemo, S. (2002) Effect of conformational aspects on the movement of the equine back. *Equine vet. J., Suppl.* **34**, 314-318.

Licka, T., Peham, C. and Zohmann, E. (2001a) Range of back movement at trot in horses without back pain. *Equine vet. J., Suppl.* **33**, 150-153.

Licka, T., Peham, C. and Zohmann, E. (2001b) Treadmill study of the range of back movement at the walk in horses without back pain. *Am. J. vet. Res.* **62**, 1173-1179.

Mickelborough, J., van der Linden, M.L., Richards, J. and Ennos, A.R. (2000) Validity and reliability of a kinematic protocol for determining foot contact events. *Gait Posture* **11**, 32-37.

Peham, C., Scheidl, M. and Licka, T. (1999) Limb locomotion - speed distribution analysis as a new method for stance phase detection. *J. Biomech.* **32**, 1119-1124.

Perl, E.R. (1976) Sensitisation of the nocioceptors and its relation to sensation. In: *Advances in Pain Research and Therapy*, Eds: J.J. Bonica and D.G. Albe-Fessard, Raven Press, New York. pp 1-17.

Robert, C., Audigié, F., Valette, J.P., Pourcelot, P. and Denoix, J.-M. (2001) Effects of treadmill speed on the mechanics of the back in the trotting saddle horse. *Equine vet. J., Suppl.* **33**, 154-159.

II

EQUINE VETERINARY JOURNAL
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Effect of local analgesia on movement of the equine back

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Keywords: horse; back movements; local analgesia; kinematic evaluation

Summary

Reasons for performing study: **Diagnostic infiltration of local anaesthetic solution is commonly used in cases of equine back pain. Evaluation is subjective and it is not known how local analgesia of the back affects horses without clinical signs of back pain.**

Objectives: **To evaluate the effect of infiltration of local anaesthetics on the movement of the back in horses without clinical signs of back pain, and to evaluate the usefulness of kinematic studies as an objective and quantitative tool in evaluating local analgesia in clinical practice.**

Methods: **The kinematics of the back in 10 clinically sound horses were measured on 2 occasions at walk and trot before and after injections with mepivacaine and sodium chloride around the interspinous spaces between T16 and L2. The kinematics were compared between the 2 occasions before injections and before and after each injection.**

Results: **The range of motion (ROM) for dorsoventral flexion-extension (FE) of the back was increased significantly in all measured segments other than T10 at walk, as was lateral bending (LB) at T10, L3 and L5 after injection of mepivacaine. For lateral excursion (LE), total movement increased at all measured segments. At trot the only affected segment was L3, where the injection with mepivacaine decreased the ROM for FE. After injection of sodium chloride the ROM for FE increased at T13 and T17 at walk. Lateral bending and LE were not affected at walk. At trot, LB increased at L3 and L5.**

Conclusions and potential relevance: **Diagnostic infiltration of local anaesthetic solution affects the function of the back in clinically sound horses, which must be considered when interpreting the use of this clinical aid in assessing clinical cases of back dysfunction. Kinematics can qualitatively and quantitatively evaluate the effect of local analgesia of the back.**

Introduction

Back pain and dysfunction are common issues in equine practice and are often considered to be a cause of poor performance, stiffness in the back and/or abnormality of the hindlimb gait in sport horses (Jeffcott 1980). History and clinical signs are often nonspecific and a definite diagnosis is a challenge. The complex anatomy of the equine back contributes to the uncertainty of the localisation and nature of the injury. While clinical history and physical examination are fundamental in the diagnosis of back pain, many ancillary aids, such as different imaging techniques and diagnostic infiltration of local anaesthetic solution, are often used to confirm the clinical problem.

One commonly diagnosed disorder of the equine back is impingement of the dorsal spinous processes (DSPs) (Jeffcott 1979a, 1980; Townsend *et al*. 1986; Marks 1999). The diagnosis is made on the basis of radiography and/or scintigraphy or ultrasonography. Several studies (Jeffcott 1979a; Erichsen *et al.* 2003) have, however, shown that different degrees of impingement of the DSPs commonly occur in horses without clinical signs of back pain and it is therefore important to correlate imaging findings with pain and impaired performance in the clinical case. In some horses, impingement of the DSPs might be a subclinical problem, caused by the wear and tear of age (Johnston *et al*. 2004).

Jeffcott (1980) found that local anaesthesia of the interspinous spaces in horses with overriding DSPs could eliminate the back pain and result in marked improvement of performance. This technique is often used as a method of evaluating back pain. Walmsley *et al*. (2002) considered diagnostic analgesia to be the most important test to confirm that clinical signs of back dysfunction are associated with impingement of the DSP.

Local analgesia is extensively used in evaluating problems of the locomotor system, as in lameness or back pain, with the assumption that the technique itself does not change the movement pattern of the horse (Drevemo *et al*. 1999). That this is not necessarily the case was, however, shown by Drevemo *et al.* (1999) in evaluating distal limb anaesthesia in sound horses. In this study it was shown that a high palmar digital nerve block altered the locomotion pattern in sound horses, possibly by affecting proprioception.

The effect of local analgesia of the back is traditionally evaluated through repetition of the same exercise or riding test before and 20–30 mins after infiltration of local anaesthetic solution (Jeffcott 1975; Marks 1999; Walmsley *et al*. 2002; Denoix and Dyson 2003). In a positive test, a marked improvement in performance is expected to be observed from the ground, as well as felt by the rider. Although Walmsley *et al*. (2002) considered false positive tests unlikely, assessing the result of the analgesia from the rider's judgment demands both skill and objectivity of the rider. As pointed out by Denoix and Dyson (2003), examination of a horse

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with a potential back problem while it is ridden also allows the clinician to assess the rider. However, scientific evidence of the effect that local analgesia has on a clinically sound back is needed to use this aid in clinical cases.

Meaningful criteria for the assessment of back pain and an objective system of quantifying it would solve many of the difficulties in clinical diagnosis (Jeffcott 1979b). Such a system would also be an asset in evaluating local analgesia of the equine back, to complement the veterinarian's eye and the rider's perception. In several studies (Audigié *et al*. 1999; Faber *et al*. 2000, 2001a,b; Haussler *et al*. 2001; Robert *et al*. 2001) the kinematics of the equine back have been studied with a motion analysis system during treadmill work. Faber *et al*. (2000) developed a protocol that was validated and shown to be reliable and repeatable within individual animals and between days (Faber *et al*. 2001c, 2002). This protocol has since been used to establish databases on the movement of the back in fully functioning (Johnston *et al*. 2004) as well as dysfunctional (Wennerstrand *et al*. 2004) riding horses, and could be used to quantify objectively the effect of local analgesia of the back.

The aim of the present study was to evaluate, using kinematic studies, the effect of local analgesia on the movement of the back in horses without clinical signs of back pain, thereby also evaluating the usefulness of kinematics as a clinical tool in the diagnosis of equine back dysfunction. The hypothesis was that local analgesia affects the movement of the back in a clinically sound horse.

Materials and methods

The study was a randomised cross-over design. All horses were measured twice on 2 occasions at walk and trot on a treadmill. After the first measurement, the back of each horse was injected with either a local anaesthetic solution or sodium chloride (see below for details). A second measurement was taken 25 mins after injections. Seven days later, the movement of the back was measured a third time. The horses first injected with local anaesthetics were then injected with sodium chloride and *vice versa*. A last measurement was carried out 25 mins after the second injection.

Horses

Ten horses were used for this study; one Warmblood riding horse, the rest Standardbred trotters, 7 mares and 3 geldings, age 3–14 years (mean age 7.5 years), bodyweight 426–541 kg (mean 501 kg). All horses were used for teaching purposes at the University clinics and were neither regularly ridden nor driven. Before the horses were included in the study, a full physical examination including inspection and palpation of all 4 limbs and the back, plus observation of the horse moving in-hand on a hard surface at walk and trot and flexion tests of the entire 4 limbs, was performed. If a horse was initially lame, showed a response of more than one degree (scale 0–5) on a flexion test or demonstrated a painful reaction on palpation of the back, it was excluded.

Radiographic examination

Radiographs of the DSPs in the thoracolumbar spine were obtained in 9 of the horses. Radiolucency and sclerosis in each DSP of T15–L2 was evaluated (Erichsen *et al*. 2003). The width of the interspinous spaces was measured with a digital calliper, and was considered narrow when <4 mm. Presence or absence of anatomically coinciding radiolucency, sclerosis and narrow interspinous space in the DSPs were used as criteria in this study.

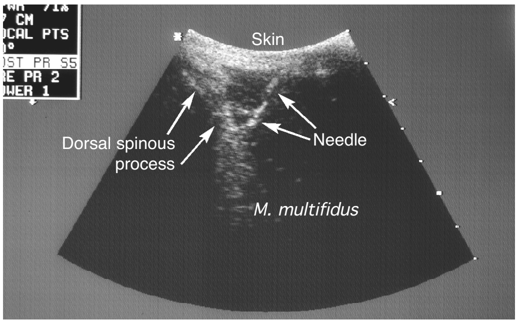

Fig 1: Ultrasonographic image in the transverse plane showing the position of the needle in the multifidus muscle at injection of the caudal thoracic back.

One of the horses examined (the Warmblood riding horse) demonstrated mild narrowing of the interspinous processes in T16–L2 and accompanying mild sclerosis. The other 8 horses radiographed did not show any radiographic signs of abnormality.

Injection technique

The DSPs of T16, T17, T18, L1 and L2 were identified by palpation. Ten ml mepivacaine hydrochloride (Carbocain 20 mg/ml)[1] or physiological sodium chloride were injected on either side of the interspinous space between T16–17, T17–18, T18–L1 and L1–2, approximately 20 mm lateral to the midline, with the needle pointing towards the midline. In clinical cases, the selection of which interspinous spaces to inject is based on palpation and radiological findings. In this study, the above-mentioned locations were chosen on the basis of findings in an earlier study (Wennerstrand *et al*. 2004) of sport horses with back pain, where the caudal thoracic back and the T/L junction were the most frequent locations of back pain.

The position of the needle during injection is shown in Figure 1. The total amount of mepivacaine or sodium chloride injected in each horse at each occasion was 80 ml. Forty mm long, 21 gauge needles were used. The length of needles was chosen so that mainly the upper half of the DSP would be affected by the analgesia and to minimise the risk of affecting deeper structures, such as the intervertebral articulations, which would confound the interpretation of the analgesia. The reasons for not injecting in the midline were that in clinical cases it is often not possible due to impinging spinous processes, and also it allowed markers used for the measurements before injections to be left in place for those made after injections.

Experimental set-up and data collection

Before the first recording, all horses were trained 4 times on the treadmill at walk and trot (Fredricson *et al*. 1983; Buchner *et al*. 1994). The DSPs of T6, T10, T13, T17, L1, L3, L5 and S3 and both left and right *tubera coxae* were identified by palpation. Spherical reflective markers (diameter 19 mm) were placed over the identified landmarks using quick-drying glue. An additional marker was placed on the lateral hoof wall of the right hindlimb.

For collecting the position data of the markers, a modern commercially available motion analysis system (Proreflex)[2] consisting of 6 cameras was used. The system is based on passive markers and infrared cameras. The cameras were placed around the treadmill so that each marker was always seen by at least 2 cameras. The inaccuracy in identifying the marker location was <1.5 mm.

The measurement volume made up a laboratory coordinate system with the positive y-axis oriented in the line of progression, positive z-axis oriented upward and x-axis oriented perpendicular to the direction of the y- and z-axes. The calibration was performed dynamically using a calibration frame which defined the orientation of the right-handed orthogonal laboratory coordinate system and a wand with an exactly defined length. Data were captured at a sampling rate of 240 Hz for 1 sec at a square stance and for 10 secs with the horses walking (1.4 m/sec) and trotting (3.5 m/sec).

Calculations of back kinematics in 2D

The reconstruction of the 3D position of each marker was based on a direct linear transformation algorithm (Qtrack)[2]. Subsequently, the raw x-, y- and z-coordinates were exported into Matlab[3] and BacKin[2] programme packages for further data processing. The individual stride cycles were determined and the beginning of each stride cycle was defined as the moment of first ground contact of the right hind hoof, determined from the velocity profile of the marker on the right hind hoof (Peham *et al.* 1999; Mickelborough *et al.* 2000). The x-, y- and z-coordinates were used to calculate the back movements in accordance with Faber *et al.* (1999). An explanation of the principles of the instantaneous orientation of a vertebra was presented by Johnston *et al.* (2002).

Coordinate and angular motion pattern (AMP) data were extracted at walk and trot from approximately 8 and 12 representative strides, respectively. Each stride was normalised to 101 data points, in order to allow averaging of the AMPs over strides. Stride length and velocity were calculated from the hoof marker. The range of motion (ROM) was derived from the AMPs.

Statistical analysis

The results are presented as means of the total ROM. Wilcoxon matched pairs test was used to analyse possible differences in spatiotemporal parameters as well as in the kinematics between horses' back movements before and after injection of mepivacaine and sodium chloride, respectively, and before the different injections. The minimum level of statistical significance was set to P<0.05. Statistical analyses were performed with a statistical software package (Statistica)[4].

Ethical review

Before the study's initiation, the local ethical committee for the Swedish National Board for Laboratory Animals reviewed the study and considered it to be acceptable.

Results

Kinematics

No spatiotemporal variables (stride length, stride velocity and protraction and retraction of the right hindlimb) changed due to the injection of local anaesthetic solution or sodium chloride.

TABLE 1: Mean ± s.d. range of motion (ROM) for flexion-extension (FE), lateral bending (LB), axial rotation (AR) and lateral excursion (LE) of 6 back vertebrae (T10–L5) and the pelvis on 2 occasions at walk and trot before and after injections of sodium chloride and mepivacaine

	Sodium chloride		Mepivacaine	
	Before	After	Before	After
Walk 1.4 m/sec				
FE (°)				
T10	5.6 ± 1.09	6.0 ± 0.87	5.5 ± 1.27	5.9 ± 1.47
T13	7.2 ± 1.37	7.8* ± 1.47	7.1 ± 1.69	7.9* ± 1.58
T17	6.9 ± 1.37	7.5* ± 1.53	7.1 ± 1.63	8.1* ± 1.37
L1	6.4 ± 1.39	6.8 ± 1.81	6.3 ± 1.48	7.6* ± 1.28
L3	6.2 ± 1.57	6.7 ± 1.82	6.0 ± 1.45	7.4* ± 1.30
L5	5.7 ± 1.38	6.0 ± 1.47	5.6 ± 1.22	6.8* ± 1.02
LB (°)				
T10	9.4 ± 1.12	9.7 ± 1.15	9.2 ± 1.44	10.0* ± 1.41
T13	7.0 ± 1.87	6.8 ± 1.52	7.1 ± 1.80	7.3 ± 1.72
T17	4.5 ± 1.81	4.5 ± 1.57	4.8 ± 1.84	4.8 ± 1.44
L1	3.3 ± 1.01	3.6 ± 1.15	3.1 ± 0.90	3.2 ± 1.17
L3	4.4 ± 1.50	4.8 ± 1.41	3.9 ± 1.36	4.6* ± 1.31
L5	5.2 ± 1.51	5.7 ± 1.45	4.7 ± 1.70	5.8* ± 1.37
LE (mm)				
T10	23.4 ± 4.65	25.3 ± 4.82	20.1 ± 4.42	24.4* ± 3.90
T13	37.2 ± 5.58	39.8 ± 5.11	35.3 ± 4.17	39.3* ± 3.77
T17	49.0 ± 5.44	50.8 ± 7.53	46.7 ± 5.51	51.1 ± 5.75
L1	47.5 ± 5.51	49.0 ± 6.95	45.0 ± 6.27	49.8* ± 5.74
L3	39.7 ± 4.69	41.3 ± 6.13	37.1 ± 6.38	41.4* ± 5.67
L5	29.8 ± 4.15	31.0 ± 5.51	27.8 ± 5.29	31.1* ± 5.09
AR (°)				
Pelvis	11.2 ± 2.32	12.0 ± 2.95	10.9 ± 2.50	11.5 ± 3.15
Trot 3.5 m/sec				
FE (°)				
T10	3.7 ± 1.34	3.5 ± 1.03	3.4 ± 1.03	3.3 ± 1.01
T13	3.2 ± 1.85	3.0 ± 0.56	2.9 ± 0.72	3.0 ± 0.73
T17	3.0 ± 1.74	2.4 ± 0.54	2.3 ± 0.48	2.6 ± 0.57
L1	3.4 ± 1.24	3.2 ± 0.86	3.3 ± 0.84	2.9 ± 0.55
L3	4.1 ± 0.83	4.0 ± 0.81	4.3 ± 1.06	3.8* ± 0.94
L5	3.3 ± 1.38	2.8 ± 0.63	3.2 ± 0.95	2.8 ± 0.73
LB (°)				
T10	7.3 ± 1.54	7.7 ± 1.55	7.3 ± 1.75	7.0 ± 1.54
T13	5.1 ± 1.20	4.9 ± 1.28	5.1 ± 0.99	4.8 ± 1.29
T17	3.2 ± 0.62	3.4 ± 0.98	3.7 ± 0.66	3.4 ± 1.10
L1	2.8 ± 0.82	3.2 ± 0.87	3.0 ± 1.02	3.1 ± 0.94
L3	3.3 ± 0.97	3.8* ± 0.92	3.7 ± 1.13	3.7 ± 1.15
L5	3.5 ± 0.87	4.0* ± 1.02	4.0 ± 0.91	4.2 ± 1.40
LE (mm)				
T10	21.0 ± 4.56	23.1 ± 4.04	19.8 ± 4.19	20.3 ± 3.33
T13	27.3 ± 7.56	29.7 ± 5.04	28.4 ± 6.43	28.0 ± 5.32
T17	30.3 ± 8.02	31.4 ± 5.22	30.7 ± 7.35	30.4 ± 5.95
L1	28.7 ± 7.36	30.2 ± 5.02	29.9 ± 6.80	29.8 ± 6.40
L3	24.9 ± 6.16	26.6 ± 4.55	26.6 ± 6.88	26.3 ± 7.02
L5	18.6 ± 4.81	20.4 ± 4.20	20.4 ± 5.79	20.4 ± 6.44
AR (°)				
Pelvis	5.4 ± 1.61	5.3 ± 1.34	5.4 ± 1.38	5.0 ± 1.60

*ROM after injection of sodium chloride or mepivacaine significantly different (P<0.05) from that before injection.

After injection of local anaesthetic solution, there was a significant increase in the ROM for dorsoventral flexion and extension (FE) at all measured segments other than T10 at walk (Table 1). For lateral bending (LB) at walk, ROM increased in T10, L3 and L5, and for lateral excursion (LE) (Faber *et al.* 2003) total movement increased in all measured segments. Axial rotation (AR) of the pelvis was not affected.

At trot, there was a significant decrease in the ROM for FE at L3 after injection of local anaesthetic solution. No other movement was significantly affected at trot.

After injection of sodium chloride, there was a significant increase in the ROM for FE at T13 and T17 at walk (Table 1). Lateral bending, LE and AR of the pelvis were not affected. At trot, the only variables that changed significantly were LB at L3 and L5 after injection of sodium chloride.

The movement of the back before injection of mepivacaine compared with that before sodium chloride did not differ significantly in walk or trot other than a decrease in LB at L5 and LE at L3 and L5 at walk.

Discussion

Diagnostic infiltration of local anaesthetics is often used in examination of cases of impingement of the DSPs in the horse (Marks 1999; Walmsley *et al.* 2002). The method has some limitations in being unspecific if care is not taken with the injection technique, where the goal is to limit the analgesia to the upper part of the DSP. Interpretation of the result can otherwise be confounded (Denoix and Dyson 2003). Another limitation is the subjective evaluation of the analgesia, traditionally by observation of the horse while being ridden, as well as the rider's experience. Evaluation of the analgesia could be greatly improved with an objective and quantitative method of evaluating the movement of the back. Kinematic studies of the equine back during treadmill locomotion have proven to be a reliable and repeatable tool (Faber *et al.* 2001c, 2002). Smaller changes in back movement than the eye can detect can be registered and the method can also be used in horses that are dangerous to ride. Motion analyses register only differences in movements, whereas the riding test allows an evaluation of differences in the horse's attitude and willingness to perform after local analgesia. In some cases, diagnostic injection of local anaesthetics might remove pain but not affect the mechanics of movement in the back, which could give a true improvement of performance in the ridden situation but not during kinematic studies. On the other hand, kinematics can register changes in back movement in a horse that, due to habit or mental reasons, remains unwilling or difficult to ride after analgesia. As to whether kinematics can complement clinical evaluation of local analgesia in horses with back problems, further studies will be required.

In this study, all but one in the group of clinically sound horses were Standardbred trotters. It has been shown that different breeds of horses have different movement patterns in the back (Faber *et al.* 2002). When using horses without clinical signs of back pain as reference to clinical cases, horses in the 2 groups should ideally be of the same breed. The within-horse differences seen in the study should, however, be valid for different breeds.

One horse demonstrated low-grade abnormal radiographic findings in the DSP of T16-L2. The clinical examination, together with the radiographic examination, indicated that the horses used in this study were clinically sound with regard to the back.

Changes in movement of the back were seen mainly at walk, which is probably due to the fact that the normal movement of the back at walk is more passive (Denoix 1999) and at trot more controlled by muscle activity. The injections (Fig 1) were made in the multifidus muscle, which plays a major role in stabilisation of the vertebrae and proprioceptive adjustment of the spine (Denoix and Dyson 2003). The injection of local anaesthetic solution appeared to affect the natural rigidity of the back, causing an increased flexibility in the areas affected by injections. The neuromuscular activity of the back was apparently modified, resulting in altered natural back rigidity. These effects can also be seen, to a smaller extent, after injection of sodium chloride. The question arises as to whether there is also a local, mechanical-neuromuscular effect on the rigidity of the back of injections in the multifidus muscle.

Before injections of either mepivacaine or sodium chloride, a high degree of repeatability was seen between the 2 measurements. This is in accordance with the conclusion of Faber *et al.* (2002) that analysis of back kinematics in the horse can provide highly repeatable data, making it suitable for clinical use.

In conclusion, if diagnostic infiltration of local anaesthetic solution is used as a tool in evaluating horses with back problems, the effect that the analgesia has on the back of clinically sound horses should be taken into account, to avoid false interpretation. Combining the riding test with kinematic studies should improve interpretation of the analgesia, adding an objective evaluation of movement to the more subjective test of improved performance that the riding test provides.

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Manufacturers' addresses

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[2]Qualysis Medical AB, Gothenburg, Sweden.
[3]Math Works Inc, Natick, Massachusetts, USA.
[4]StatSoft Inc, Tulsa, Oklahoma, USA.

References

Audigié, F., Pourcelot, P., Degueurce, C., Denoix, J.-M. and Geiger, D. (1999) Kinematics of the equine back: flexion-extension movements in sound trotting horses. *Equine vet. J., Suppl.* **30**, 210-213.

Buchner, H.H.F., Savelberg, H.H.C.M., Schamhardt, H.C., Merkens, H.W. and Barneveld, A. (1994) Habituation of horses to treadmill locomotion. *Equine vet. J., Suppl.* **17**, 13-15.

Denoix, J.-M. (1999) Spinal biomechanics and functional anatomy. *Vet. Clin. N. Am.: Equine Pract.* **15**, 27-60.

Denoix, J.-M. and Dyson, S. (2003) Thoracolumbar spine. In: *Diagnosis and Management of Lameness in the Horse*, 1st edn., Eds: M.W. Ross and S.J. Dyson, W.B. Saunders Co., Philadelphia. pp 509-521.

Drevemo, S., Johnston, C., Roepstorff, L. and Gustås, P. (1999) Nerve block and intra-articular anaesthesia of the forelimb in the sound horse. *Equine vet. J., Suppl.* **30**, 266-269.

Erichsen, C., Eksell, P., Widström, C., Roethlisberger Holm, K., Johnston, C. and Lord, P. (2003) Scintigraphic evaluation of the thoracic spine in the asymptomatic riding horse. *Vet. Radiol. Ultrasound* **44**, 330-338.

Faber, M., Schamhardt, H. and van Weeren, P.R. (1999) Determination of 3D spinal kinematics without defining a local vertebral co-ordinate system. *J. Biomech.* **32**, 1355-1358.

Faber, M., Johnston, C., van Weeren, P.R. and Barneveld, A. (2002) Repeatability of back kinematics in horses during treadmill locomotion. *Equine vet. J.* **34**, 235-241.

Faber, M., van Weeren, R., Schepers, M. and Barneveld, A. (2003) Long-term follow-up of manipulative treatment in a horse with back problems. *J. vet. Med. A Physiol. Pathol. Clin. Med.* **50**, 241-245.

Faber, M., Schamhardt, H., van Weeren, P.R., Johnston, C., Roepstorff, L. and Barneveld, A. (2000) Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *Am. J. vet. Res.* **61**, 399-406.

Faber, M., Johnston, C., Schamhardt, H., van Weeren, P.R., Roepstorff, L. and Barneveld, A. (2001a) Basic three-dimensional kinematics of the vertebral column of horses during trotting on a treadmill. *Am. J. vet. Res.* **62**, 757-764.

Faber, M., Johnston, C., Schamhardt, H., van Weeren, P.R., Roepstorff, L. and Barneveld, A. (2001b) Three-dimensional kinematics of the equine spine during canter. *Equine vet. J., Suppl*. **33**, 145-149.

Faber, M.J., Schamhardt, H.C., van Weeren, P.R. and Barneveld, A. (2001c) Methodology and validity of assessing kinematics of the thoracolumbar vertebral column in horses on the basis of skin-fixated markers. *Am. J. vet. Res*. **62**, 301-306.

Fredricson, I., Drevemo, S., Dalin, G., Hjertén, G., Björne, K. and Rynde, R. (1983) Treadmill for equine locomotion analysis. *Equine vet. J*. **15**, 111-115.

Haussler, K.K., Bertram, J.E.A., Gellman, K. and Hermanson, J.W. (2001) Segmental *in vivo* vertebral kinematics at the walk, trot and canter: a preliminary study. *Equine vet. J., Suppl*. **33**, 160-164.

Jeffcott, L.B. (1975) The diagnosis of diseases of the horse's back. *Equine vet. J*. **7**, 69-78.

Jeffcott, L.B. (1979a) Radiographic features of the normal equine thoracolumbar spine. *Vet. Radiol*. **20**, 140-147.

Jeffcott, L.B. (1979b) Back problems in the horse - a look at past, present and future progress. *Equine vet. J*. **11**, 129-136.

Jeffcott, L.B. (1980) Disorders of the thoracolumbar spine of the horse - a survey of 443 cases. *Equine vet. J*. **12**, 197-210.

Johnston, C., Holm, K., Faber, M., Erichsen, C., Eksell, P. and Drevemo, S. (2002) Effect of conformational aspects on the movement of the equine back. *Equine vet. J., Suppl*. **34**, 314-318.

Johnston, C., Roethlisberger Holm, K, Erichsen, C., Eksell, P. and Drevemo, S. (2004) Kinematic evaluation of the back in fully functioning riding horses. *Equine vet. J*. **36**, 495-498.

Marks, D. (1999) Medical management of back pain. *Vet. Clin. N. Am.: Equine Pract*. **15**, 179-194.

Mickelborough, J., van der Linden, M.L., Richards, J. and Ennos, A.R. (2000) Validity and reliability of a kinematic protocol for determining foot contact events. *Gait Posture* **11**, 32-37.

Peham, C., Scheidl, M. and Licka, T. (1999) Limb locomotion - speed distribution analysis as a new method for stance phase detection. *J. Biomech*. **32**, 1119-1124.

Robert, C., Valette, J.P., Audigié, F., Pourcelot, P. and Denoix, J.-M. (2001) Effects of treadmill speed on the mechanics of the back of trotting saddlehorses. *Equine vet. J,. Suppl*. **33**, 154-159.

Townsend, H.G.G., Leach, D.H., Doige, C.E. and Kirkaldy-Willis, W.H. (1986) Relationship between spinal biomechanics and pathological changes in the equine thoracolumbar spine. *Equine vet. J*. **18**, 107-112.

Walmsley, J., Pettersson, H., Winberg, F. and McEnvoy, F. (2002) Impingement of the dorsal spinous processes in 215 horses: case selection, surgical technique and results. *Equine vet. J*. **34**, 23-28.

Wennerstrand, J., Johnston, C., Roethlisberger Holm, K., Erichsen, C., Eksell, P. and Drevemo, S. (2004) Kinematic evaluation of the back in the sport horse with back pain. *Equine vet. J*. **36**, 707-711.

III

Spinal kinematics in horses with induced back pain

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Keywords: equine; horse; back movement; back pain, lactic acid; kinematic evaluation

Summary

Reasons for performing the study: **Back problems are important contributors to poor performance in sport horses. It has been shown that objective evaluation of the function of the back through kinematic analysis can differentiate horses with back problems from asymptomatic horses. The underlying mechanism can, however, only be identified in a uniform, experimental setting.**

Objectives: **The aim was to evaluate if induction of back pain in a well-defined site would result in a consistent change in back movement.**

Methods: **Back kinematics was recorded in eight horses at the walk and trot on a treadmill. After the first measurement, unilateral back pain was induced by injecting lactic acid into the longissimus dorsi muscle. Additional measurements were done during the week following the injections. Data were captured during steady state locomotion for 10 seconds at 240 Hz using an infrared-based automated gait analysis system. Vertebral range of motion and mean angles were derived from angular motion pattern data.**

Results: **After the injections, the caudal thoracic back was more extended at both gaits. At trot, the back was also more bent to the left, while at the walk it first bent to the left, followed by bending to the right. Additionally, the pelvis rotated more to the left after the injections.**

Conclusions: **Horses with identical back injuries appear to show similar changes in their back kinematics, as compared to the asymptomatic condition. Unilateral back pain seems to result in an increased extension of the back, as well as compensatory lateral movements.**

Possible clinical relevance: **Back movements are complex and subtle, and changes are difficult to detect with the human eye. Present-day gait analysis systems can identify changes in the back movement, and knowledge of the relationship between such changes and the site of injury will be of help in better localizing and diagnosing disorders of the equine back.**

Introduction

Equine back pain and dysfunction are common and important problems in veterinary medicine (Jeffcott, 1980). An exact diagnosis is however often hard to arrive at. Essential information can be obtained from the anamnesis and the clinical examination, but additional information is usually needed to correctly diagnose the patient. Frequently used techniques, such as regional analgesia, radiography, scintigraphy and ultrasound, are valuable diagnostic aids when evaluating a horse with back dysfunction, but sometimes they are insufficient to detect the origin of the problem. Earlier studies have shown that it is possible to measure objectively the movement of the back in detail (Audigié *et al.*, 1999; Denoix, 1999; Faber *et al.*, 2000; Faber *et al.,* 2001; Haussler *et* al., 2001; Licka *et al.*, 2001a; Licka *et al.*, 2001b). It has further been shown that sport horses with decreased performance, abnormal movements during work and clinical back pain on palpation show, at both walk and trot, a significantly decreased movement of the back compared to asymptomatic, competing riding horses (Wennerstrand *et al.*, 2004).

It has been shown that back pain can be induced by the intramuscular injection of a concentrated (85%) lactic acid solution into the longissimus dorsi muscles (Jeffcott *et al.*, 1982), which creates a marked but reversible pain reaction with some heat and swelling, and an increased stiffness of the back.

To interpret the changes in the back movement properly, it is necessary to know how the changes correspond to the type and location of an injury. This can be accomplished by measuring the movement of the back in asymptomatic horses before and after inducing back pain in a specific tissue and location.

The aim of this study was to determine vertebral kinematics in horses walking and trotting on a treadmill before and after pain induction of back pain induction. Our hypothesis was that induction of back pain in a well defined site results in consistent changes in the movement of the back.

Materials and methods

Horses

Eight Warmblood horses, all mares, between 7 and 12 years old, were used in this study. Their body weights were 567 ± 22.1 kg and their heights at the withers 163 ± 3.6 cm. All horses were in regular training for dressage or show jumping, and two were also sometimes used for driving. The horses underwent a clinical examination including a visual and palpatory examination, observation of the horse moving in hand on a hard surface and lunging at both reins. If lameness was detected in any of the mentioned exams, or if a horse demonstrated pain on palpation of the back, it was excluded.

Experimental set-up and data collection

Prior to the first recording, the horses were trained at several occasions on a treadmill at walk and trot to ensure a consistent gait pattern (Fredricson *et al.*, 1983; Buchner *et al.*, 1994). Back and limb kinematics was measured at the walk and trot on the treadmill before and at 1 hour, 1 day, 2 days, 3 days and 7 days after the pain induction.

Spherical, reflective markers, 19 mm in diameter, were glued onto the skin over the dorsal spinous processes of thoracic (T), lumbar (L) and sacral (S) vertebrae: T6, T10, T13, T17, L1, L3, L5 and S3. Markers were also placed on both left and right tubera coxae and proximally on the lateral part of the hoof wall of each hoof. Additional markers were placed on the neck and limbs for a parallel study. The landmarks were identified by palpation in the square standing horse. The positions of the markers (spatial resolution less than 1.5 mm) were captured by six infrared cameras (ProReflex®)[1], which were positioned around the treadmill in a way that each marker was always seen by at least two cameras.

Measurements were made relative to a right-handed orthogonal laboratory coordinate system with the positive y-axis oriented in the line of progression, the positive z-axis oriented upward and the x-axis oriented perpendicular to the direction of the y- and z-axes. Data was captured at a sampling rate of 240 Hz for 5 seconds at a square stance and for 10 seconds with the horses walking (1.6 ms^{-1}) and trotting (4.0 ms^{-1}) on the treadmill.

After each session on the treadmill except for the first, the back was examined. The tips of the spinal processes and the muscles were palpated and any swellings were noted. Back pain was considered present if the horse showed signs of pain/discomfort on palpation of the back.

Injection technique

Each horse stood unsedated in a quiet room. The back was clipped and aseptically prepared. The dorsal spinous processes of T13, T14, T15, T16, T17, T18 and L1 were identified by palpation. Two ml of 85 % lactic acid solution was injected into the left *M. longissimus dorsi* at the height of the caudal edges of T13, T14, T15, T16, T17 and T18, approximately 10 cm left of the midline using a 40 mm long, 21 gauge needle. Total volume injected was thus 12 ml.

Calculation of back kinematics

The reconstruction of the 3-dimensional position of each marker is based on a direct linear algorithm (QTrack™)[2]. The raw x-, y- and z-coordinates were exported into MatLab®[3] and Backkin®[4] programme packages for further data processing. The beginning of each stride cycle was defined as the moment of first ground contact of the left hind hoof.

The x-, y-, and z-coordinates were used in accordance to Faber *et al*. (1999) to calculate the flexion-extension and lateral bending movements of the back, and the axial rotation of the pelvis. An explanation of the principles of the instantaneous orientation of a vertebra has been presented by Johnston *et al*. (2002).

Coordinates were extracted for the walk and trot from approximately 8 and 10 representative strides, respectively. Angular motion patterns (AMPs) were calculated for each vertebral angle and the pelvis. In order to allow averaging of the AMPs over strides, each stride was normalised to 101 data points.

Stride length and duration were calculated from the marker on the left hind hoof. The total range of motion (ROM) and the mean movement were derived from the AMPs.

Statistical analysis

The results are presented as means ± s.d. Data were tested for normality of distribution. The variations in the back vertebral angles throughout the stride were normally distributed and further analysed with Students' t-test, in which each individual percentage of the stride post injection was compared to its ditto prior to the injections. Wilcoxon matched pairs test was used to analyse possible ROM and AMP differences. The minimum level of statistical significance was set to $p<0.05$.

Ethical Review

The study was approved by the Animal Experimentation Committee of the Utrecht University, in compliance with the Dutch Act on Animal Experimentation.

Results

Clinical signs

Subsequent to the lactic acid injections, the horses demonstrated mild to moderate pain on palpation of their backs during a few days. One hour after the injections, mild swelling had appeared in some of the horses. The injected areas were also mildly to moderately painful. Twenty-four hours after the injections, the injection sites were swollen in all horses, with a maximum diameter of 5 cm. On palpation, 4 of the horses demonstrated mild pain in the left half of the caudal thoracic back. Due to technical circumstances, the other four horses were not palpated 24 hours post injection.

The swelling peaked at 48 hours after the injections, with diameters up to 10 cm around the injection sites. At that time, 6 of the horses were mildly and 2 moderately painful left to the mid-line in the region from the withers to the mid-lumbar back. Three days after the lactic acid injections, most swellings had started decrease. The left *M. longissimus dorsi* was still mildly to moderately painful from T13 to the T/L-junction in all 8 horses. Two of them also demonstrated pain on palpation of the cranial lumbar back.

After one week, most swellings had reduced to barely visible or only palpable. Clearly visible swellings were noted at only four injection sites, the largest with a diameter of 2 cm. On palpation of the back, no abnormality was noted in 2 of the horses, while 6 had mildly tensed back muscles or a stiff skin. Of these 6, 5 were not painful at all, and the last one was painful only from T12 to T14.

Back kinematics

Range of motion (ROM)

Flexion-extension

Changes in the back kinematics were observed throughout the entire week following the injections. One hour after the injections, the ROM for dorsoventral flexion and extension was increased by 0.5° at the withers (T10) at the trot (Fig 1b). Two days after the injections, the ROM for the flexion and extension was increased 0.6° at T10 at the walk (Fig 1a). It was also increased at the caudal thoracic back at the trot (T13=0.4º, T17=0.4º) (Fig 1b), while it was decreased 0.3° at L5 at the same gait. Three days following the injections, the flexion and extension ROM at T13 was still increased (0.3°) at the trot.

One week after the horses had been injected, most of them were no longer painful on palpation, but the back movement was still changed. At the trot, the increased flexion and extension movement remained at the caudal thoracic back (T13=0.4º, T17=0.2º) and an increase was also observed at the lumbar back (L3=0.3º) (Fig 1b).

Lateral bending

One hour after the lactic acid injections, the ROM for lateral bending was significantly reduced (0.8°) at L5 at the walk (Fig 2a). This change remained for 24 hours. The day after the injections, the ROM for lateral bending was also decreased at the withers at the trot (T10=0.7º) (Fig 2b), a decrease that also remained for 24 hours. Two days after the injections, the lateral bending ROM had increased 0.3° at the T/L-junction (L1) at the walk (Fig 2a) while it was 0.3° smaller at the T/L-junction (L1) at the trot. The increased lateral bending movement at L1 at the walk, could be observed again at the end of the week, together with a 0.5° decrease in lateral bending movement at T13.

Axial rotation

No significant change was observed at the walk or trot for the axial rotation ROM of the pelvis after the injections.

Figure 1a

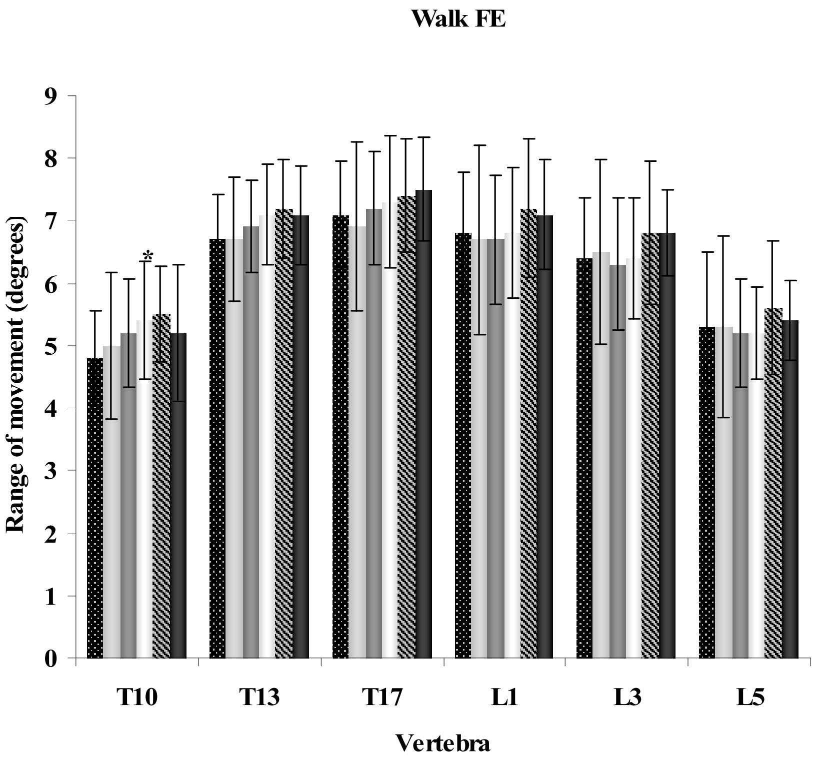
Walk FE
Range of movement (degrees)
0
1
2
3
4
5
6
7
8
9
*
T10
T13
T17
L1
L3
L5
Vertebra

Figure 1b

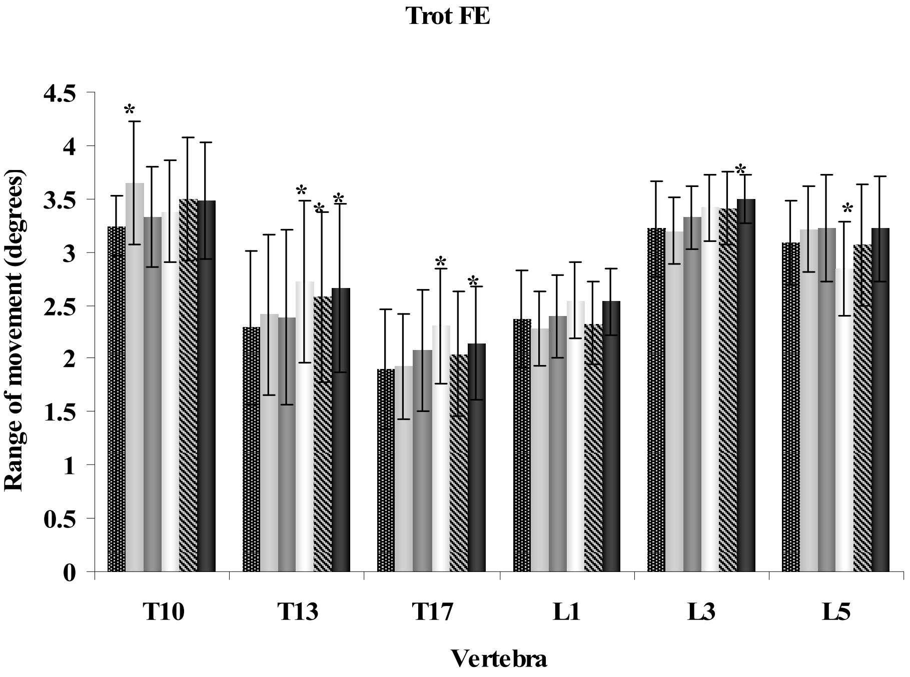

Figure 1a and 1b. The mean ROM with s.d. for the flexion and extension (FE) movement of six back segments at the walk (1a) and trot (1b). Stippled = pre injections; light grey = 1 hour post injections; dark grey = 1 day post injections; white = 2 days post injections; striped = 3 days post injections; black = 7 days post injections. *Movement statistically significant different ($p<0.05$) compared to before the induction of back pain.

Figure 2a

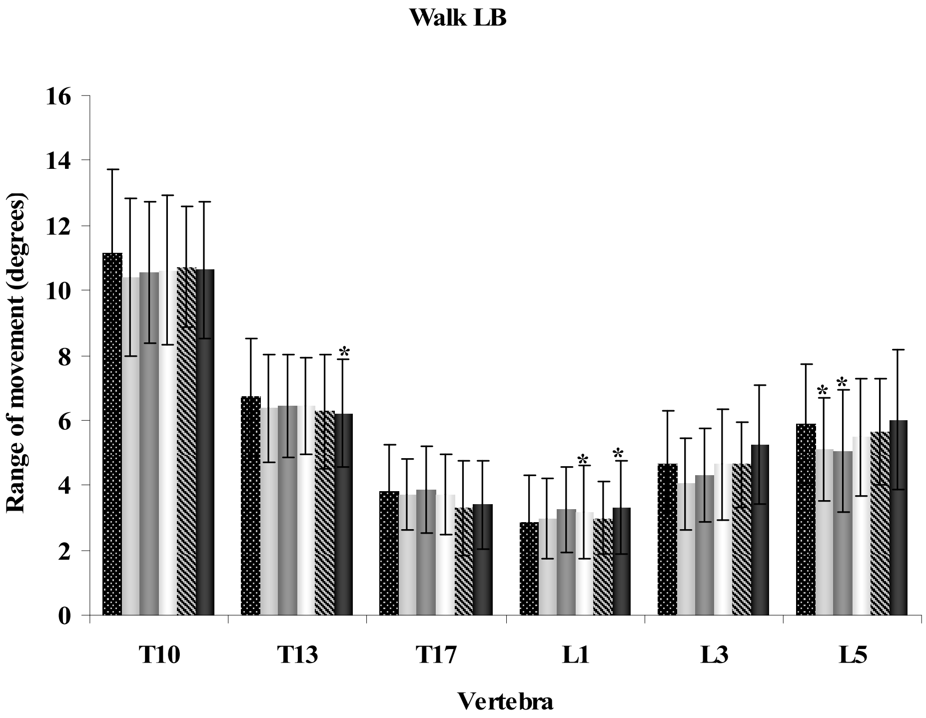
Walk LB
Range of movement (degrees)
0
2
4
6
8
10
12
14
16
T10
T13
T17
L1
L3
L5
Vertebra
*
*
*
*
*

Figure 2b

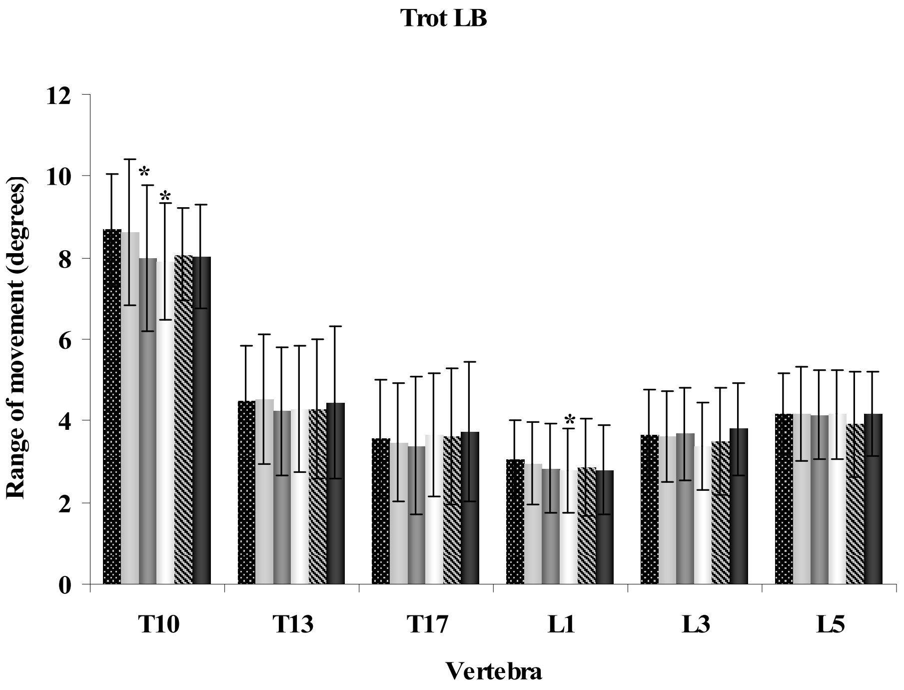

Figure 2a and 2b. The mean ROM with s.d. for the lateral bending (LB) movement of six back segments at the walk (2a) and trot (2b). Stippled = pre injections; light grey = 1 hour post injections; dark grey = 1 day post injections; white = 2 days post injections; striped = 3 days post injections; black = 7 days post injections. *Movement statistically significant different ($p<0.05$) compared to before the induction of back pain.

<u>Vertebral angles throughout the stride cycle</u>

During the week following the lactic acid injections, some of the mean angles of back motion changed significantly at both gaits compared to before the injections. This was true at walk for the flexion-extension of T10 and T13, and for the lateral bending of T10, T13 and L5. At trot, significant changes were seen for the flexion-extension of T10, T13 and T17, the lateral bending of T17 and L5, and for the axial rotation of the pelvis. Some changes could be observed during the whole stride cycle, while others were seen during one or more periods of the same, for example during the first 50 percent or at ground contact of the respective hind limb (Table 1, Fig 3a, 3b and 3c).

<u>Stride parameters</u>

There was no change in the linear or temporal gait parameters. The stride length was 2.6±0.1 m at all days at the trot, and 1.7±0.1 m at all days at the walk, except for the seventh day after the pain induction, when the stride length was 1.7±0.0 m. The stride duration was 0.7±0.0 s at all days at the trot, and 1.1±0.1 s at all days at the walk, except for the seventh day after pain induction, when it was 1.1±0.0 s.

Table 1

Vertebral angles throughout the stride cycle

Walk 1.6 m^{-s}

Flexion/ Extension	*Type of change*	*Part of stride when change was observed*	*% of stride during which change was observed*	*Time when changes was observed*	*Change in the total mean angle*
T10	**Increased Extension**	Whole	100	1 hour post	1.4 °
			100	3 days post	1.2 °
T13	**Increased Extension**	Just before ground contact of LH and during the stance phase of LH	72	2 days post	0.6 °
			53	3 days post	
			46	7 days post	
T17	**Increased Extension**	Just before ground contact of LH and during the stance phase of LH	64	3 days post	
			47	7 days post	
Lateral Bending					
T10	**Increased Bending to the Right**	Whole	100	7 days post	1.4 °
T13	**Increased Bending to the Left**	Whole	76	2 days post	0.7 °
T17	**Increased Bending to the Left**	Whole	60	2 days post	
L5	**Increased Bending to the Right**	Whole	100	7 days post	1.2 °

Trot 4.0 m^{-s}

Flexion/ Extension	*Type of change*	*Part of stride when change was observed*	*% of stride during which change was observed*	*Time when changes was observed*	*Change in the total mean angle*
T10	**Increased Extension**	Whole	90	2 days post	
			97	3 days post	1.1°
			94	7 days post	
T13	**Increased Extension**	Whole	25	1 day post	
			36	2 days post	
			64	3 days post	0.8°
			79	7 days post	0.7°
T17	**Increased Extension**	Whole	86	1 day post	0.6°
			55	2 days post	0.4°
			88	3 days post	0.7°
			100	7 days post	0.8°
Lateral Bending					
T10	**Increased Bending to the Left**	Whole	42	2 days post	
			41	7 days post	
T17	**Increased Bending to the Left**	Whole	84	7 days post	1.0°

L5	**Increased Bending to the Left**	Whole	100 100	2 days post 7 days post	1.0° 1.4°
Axial Rotation					
Pelvis	**Increased Rotation to the Left**	Whole	57	1 hour post	0.6°

Table 1. The flexion-extension and lateral bending angles of six back segments and the axial rotation angles of the pelvis during the stride cycle at the walk and trot during the week subsequent to the lactic acid injections. All changes are statistically significant ($p<0.05$) to before the injections.

Figure 3a

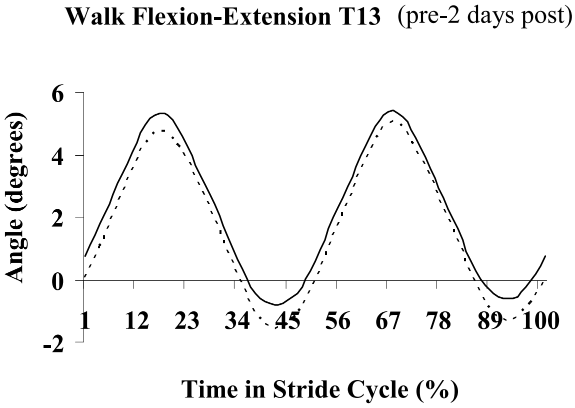

Figure 3b

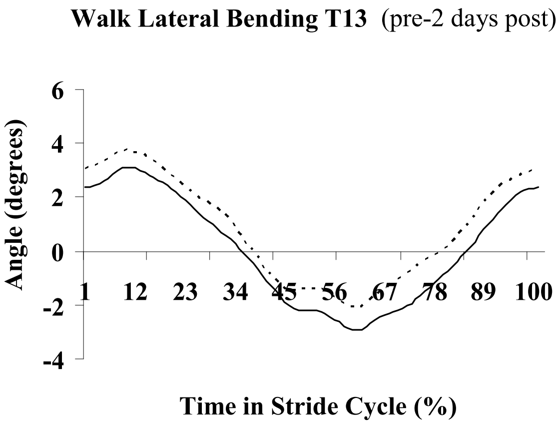

Figure 3c

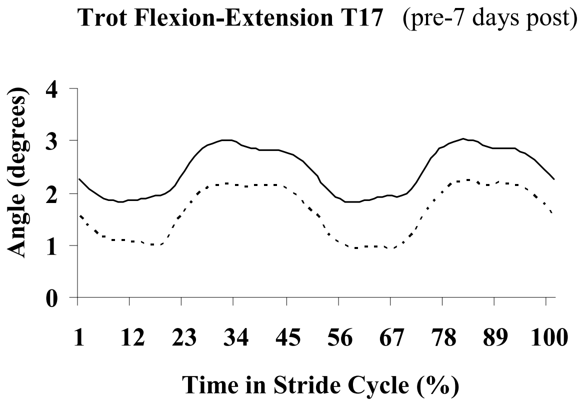

Figure 3a, 3b and 3c. The flexion-extension and lateral bending angles of T13 (walk) and the flexion-extension angles of T17 (trot) during the stride cycle during the week subsequent to the lactic acid injections. Solid line = pre injections; dotted line = post injections. Positive represents dorsoventral flexion and lateral bending to the left. Negative represents dorsoventral extension and lateral bending to the right.

Discussion

The results of the present study confirm the hypothesis that back pain in a well-defined site results in significant and consistent changes in the vertebral kinematics.

Lactic acid injected into the *M. longissimus dorsi* has been used earlier as a model for reversible back pain and was shown to cause a mild pain at walk and trot, and a pain reaction on palpation (Jeffcott *et al.*, 1982). In that study, no changes were observed in the linear and temporal stride parameters, but the level of performance decreased.

Two studies on patients have shown that horses with natural back pain have an aberrant movement pattern of the back (Faber *et al.*, 2003; Wennerstrand *et al.*, 2004), which is in accordance with our present findings. In one of the previous studies (Wennerstrand *et al.*, 2004), the horses, among other signs, showed a decreased ROM for flexion-extension at the caudal thoracic back and T/L-junction. That observation is opposite to the findings of the present study, but may be related to the differences in the anatomical origin of the pain between naturally occurring back pain in patients and the artificially induced back pain in the present study.

Back pain was clearly evident in all horses subsequent to the injections in the present study. Whereas no abnormal back movements could be detected by clinical observation, the kinematic analysis technique revealed several. The increased extension of the caudal back at both walk and trot may have been induced by a shortened and stiffer *M. longissimus dorsi* not able to adequately control the vertebral column. However, the stiffness was not reflected by a decreased flexion-extension movement, but instead shown as an increased ROM for this parameter. This may be due to the fact that the back pain was unilaterally induced and the compensatory mechanisms can be assumed to differ between uni- and bilateral back pain. Bilateral back pain is likely to cause a more general restriction of the back movement.

As expected, the back showed a transient accentuated lateral bending due to the unilaterally induced back pain. The increased lateral bending was most likely a consequence of an impaired muscle function at the painful side. Loss of normal activity in the left epaxial musculature may have affected the naturally existing left/right balance and leading to a scoliosis of the back with, in this case, right convexity as a result.

At the walk, the horses showed a reversed pattern, *i.e.* bending to the unaffected side, 7 days after the injections. This may have been caused by a decreased contraction capacity in the injected muscle. This biphasic response was also observed in the earlier study in trotters with induced back pain (Jeffcott, 2007, personal communication).

The clinical examinations showed that the lactic acid injections resulted in an immediate onset of back pain, while most changes in movement appeared 48-72 hours post injections. This can be explained by the mechanisms of pain physiology. Muscle soreness occurs during or immediately after high intensity exercise. The soreness is caused by the naturally produced lactic acid that accumulates in the tissue in situations with intensive, rapidly increased, or changed exercise. One to two days after exercise there is another, sometimes more severe peak of soreness accompanied by stiffness. This is in human medicine called delayed onset muscle soreness (DOMS) (Marlin and Nankervis, 2002). It seems that a similar phenomenon occurred after the injection of lactic acid in the horses in the present study. In accordance with the nature of lactic acid, there was first a direct effect, reflected by the acute pain reaction and a few early changes in movement. The changes in movement after a couple of days may represent the natural second peak of muscle pain.

In naturally occurring muscle pain, the acute soreness is caused by the lactic acid itself, an effect of the produced hydrogen ions and the oedema due to fluid uptake into the interstitial spaces (Marlin and Nankervis, 2002). In the artificially induced back pain in this study, there was a difference compared to the natural situation. Whereas the total volume of fluid may perhaps have been comparable to the naturally occurring oedema, the fluid was in this case administered as a single bolus and there was no gradual build-up. It has been shown that injection of a certain volume of saline *per se* also influences back movement, presumably by its effect on proprioception (Roethlisberger-Holm *et al*., 2006).

In general, back movement seems to change in a similar way at the walk and trot. There were only some minor differences. At both gaits, the back was generally more extended and also bent towards the painful left side. This asymmetry was most evident at the trot. Since back muscle activity is normally greater at the trot than at walk, where the lateral movement of the back is largely passive (Robert *et al*., 1998), it is reasonable to believe that muscle soreness will affect back movement more, and remain manifest for a longer period of time, at this gait.

The caudal thoracic back and T/L-junction were chosen as sites of injection partly based on the previous study by Jeffcott *et al.* (1982), partly because abnormal findings in horses with back problems are most commonly seen in this region (Jeffcott, 1980; Denoix, 1999; Marks, 1999; Walmsley *et al*., 2002), and partly due to earlier observations of the back movement at the walk and trot in horses with back pain (Wennerstrand *et al*., 2004).

Back movements of the horse are subtle and complex, and different injuries may affect back movement patterns in various ways. Present-day technology has proven to be a valuable and adequate tool to document back movements and changes therein, changes that are often undetectable to the human eye, which also becomes clearly evident in the present study. The present-day technology will thus help discover changes due to pain or other influences earlier than would be possible by clinical observation only.

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Manufacturers' addresses

[1]ProReflex®, Qualysis Medical AB, Gothenburg, Sweden
[2]QTrack™, Qualysis Medical AB, Gothenburg, Sweden
[3]MatLab®, The Math Works Inc., Natick, USA
[4]Backkin®, Qualysis Medical AB, Gothenburg, Sweden

References

Audigié, F., Pourcelot, P., Degueurce, C., Denoix, J.M. and Geiger, D. (1999) Kinematics of the equine back: flexion-extension movements in sound trotting horses. *Equine vet. J., Suppl.* **30**, 210-213.

Buchner, H.H.F., Savelberg, H.H.C.M., Schamhardt, H.C., Merkens, H.W. and Barneveld, A. (1994) Habituation of horses to treadmill locomotion. *Equine vet. J., Suppl.* **17**, 13-15.

Denoix, J.M. (1999) Spinal biomechanics and functional anatomy. In: *Vet. Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia. pp 27-60.

Faber, M., Schamhardt, H. and van Weeren, R. (1999) Determination of 3D spinal kinematics without defining a local vertebral co-ordinate system. *J. Biomech.* **32**, 1355-1358.

Faber, M.J., van Weeren, P.R., Schepers, M. and Barneveld, A. (2003) Long-term follow-up of manipulative treatment in a horse with back problems. *J. vet. Med. A* **50**, 241-245.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2000) Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *Am. J. vet. Res.* **61**, 399-406.

Faber, M., Schamhardt, H., van Weeren, R., Johnston, C., Roepstorff, L. and Barneveld, A. (2001) Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *Am. J. vet. Res.* **62**, 757-764.

Fredricson, I., Drevemo, S., Dalin, G., Hjertén, G., Björne, K., Rynde, R. and Franzén, G. (1983) Treadmill for equine locomotion analysis. *Equine vet. J.* **15**, 111-115.

Haussler, K.K., Bertram, J.E.A., Gellman, K. and Hermanson, J.W. (2001) Segmental in vivo vertebral kinematics at the walk, trot and canter: a preliminary study. *Equine vet. J., Suppl.* **33**, 160-164.

Jeffcott, L.B. (1980) Disorders of the thoracolumbar spine of the horse – a survey of 443 cases. *Equine vet. J.* **12**, 197-210.

Jeffcott, L.B., Dalin, G., Drevemo, S., Fredriccson, I., Björne, K. and Bergquist, A. (1982) Effect of induced back pain on gait and performance of trotting horses. *Equine vet. J.* **14**, 129-133.

Johnston, C., Holm, K., Faber, M., Erichsen, C., Eksell, P. and Drevemo, S. (2002) Effect of conformational aspects on the movement of the equine back. *Equine vet. J., Suppl.* **34**, 314-318.

Licka, T., Peham, C. and Zohmann, E. (2001a) Range of back movement at trot in horses without back pain. *Equine vet. J., Suppl.* **33**, 150-153.

Licka, T., Peham, C. and Zohmann, E. (2001b) Treadmill study of the range of back movement at the walk in horses without back pain. *Am. J. vet. Res.* 62, 1173-1179.
Marks, D. (1999) Medical management of back pain. In: *Vet. Clin. N. Am.: Equine Pract.* **15(1)**, Eds: A.S. Turner and K.K. Haussler, W.B. Saunders Co., Philadelphia. pp 179-194.
Marlin, D. and Nankervis, K. (2002) Part II, Exercise and training responses: Muscular responses. In: *Equine exercise physiology*. Eds: D. Marlin and K. Nankervis, Blackwell Science Ltd, Malden. pp 75-85.
Robert, C., Valette, J.P. and Denoix, J.M. (1998) Surface electromyographic analysis of the normal horse locomotion: a preliminary report. In: *Proceedings of the Conference of Equine Sports Medicine and Science*, Cordoba, Spain, pp 80-85.
Roethlisberger-Holm, K., Wennerstrand, J., Lagerquist, U., Eksell, P. and Johnston, C. (2006) Effect of local analgesia on movement of the equine back. *Equine vet. J.* **38**, 65-69.
Wennerstrand, J., Johnston, C., Roethlisberger-Holm, K., Erichsen, C., Eksell, P. and Drevemo, S. (2004) Kinematic evaluation of the back in the sport horse with back pain. *Equine vet. J., Suppl.* **36**: 707-711.
Walmsley, J.P., Pettersson, H.P., Winberg, F. and McEvoy, F. (2002) Impingement of the dorsal spinous processes in two hundred and fifteen horses: case selection, surgical technique and results. *Equine vet. J.* **34**, 23-28.

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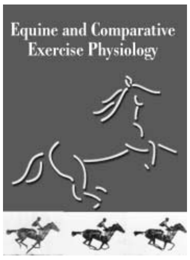

The effect of weighted boots on the movement of the back in the asymptomatic riding horse

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Abstract

Back dysfunction is an important reason for impaired performance in sport horses. Limb movements influence the movements of the back and factors affecting the limbs may therefore affect the movement of the back. The aim of the study was to investigate the influence of weighted boots on the fore- and hind limbs on the movement of the back. The back kinematics of eight horses was studied at the walk and trot on a treadmill. The ranges of movement (ROM) of the back were compared intra-individually, using Wilcoxon matched pairs test, when the horses moved with and without weighted boots on the fore- and hind limbs, respectively. Differences were considered significant at $P < 0.05$. Weighted boots on the hind limbs increased the ROM for dorsoventral flexion and extension in the lumbar back at the walk and decreased the ROM for lateral bending at the thoracolumbar junction at the trot. Weighted boots on the forelimbs decreased the ROM for lateral bending at the withers at the trot. Knowledge of the effect of weighted boots on the back movement is useful in training and rehabilitation of sport horses. Weighted boots on the hind limbs at the walk may induce strengthening of the flexors of the lumbar back and increase the flexion–extension of the lumbar back under controlled conditions.

Keywords: equine; horse; back; kinematics; locomotion; limb movements; weighted boots

Introduction

Poor performance is not uncommonly related to back dysfunction[1]. In order to mitigate a back-related problem and to reduce the risk of re-injury, it is important to understand how a normal, asymptomatic horse moves and how its movements can be affected.

At all gaits and in all movements, different parts of the body are synchronized[2–4], and one body segment may induce or inhibit the movement of another. The position of the neck and limbs influences the movement of the back[5] and the protraction and retraction of the hind limb correlate directly with the flexion and extension of the lumbosacral joint[6,7].

Weights attached to the hooves affect the movement characteristics of the limbs. Willemen *et al.*[8] found that the stride duration and the stride length were increased and the relative stance duration decreased after a horse was shod. Greater inertia of the distal limb improved the quality of the gait. Lanovaz *et al.*[9] reported that changes in the segment mass of the forelimb segments affected the peak net joint moments and powers across the joints of the limb. A changed three-dimensional movement pattern of the limb may possibly result in altered movements of the back.

Recently, a Dutch group showed that a weighted saddle changed the movement of the lumbar spine[10], but at present there are no studies published that describe to what extent it is possible to change the movements of the vertebral column by adding weights to the limbs. The aim of the present study was to explore what effect weighting of the limbs might have on the movement of the back. To achieve this goal, back kinematics was evaluated before and after weighted boots were attached to the limbs.

The amplitude of the back movement is greater at the walk than at the trot[2,4,11]. At the trot, the stabilizing muscle activity of the back is high, while the movement at the walk is more passive[12], and therefore probably more responsive to external influences. Based on these facts, our hypotheses were that the ranges of motion (ROM) of the back would increase at the walk and decrease at the trot when weighted boots were put on either the fore or the hind limbs.

Materials and methods

Horses

Warmblood riding horses that had previously been used in another study[11] participated in the present one. They were in regular training for dressage up to Intermediaire I or show jumping at levels up to 1.30 m, and were considered sound and fully functioning by their owners.

The horses underwent an examination in accordance with standardized routines at the University clinic. Body weights varied from 530 to 640 kg and height at the withers varied between 158 and 176 cm. No abnormalities of clinical importance were found in the extremities or the back in the conformation or on palpation. The horses were examined in hand at the walk and trot on a hard surface. They were also lunged at the walk and trot on both reins and a flexion test of the entire leg was performed on all four limbs. If lameness was detected in any of the above examinations or a response of more than 1 degree of lameness (on a scale of 0–5) on a flexion test was found, the horse was excluded. The back was thoroughly examined, including visual inspection of the muscle symmetry of the back, and palpation of the tips of the dorsal spinal processes of thoracic and lumbar vertebrae and the sacrum, as well as of the back muscles. Finally, a test of the back reflexes and the passive lateral flexibility was carried out. If a horse showed a significant reaction[13] during palpation, it was excluded. Eight horses between 6 and 14 years of age (one stallion, three mares and four geldings) passed the clinical examination and were included in the study.

Experimental set-up and data collection

The horses were accustomed to and trained on a coir mat treadmill at the walk and trot on several occasions before they were measured[14,15]. The horses were also accustomed to walking and trotting on the treadmill with the weighted boots on the fore- and hind limbs, respectively. The boots, that were fastened around the metacarpal or metatarsal regions, were made of terylene and artificial leather and had vertical pockets side by side intended for weights (Fig. 1). Each boot weighed 700 g. The horses showed no signs of distraction related to the boots after becoming accustomed to them.

Spherical, reflective markers, 19 mm in diameter, were glued to the skin[16] over the dorsal spinous processes of eight back vertebrae (T6, T10, T13, T17, L1, L3, L5 and S3). Markers were also placed on both left and right *tubera coxae*, on the lateral styloid process of the left radius, on the lateral malleolus of the left tibia and proximally on the lateral part of the left fore and hind hoof walls. The landmarks were all identified by palpation. The positions of the markers (inaccuracy less than 1.5 mm) were collected by six infrared cameras (ProReflex®, Qualysis Medical AB, Gothenburg, Sweden). They were placed around the treadmill and positioned so that each marker was always seen by at least two cameras.

The measurement volume made up a laboratory coordinate system with the positive y-axis oriented in the line of progression, parallel to the direction of the treadmill, the positive z-axis oriented upward and the x-axis oriented perpendicular to the y- and z-axes. The calibration was done dynamically by use of a calibration frame, which defined the orientation of the right-handed orthogonal laboratory coordinate system and a wand with an exactly defined length. Data were captured for 10 s at a sampling rate of 240 Hz when the horses were walking (1.5 m s^{-1}) and trotting (3.5 m s^{-1}) at a steady state.

Each horse was measured three times at each gait: once with the weighted boots on the forelimbs, once with the boots on the hind limbs and once without boots. The measurement sequence of the different conditions was chosen randomly within each gait and for every horse. The repeatability for measurements like

FIG. 1 Weighted boots with separate weights in pockets

these has earlier been validated in a Dutch–Swedish cooperation project[17].

Calculation of the back kinematics in two dimensions

The reconstruction of the three-dimensional position of each marker is based on a direct linear transformation algorithm (QTrack™, Qualysis Medical AB). Subsequently, the raw *x*-, *y*- and *z*-coordinates were exported into MatLab® (The Math Works Inc., Natick, MA, USA) and Backkin® (Qualysis Medical AB) for further data processing. The individual stride cycles were determined and the beginning of each stride cycle was defined as the moment for first ground contact of the left hind hoof. The moment of ground contact was determined from the velocity profile of the marker on the left hind hoof.

The *x*-, *y*-, and *z*-coordinates were used to calculate the back rotations in accordance with Faber *et al.*[18]. An explanation of the principles of the instantaneous orientation of a vertebra was presented by Johnston *et al.*[19]. The amount of protraction and retraction of the left hind limb was determined from the marker on S3 and the marker on the left hind hoof.

Coordinate and angular motion pattern (AMP) data were extracted at the walk and trot from *c.* 7 and 12 representative strides, respectively. Each stride was normalized to 101 data points to make averaging of the AMPs possible over strides.

Statistical analysis

All results are presented as means ± SD. The ROM of the vertebral column when wearing weighted boots on the forelimbs or on the hind limbs was compared intra-individually to the ROM without weights and to each other. Comparisons of stride data were performed in a similar way. The results are not normally distributed. For the statistical calculations, Wilcoxon matched pairs test was used. Differences were considered significant at $P < 0.05$.

Ethical review

The local ethical committee for the Swedish National Board for Laboratory Animals approved the study.

Results

At the walk, the ROM for the dorsoventral flexion and extension was greater at L3 and L5 with weighted boots on the hind limbs compared to that without boots (Table 1). Hind limb boots also resulted in a greater flexion–extension at L5 compared to the forelimb boots. The ROM for the lateral bending was greater at L5 with the weighted boots on the hind limbs compared to that on the forelimbs at the walk.

At the trot, weighting of the hind limbs resulted in a significantly smaller ROM for the flexion–extension at L5 than weighting of the forelimbs, and a significantly smaller lateral bending at the thoracolumbar junction (L1) compared to the movement without boots (Table 1). Boots on the forelimbs led to a smaller ROM for the lateral bending at the withers (T10 and T13) and a greater ROM for the same parameter at L3 (Table 1) compared to that without boots. At T10, weighted forelimbs also gave a smaller ROM for the lateral bending compared to that for weighted hind limbs. The lateral bending of the back at the trot was greater at L3 with forelimb boots than with hind limb boots.

The weighted boots did not change the ROM for the axial rotation of the pelvis at either the walk or the trot

Table 1 The mean ROM in degrees with SD for the flexion–extension and lateral bending movements of the back at the walk and trot

			Flexion–extension		Lateral bending	
		Back segment	Mean	SD	Mean	SD
Walk	Normal	T10	6.1	1.6	11.2	1.5
		T13	8.3	1.4	7.4	1.5
		T17	8.8	1.2	5.5	1.6
		L1	8.3	0.9	4.3	0.9
		L3	8.0	1.1	5.0	1.7
		L5	7.1	1.3	6.4	1.6
	Hind limb	T10	6.0	1.4	11.4	1.7
		T13	8.5	1.3	7.1	1.2
		T17	9.0	1.1	5.0	0.9
		L1	8.8	1.0	4.1	1.1
		L3	8.6[a]	1.1	5.0	1.4
		L5	7.8[a,b]	1.5	6.5[b]	1.4
	Forelimb	T10	6.2	1.4	11.1	1.9
		T13	8.8	1.5	7.3	1.5
		T17	9.2	1.4	5.5	1.1
		L1	8.5	1.3	4.5	0.8
		L3	8.2	1.3	4.9	1.2
		L5	7.1	1.4	5.9	1.2
Trot	Normal	T10	5.1	0.8	8.3	1.8
		T13	3.7	0.6	6.6	1.2
		T17	3.0	0.7	5.5	1.7
		L1	3.5	0.9	4.1	1.0
		L3	4.7	1.3	4.9	1.4
		L5	4.0	1.1	5.9	1.2
	Hind limb	T10	5.0	0.8	8.1[b]	1.6
		T13	3.9	0.7	6.2	1.2
		T17	3.2	0.9	5.3	1.6
		L1	3.4	0.9	3.7[a]	0.7
		L3	4.5	1.3	4.7[b]	1.5
		L5	3.8[b]	1.1	5.9	1.3
	Forelimb	T10	5.2	0.8	7.8[c]	1.4
		T13	3.6	0.5	6.2[c]	1.2
		T17	2.9	0.7	5.3	1.8
		L1	3.6	1.1	4.1	1.4
		L3	4.8	1.4	5.5[c]	2.1
		L5	4.2	1.1	6.0	1.2

Normal, no boots on the limbs; hind limb, weighted boots on the hind limbs; forelimb, weighted boots on the forelimbs.

[a] Hind limb statistically significant ($P < 0.05$) compared to normal.

[b] Hind limb statistically significant ($P < 0.05$) compared to forelimb.

[c] Forelimb statistically significant ($P < 0.05$) compared to normal.

Table 2 The mean ROM in degrees with SD for the axial rotation movement of the pelvis and pro- and retraction of the hind limb at the walk and trot

	Axial rotation	Pro- and retraction
Walk		
Normal	12.6 ± 2.0	43.4 ± 2.1
Hind limb	12.8 ± 2.7	43.9 ± 2.1
Forelimb	12.9 ± 2.1	43.8 ± 1.6
Trot		
Normal	5.7 ± 1.1	39.5 ± 2.6
Hind limb	5.3 ± 0.9	38.9 ± 2.5[a,b]
Forelimb	6.0 ± 1.1	39.4 ± 2.4

Normal, no boots on the limbs; hind limb, weighted boots on the hind limbs; forelimb, weighted boots on the forelimbs.

[a] Hind limb statistically significant ($P < 0.05$) compared to normal.

[b] Hind limb statistically significant ($P < 0.05$) compared to forelimb.

(Table 2). The protraction and retraction of the hind limb decreased significantly at the trot when the weighted boots were on the hind limbs compared to that without boots or when the boots were on the forelimbs (Table 2).

The means and SD for the stride duration and stride velocity were calculated for the three conditions at the walk and trot (Table 3). No significant difference was found for any of these parameters.

Discussion

This study describes how weighted boots on the fore- or hind limbs affect the movement of individual segments of the thoracolumbar region. A validated, repeatable, standardized protocol and asymptomatic, fully functioning riding horses were used in order to minimize biases. The flexion–extension of the lumbar spine increased with boots on the hind limbs at the walk and the lateral bending of the thoracic spine decreased with boots on the forelimbs at the trot. This was in accordance with the hypotheses and it also supports previous work[12].

Earlier studies have shown that the movement of the back is greater at the walk than at the trot[2,4,11]. This was also the case in the present study. For all three types of back movement, the overall total ROM was greater at the walk than at the trot, most likely caused by the greater muscle activity at the trot as earlier shown by Robert[12].

Several studies indicate that important roles of the muscles associated with the vertebral column is to stabilize the back and to moderate movements that may arise[6,7,20–22]. Back muscle activity does contribute to the movement of the back[3] but this influence seems to be secondary rather than primary[2,4], which indicates an external influence on the movement of the back. There are indications that the dorsoventral flexion–extension of the back is generated by the hind limbs[2,4]. At the walk, both flexion and extension movements start in the caudal part and are then transmitted cranially with a time-shift[2]. This has also been observed in humans[23].

The flexion–extension of the back, especially in the caudal part, has been found to be directly correlated to the protraction and retraction of the hind limb[2]. In the present study, weighted boots on the hind limbs increased the ROM for the flexion–extension at the lumbar back at the walk. However, there was no change in the protraction and retraction of the hind limbs at the walk. At the trot, the protraction and retraction of the hind limbs decreased significantly when the boots were fastened around the hind limbs, while the flexion–extension did not change significantly at any back segment.

It seems that the movement of the back is less susceptible to external influences at the trot compared to that at the walk. A possible contributing factor could be the difference in muscle activity between the two gaits. A horse at the trot has only a diagonal support during the support phase. To maintain the horse in balance, a muscle activity reasonably greater compared to at the walk is required[12]. The muscle activity stabilizes the back more at the trot than at the walk.

A recent study has shown that loading of the distal hind limbs results in a changed movement pattern of the limbs[24]. Distal hind limb loading increased the total ROM of the stifle, hock and hind fetlock, and decreased the ROM of the distal inter-phalangeal joint. The weighting did not affect the movement of the hip joint. In another study, it was observed that the increased

Table 3 Stride data for the left hind limb expressed as mean ± SD

	Normal	Hind limb	Forelimb
Walk			
Stride duration (s)	1.14 ± 0.053	1.15 ± 0.038	1.14 ± 0.055
Stride velocity (m s^{-1})	1.5 ± 0.06	1.5 ± 0.10	1.5 ± 0.08
Trot			
Stride duration (s)	0.75 ± 0.033	0.75 ± 0.020	0.76 ± 0.022
Stride velocity (m s^{-1})	3.5 ± 0.13	3.5 ± 0.24	3.5 ± 0.22

Normal, no boots on the limbs; hind limb, weighted boots on the hind limbs; forelimb, weighted boots on the forelimbs.

flexion of the joints, seen at increased trotting speed, was accompanied by higher excentric muscle activity during the stance phase, and during the swing phase shortened limbs because of higher concentric activity of the muscles[25]. It seems reasonable to believe that distal weighting results in similar muscular activity and that this may be the reason for the increased flexion–extension of the lumbar back at the walk with the boots on the hind limbs. *M. longissimus dorsi* acts during the intermediate stance phase of the hind limbs to facilitate propulsion[3]. Weights on the hind limbs may increase the activity of this muscle. It is possible that non-weighted boots could also affect the three-dimensional movement pattern of the limbs[26], and perhaps in turn result in altered movements of the back.

If the flexion–extension of the back is affected by the hind limbs to a greater extent than by the forelimbs, it could explain why this parameter was not significantly affected when the weighted boots were applied to the forelimbs.

Just as for the flexion–extension, the lateral bending of the back is linked to the protraction and retraction of the hind limbs[4]. Since the lateral bending shows a mono-sinusoidal movement pattern during the stride cycle, the inter relationship becomes somewhat different, however. With the boots on the hind limbs at the trot, the lateral bending decreased significantly at the thoracolumbar junction (L1). This change may correspond to the significantly decreased protraction and retraction of the hind limbs caused by the hind limb boots.

It has been stated that the lateral bending of the thoracic back is influenced by the movement of the forelimbs. Boots on the forelimbs at the trot resulted in a smaller lateral bending at the cranial part of the back (T10 and T13). In humans, it has been shown that additional loading results in a greater muscular output[27]. In the horse, it is possible that added extra weight on the forelimbs results in increased muscle activity, which may lead to more stable and balanced movements. In addition to the decreased lateral bending of the thoracic back with boots on the forelimbs, there was also a significant increase of the lateral bending at L3. This change was unexpected, especially as the protraction and retraction of the hind limbs did not change, and we do currently not have an explanation for this specific change.

Since the limb movements can change due to training[28,29], fatigue, pain or other factors, knowledge of their inter relationship with the movement of the back improves our understanding for which movements and situations may be beneficial or potential risk factors to the health of the back.

In the training and rehabilitation of sport horses, exercises to increase the flexion and extension flexibility of the lumbar back in a controlled way can sometimes be desirable. The weighted boots used in the present study may be a good alternative for this purpose, especially when considering that the risk of overstraining and of injuries is supposedly low at the walk. Earlier studies have shown that confidence intervals are large between individuals, although very small within individuals[2]. This study is an intra-individual study and the intervals only slightly overlap, if they do at all. Thus, we are confident that this study is significant[17]. The clinical relevance might be of great importance. Anecdotal observations indicate that the weights are sometimes successfully used to rehabilitate horses with caudal back problems in Sweden. Weights on the hind limbs are likely to, at the walk, induce strengthening of the flexor muscles of the caudal lumbar back and increase the mobility of the lumbar back in a controlled way. The boots we used were not very heavy. Increased weighting will probably affect the movements further, but excessively heavy boots may also increase the risk of overstraining. Walking over ground is likely to bring about the same results as in the study, although there might be minor differences in the movement pattern compared to on the treadmill. Before the full effects of the weighted boots can be evaluated, further studies, over a longer period of time and perhaps with the use of electromyography, are required.

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References

1 Jeffcott LB (1980). Disorders of the thoracolumbar spine of the horse – a survey of 443 cases. *Equine Veterinary Journal* **12**: 197–210.
2 Faber M, Schamhardt H, van Weeren R, Johnson C, Roepstroff L and Barneveld A (2000). Basic three-dimensional kinematics of the vertebral column of horses walking on a treadmill. *American Journal of Veterinary Research* **61**: 399–406.
3 Denoix JM and Audigié F (2001). The neck and back. In: W Back and H Clayton (eds), *Equine Locomotion.* London: WB Saunders, 167–191.
4 Faber M, Schamhardt H, van Weeren R, Johnston C, Roepstroff L and Barneveld A (2001a). Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *American Journal of Veterinary Research* **62**: 757–764.
5 Rhodin M, Johnston M, Roethlisberger-Holm K, Wennerstrand J and Drevemo S (2005). The influence of head and neck position on the kinematics of the back in riding horses at the walk and trot. *Equine Veterinary Journal* **1**: 7–11.
6 Denoix JM (1999). Spinal biomechanics and functional anatomy. In: AS Turner and KK Haussler (eds), *Veterinary*

Clinics of North America Equine Practice. Philadelphia: WB Saunders, **15**(1), pp. 27–60.

7 Faber M (2001b). Kinematics of the equine back during locomotion. PhD Thesis. University of Utrecht, The Netherlands, pp. 91–110.

8 Willemen MA, Savelberg HHCM and Barnveld A (1997). The improvement of the gait quality of sound trotting warmblood horses by normal shoeing and its effect on the load on the lower forelimb. Horseshoeing, a biomechanical analysis. PhD Thesis. University of Utrecht, The Netherlands, pp. 19–32.

9 Lanovaz JL and Clayton HM (2001). Sensitivity of forelimb swing phase inverse dynamics to inertial parameter errors. *Equine Veterinary Journal Supplement* **33**: 27–31.

10 de Cocq P, van Weeren PR and Back W (2004). Effects of girth, saddle and weight on movements of the horse. *Equine Veterinary Journal* **3**: 758–763.

11 Johnston C, Holm K, Erichsen C, Eksell P and Drevemo S (2004). Kinematic evaluation of the back in the asymptomatic riding horse. *Equine Veterinary Journal* **6**: 495–498.

12 Robert C, Valette JP and Denoix JM (1998). Surface electromyographic analysis of the normal horse locomotion: a preliminary report. *Proceedings of the Conference of Equine Sports Medicine and Science,* pp. 80–85, Cordoba, Spain.

13 Wennerstrand J, Johnston C, Roethlisberger-Holm K, Erichsen C, Eksell P and Drevemo S (2005). Kinematic evaluation of the back in the sport horse with back pain. *Equine Veterinary Journal Supplement* **36**: 707–711.

14 Fredricson I, Drevemo S, Dalin G, Hjertén G, Björne K, Rynde R and Franzén G (1983). Treadmill for equine locomotion analysis. *Equine Veterinary Journal* **15**: 111–115.

15 Buchner HHF, Savelberg HHCM, Schamhardt HC, Merkens HW and Barneveld A (1994). Habituation of horses to treadmill locomotion. *Equine Veterinary Journal Supplement* **17**: 13–15.

16 Faber M, Schamhardt H, van Weeren R and Barneveld A (2001c). Methodology and validity of assessing kinematics of the thoracolumbar vertebral column in horses based on skin-fixated markers. Kinematics of the equine back during locomotion. PhD Thesis. University of Utrecht, The Netherlands, pp. 65–75.

17 Faber M, Johnston C, van Weeren R and Barneveld A (2002). Repeatability of back kinematics in horses during treadmill locomotion. Kinematics of the equine back during locomotion. PhD Thesis. University of Utrecht, The Netherlands, pp. 77–89.

18 Faber M, Schamhardt H and van Weeren R (1999). Determination of 3D spinal kinematics without defining a local vertebral co-ordinate system. *Journal of Biomechanics* **32**: 1355–1358.

19 Johnston C, Holm K, Faber M, Erichsen C, Eksell P and Drevemo S (2002). Effect of conformational aspects on the movement of the equine back. *Equine Veterinary Journal Supplement* **34**: 314–318.

20 Rooney JR (1969). The vertebral column. In: JR Rooney (ed), *Biomechanics of Lameness in Horses* 1st edn. Baltimore, OH: Williams and Wilkins, pp. 90–95.

21 Carlson H, Halbertsma J and Zomlefer M (1979). Control of the trunk during walking in the cat. *Acta Physiologica Scandinavica* **105**: 251–253.

22 Robert C, Audigié F, Valette JP, Pourcelot P and Denoix JM (2001). Effects of treadmill speed on the mechanics of the back in the trotting saddlehorse. *Equine Veterinary Journal Supplement* **33**: 154–159.

23 Crosbie J, Vachalathiti R and Smith R (1997). Patterns of spinal motion during walking. *Gait & Posture* **5**: 6–12.

24 Wickler SJ, Hoyt DF, Clayton HM, Mullineaux DR, Cogger EA, Sandoval E, McGuire R and Lopez C (2004). The energetic and kinematic consequences of weighting the distal limb. *Equine Veterinary Journal* **8**: 772–777.

25 Robert C, Valette JP, Pourcelot P, Audigié F and Denoix JM (2002). Effects of trotting speed on muscle activity and kinematics in saddlehorses. *Equine Veterinary Journal Supplement* **34**: 295–301.

26 Licka T, Kicker C, Peham C and Girtler D (2004). Evaluation and comparison of the effect of support boots on the fetlock joint angle during the stance phase at walk and trot. *Equine and Comparative Exercise Physiology* **2**: A17.

27 Martin PE and Cavanagh PR (1990). Segment interactions within the swing leg during unloaded and loaded running. *Journal of Biomechanics* **23**: 529–536.

28 Drevemo S, Dalin G, Fredricson I and Björne K (1980). Equine locomotion: 3. The reproducibility of gait in Standardbred trotters. *Equine Veterinary Journal* **12**: 71–73.

29 Rivero JLL, Serrano AL, Quiroz-Rothe E and Aguilera-Tejero E (2001). Coordinated changes of kinematics and muscle fibre properties with prolonged endurance training. *Equine Veterinary Journal Supplement* **33**: 104–108.