

A review on the functions of the horse back and *longissimus dorsi* muscle

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Abstract

The function of a muscle is to permit movement and maintain posture. Such a key role depends on the interplay between its anatomical structure and the way it is used during movement. From a mechanical sense, a muscle changes its length to generate force. If it generates force while shortening (concentric), it will generate mechanical power, and if it generates force whilst it is being stretched (eccentric), it will absorb mechanical power. The *longissimus dorsi*, the largest muscle of the horse's back, is of considerable importance for its key functions on the athletic ability and performance of the animal. In this review, I summarized the anatomy, functions, biomechanics, and disorders of the horse back. The biomechanics of the horse's back depend on the interaction between the spinal column and the spinal musculature. Especially, *longissimus dorsi* muscle performs different functions both along its length and different regions across each segment. Several studies have reported muscular disorders in the horse's back such as stiffness and limitation of motion range, as also by electromyography records on the muscle activity (albeit at single recording sites during locomotion). These reports are typically isolated observations and no study has yet integrated muscle activity patterns with the cycles of flexion-extension in any detail, neither a study has linked these factors to the muscle fascicle strains in the *longissimus dorsi*. Such studies will be fundamental to fully understand the mechanical role of the *longissimus dorsi*, particularly during locomotion, and will develop new treatment techniques for horse veterinarians. In addition, 3D anatomical measures of the structure *in vivo* integrated with measures of function back motion and *longissimus dorsi* muscle activity would be ideal to understand in further detail the function of the horse's back.

Keywords: Horse, *longissimus dorsi*, back, function, biomechanics

การทำงานของหลังม้าและกล้ามเนื้อ *longissimus dorsi*

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บทคัดย่อ

การทำงานของกล้ามเนื้อมีส่วนช่วยทำให้เกิดท่าทางและการเคลื่อนไหวในสัตว์ ซึ่งหัวใจสำคัญขึ้นอยู่กับความสัมพันธ์ระหว่างโครงสร้างและการทำงานของตัวกล้ามเนื้อแต่ละมัด ในเชิงกลกล้ามเนื้อสามารถเปลี่ยนแปลงความยาวเพื่อทำให้เกิดแรง ซึ่งหากมีการสร้างแรงในขณะที่หดตัวก็จะทำให้เกิดพลังในการทำงานหรือหากมีการสร้างแรงขณะที่กล้ามเนื้อยืดขยายตัวจะทำให้มีการซึมซับพลังงานเป็นต้น กล้ามเนื้อ *longissimus dorsi* เป็นกล้ามเนื้อมัดใหญ่ที่สุดของกล้ามเนื้อหลังของม้า จึงมีความสำคัญต่อสมรรถนะของม้ากีฬา ในบทความฉบับนี้จะกล่าวถึงกายวิภาค หน้าที่ ชีวกลศาสตร์ และความคิดปกติของหลังม้า ทั้งนี้ชีวกลศาสตร์ของหลังม้าขึ้นอยู่กับการทำงานที่สัมพันธ์กันระหว่างกระดูกสันหลังและกล้ามเนื้อหลัง โดยเฉพาะกล้ามเนื้อ *longissimus dorsi* จะมีการทำงานที่แตกต่างกันไปตามแนวยาวของกล้ามเนื้อและตำแหน่งของกระดูกสันหลังที่กล้ามเนื้อนี้พาดผ่าน อย่างไรก็ตามเคยมีรายงานกล่าวถึงความผิดปกติของหลังอาทิเช่น กล้ามเนื้อหลังดึงทำให้การเอี้ยวตัวของหลังถูกจำกัด โดยการศึกษาที่มีการบันทึกคลื่นไฟฟ้าตรงกล้ามเนื้อ *longissimus dorsi* เพียงตำแหน่งเดียวในขณะที่ม้ามีการเคลื่อนไหว ซึ่งการศึกษานี้ค่อนข้างจะเป็นการสังเกตการทำงานของกล้ามเนื้อ *longissimus dorsi* เพียงจุดเดียว ในปัจจุบันยังไม่มีการศึกษาใดที่ทำการเชื่อมโยงการทำงานที่เป็นแบบแผนกล้ามเนื้อเข้ากับวงจรการงอและการแอ่นของหลังม้า อีกทั้งยังไม่มีการศึกษาใดเชื่อมโยงปัจจัยความเครียดของกล้ามเนื้อมัดเล็ก (muscle fascicle strains) ของกล้ามเนื้อ *longissimus dorsi* ซึ่งการศึกษานี้จะเป็นรากฐานที่จะทำให้เราเข้าใจกลไกการทำงานของกล้ามเนื้อ *longissimus dorsi* ในขณะที่ม้าเคลื่อนที่ได้ดียิ่งขึ้น ซึ่งจะส่งผลดีต่อการพัฒนาวิธีการใหม่ในการรักษาภาวะเจ็บหลังของม้าสำหรับสัตวแพทย์ในอนาคตได้ ดังนั้นการศึกษานี้ต่อไปหากมีการเชื่อมโยงสามปัจจัยนี้เข้าด้วยกัน อาทิเช่น กายวิภาคโครงสร้างของม้าแบบสามมิติ การวัดการทำงานของกระดูกสันหลัง และการบันทึกคลื่นไฟฟ้าการทำงานของกล้ามเนื้อ *longissimus dorsi* ในขณะที่ม้าเคลื่อนที่ การเชื่อมโยงเหล่านี้เข้าด้วยกันจะทำให้เราเข้าใจการทำงานของหลังม้าได้ดียิ่งขึ้น

คำสำคัญ : ม้า; หลัง; การทำงาน; *longissimus dorsi*; ชีวกลศาสตร์

Introduction

The horse's back is considered importance for its function and athletic ability. However, there are some limiting factors in the evaluation of back problems such as difficulties in establishing a specific diagnosis, lack of knowledge of natural history of disorders and particularly insufficient research in biomechanics (Jeffcott 1979). However, several studies provide information about the stiffness and range of motion of the back, and also the electromyogram (EMG) activity. These reports are helping us to understand the biomechanics of the horse back much better.

Thus, this review will explain basic function of the horse back in term of the anatomy, mechanical properties of skeletal muscles, motor muscle unit, kinematic of the horse back and back problems.

Anatomy of the equine back

In order to appreciate the mechanisms underlying back movement, it is prerequisite to understand its anatomy. However, in addition to basic morphological anatomy, a thorough knowledge of back biomechanics is also required to be able to explain back movement. A thorough understanding of the functional anatomy of the back is a basic requirement for veterinarians or physiotherapists who diagnose or treat existing back problems or aim to prevent future problems by manipulating back movement.

The Thoracolumbar spine (back)

In the horse, the thoracolumbar spine consists of 18 thoracic vertebrae (T1-T18) and 6 lumbar vertebrae (L1-L6) (Figure 1). A typical vertebra is made up of a vertebral body, a vertebral arch and vertebral processes. The vertebral body provides the surface against which the intervertebral disc sits, whereas the vertebral arch provides a gap in the osseous structure through which the spinal cord runs. The vertebral processes are the sites of attachment for various ligaments and muscles and are named the dorsal spinous processes, the transverse processes and articular

processes. These processes vary subtly within each anatomical region and this variation reflects the functional and structural demands at the particular anatomical site, e.g. the length of spinous processes varies from region to region, being particularly long between T3 and T7. The lumbar vertebrae, in contrast, have long transverse processes and medium height dorsal spinous processes (Jeffcott 2009).

The fusion of the vertebral arches is achieved by synovial joints between the articular processes and by the interspinous and supraspinous ligaments. The interspinous ligament is short and its fibres are obliquely oriented so as not to hinder flexion and extension. The supraspinous ligament is strong and it is firmly attached to the top of the spinous processes. Its elasticity is limited in the lumbar region, but more pronounced in the thoracic and cervical regions, where it is continuous with the nuchal ligament (Denoix and Pailloux 2001). The nuchal ligament divides the dorsal cervical muscles into right and left groups (Figure 1). This ligament supports the burden of the head without interfering with the ability to lower the neck when grazing. It consists of two parts: the first, the dorsal (funicular) part is a thick cord extending between the highest spines of withers and the external occipital protuberance of the skull, and continues behind the withers as the supraspinous ligament (Dyce, Sack et al. 2002). The second is the lamina part which forms a fenestrated sheet extending cranioventrally from the funicular part and the thoracolumbar spines of T2-T3 to attach to the cervical spines of C2-C7 (Dyce, Sack et al. 2010)

Spinal nerves of the thoracolumbar regions carrying motor and sensory information emerge through the intervertebral foramen, where they soon divide into four major branches: a dorsal branch, a ventral branch, a *ramus communicans* and a meningeal ramus (Blythe and Engel 1999). The dorsal branch of the spinal nerves divides into lateral and medial branches. In the thoracic and lumbar areas the dorsolateral branches pass laterally under the *longissimus thoracis* and *longissimus*

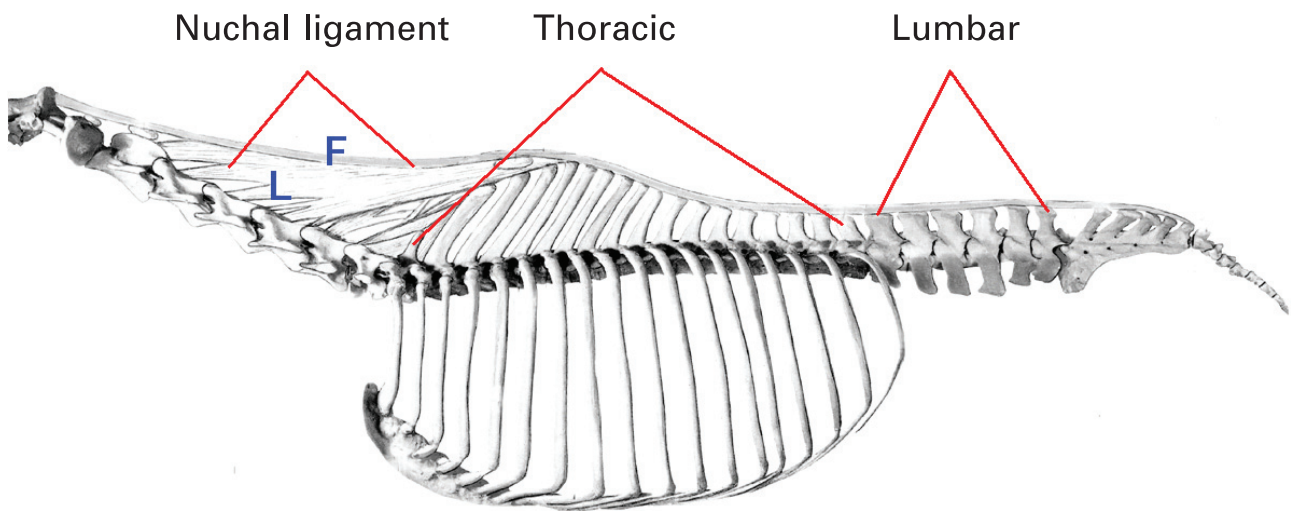


Figure 1. The thoracolumbar spine and ligaments. The thoracolumbar spine comprises of thoracic and lumbar parts. Nuchal ligament comprises of funicular (F) and lumbar (L) parts. (Adapted from: Budras, Sack et al. 2003)

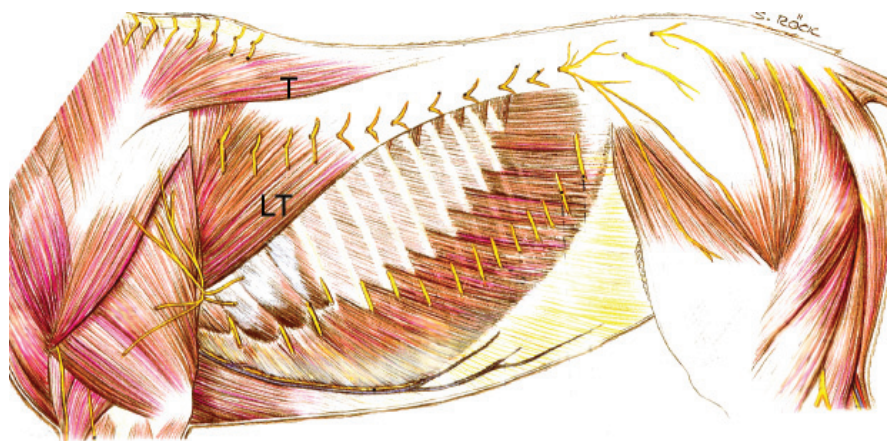


Figure 2. The superficial layer of the epaxial muscles. T = Trapezius thoracalis, LT = Latissimus dorsi. (Adapted from: Budras, Sack et al. 2003)

lumborum muscles to surface among *longissimus dorsi*, *iliocostalis thoracis* and *iliocostalis lumborum*. These dorsolateral branches provide cutaneous sensory innervations of the thoracic dorsolateral spinous areas (Fintl 2009). However, the dorsomedial branches of the spinal nerves are directed caudodorsally deep to the *multifidus* muscles (Blythe and Engel 1999).

The Back muscles

The back muscles can be divided into two groups according to their position and innervations. First, the epaxial group lies dorsal to the line of transverse processes of vertebrae and receives its nerve supply from dorsal

branches of the spinal nerves. Second, the hypaxial group lies ventral to the transverse processes and is supplied by the ventral branches of the spinal nerves; it includes the muscles of the thoracic and abdominal walls in addition to those placed closely on the vertebrae (Dyce, Sack et al. 2002). The hypaxial muscles comprise the *psoas major*, *psoas minor*, *iliacus* and *quadratus lumborum*, the function of this group is to flex the spine and they can also induce lateral movements (Kidd 2009). The epaxial group can be divided into three layers; the most superficial layer (Figure 2), is composed of the *trapezius thoracalis* and *latissimus dorsi*. The second layer

includes the *rhomboideus thoracis*, *serratus dorsalis anterior* and *serratus dorsalis posterior*. The third layer consists of the *iliocostalis*, *longissimus*, *multifidus dorsi* and *intertransversales lumborum*. The *longissimus* is the largest and longest muscle in the body, running from the sacrum and ilium to the neck (Getty 1975). The *longissimus* can be divided into five parts; the *longissimus atlantis*, *longissimus capitis*, *longissimus cervicis*, *longissimus thoracis* and *longissimus lumborum*. The *longissimus thoracis* and *longissimus lumborum* are normally named as the *longissimus dorsi* (Figure 3). These muscles tend to fuse with their medial and lateral neighbours in the lumbar region. It is the major muscle of the back, arranged segmentally with multiple individual attachments. It is thickest in the lumbar region where it is covered in thoracolumbar fascia, and narrows in the thoracic region. These muscles primarily attach to the spinous and transverse processes of thoracolumbar vertebral region and the wing of ilium and help to support the weight of saddle and rider. In addition, it originates from the ilium, spinous processes of the 1st-3rd sacrum, spinous processes of the lumbar and thoracic vertebrae, and the supraspinous ligament. It inserts on the transverse processes and articular

processes of the lumbar vertebrae, transverse processes of the thoracic vertebrae, transverse processes and dorsal spinous processes of the 4th -7th cervical vertebrae and lateral surfaces of the rib (except the first rib). It is segmentally innervated by dorsal branches of the spinal nerves. The *longissimus dorsi* is the main extensor of the back and loins of the horse. It also raises the hind limbs for bucking and forelimbs for rearing, has greatest extension during the swing phase of the hind limb stride and is used to transmit energy from the hind limbs to the back during this phase. It produces spinal extension and lateral flexion when contracted unilaterally (Hausler 1999). In healthy horses, this muscle can extend above the tops of the dorsal spinous processes, this results in a groove running down the middle of the back (Kidd 2009). The anatomical observations for the *longissimus dorsi* indicate that the muscle probably performs different functions both along its length but also from its different regions across each segment (Ritruethai, Weller et al. 2008). The patterns of muscle activity and back bending also vary between regions along the *longissimus dorsi* (Wakeling, Ritruethai et al. 2007). Related to this preliminary model study of the equine back, the muscle activity of the *longissimus dorsi* is generally responsible

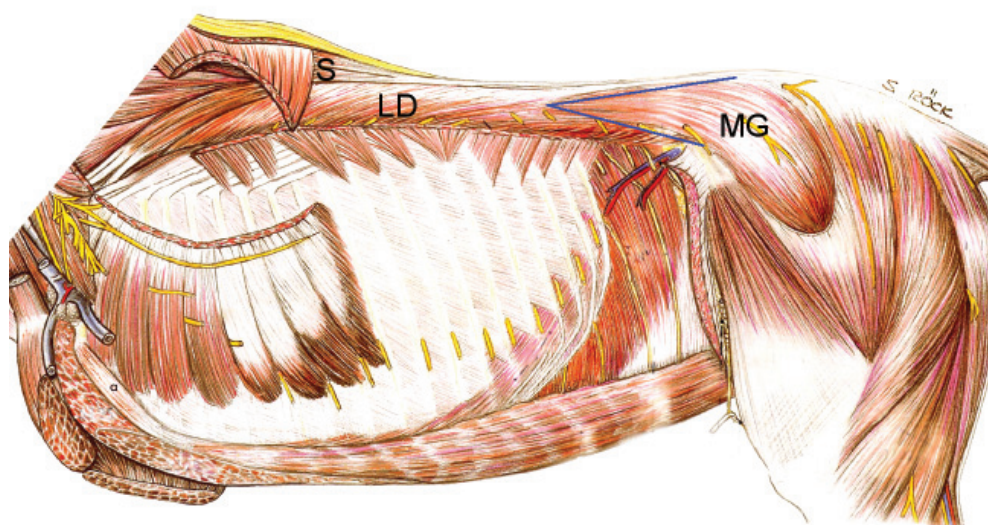


Figure 3. The longissimus dorsi and the adjacent muscles. S = Splenius, LD = Longissimus dorsi, MG = Middle gluteal, the blue lines show the border of MG, that covers the LD. (Adapted from: Budras, Sack et al. 2003)

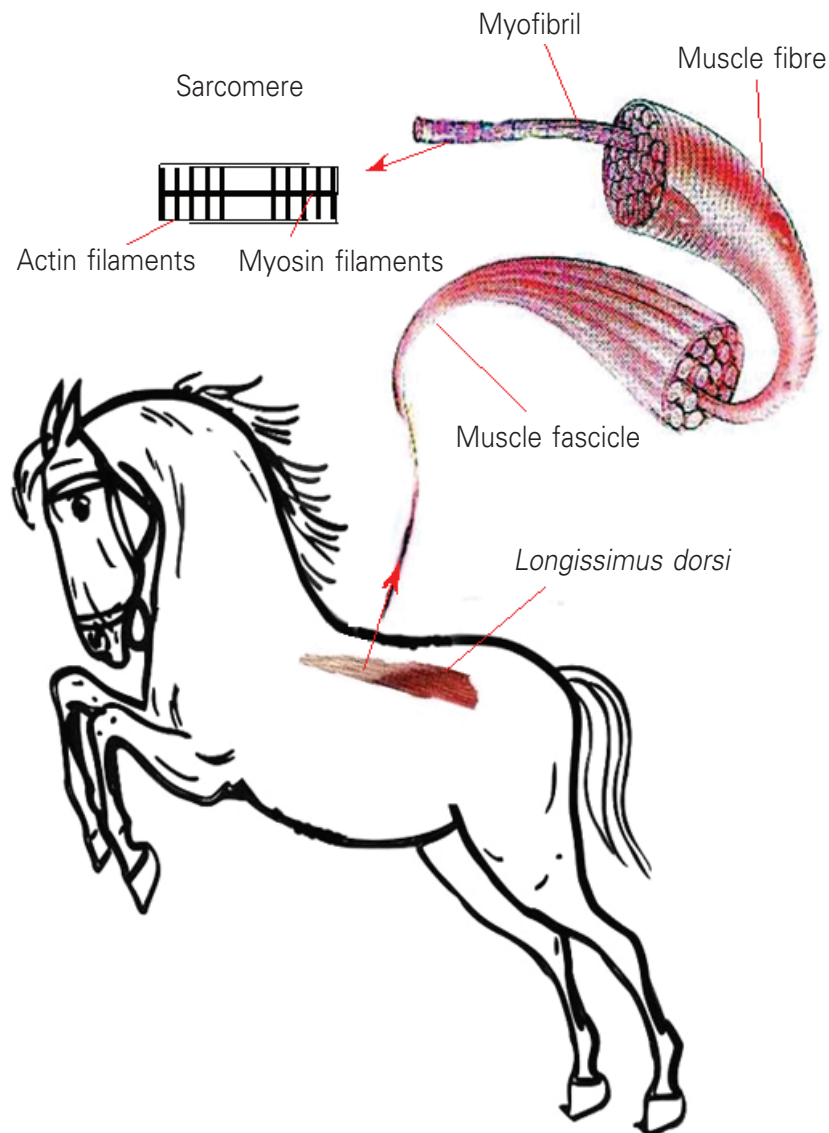


Figure 4. Muscle structure. Muscle belly composed of muscle fascicles, muscle fibres, myofilaments and sarcomeres (Adapted from: <http://www.sirinet.net/~jgjohnso/muscle.html>).

for balance of the vertebrae column with isometric muscle contraction against dynamic forces in walk and trot (Groesel, Zsoldos et al. 2010).

Mechanical properties of skeletal muscles

A muscle is composed of muscle fibres, connective tissue, blood vessels and nerves. It is connected to the skeleton via tendons, with collagen fibres as their dominant component. Muscle fibres are elongated multi-nucleated cells, and contain myofilaments (arranged in sarcomeres: the contractile units),

mitochondria (for energy supply) and endoplasmic (sarcoplasmic) reticulum (with an important function in the activation process). A muscle is made up of fascicles which are bundles of fibres, which in turn are made up of myofibrils, which are formed of lengthwise arrays of sarcomeres and their contractile filaments (Figure 4). Sarcomeres are made up of bands of thick myosin and thin actin filaments bound on either side by a Z-disc, which is important to muscle contraction because it holds adjacent sarcomeres together and anchors the actin. The muscle contraction occurs by the relative sliding of

thick and thin filaments past one another. This is well known as the "sliding filament theory" (Huxley and Niedergerke 1954). Muscle fibres are connected to their tendons via tendinous sheets. In a muscular attachment, muscle fibres insert via very short collagen fibres to the skeleton. Tendons and tendinous sheets act as force transmitters and elastic energy stores.

Due to variation in sarcomere structure and organisation, differences exist in the mechanical properties of different muscle fibres (Hill 1950; Johnston 1991). Most vertebrate muscles contain a mixture of muscle fibre types, which act like a gearing system, facilitating effective movement over a wide range of speeds and loads. Heterogeneity in sarcomere length has been shown to occur with shorter sarcomeres found at the end of a muscle fibre compared to the middle (Huxley and Peachey 1961). Variation in strain and force production will therefore occur along the length of a single muscle fibre (Julian and Morgan 1979; Sugi and Tsuchiya 1988), meaning that the stress-strain characteristics of a single sarcomere do not represent those of a whole muscle.

Muscle fascicle strains can be non-uniform across the muscle (Pappas, Asakawa et al. 2002) due to curvature within the fascicle (Blemker, Pinsky et al. 2005). It is possible that local fascicle strains and activities are linked via the local action of stretch reflexes from the muscle spindles. But we do not know the mechanisms that control regional variations in activity. It is likely that the fascicles from different regions of these muscles generate different forces and strains and thus contribute different functions to the whole muscle when it is faced with a range of mechanical task. However, the modelling studies that simulate the forces generated during muscle contractions typically treat the muscle as a homogeneous unit (Zajac 1989). It will be important to determine the extent to which regional variations in architecture, biochemistry and activation affect the function of a whole muscle.

The force potential of a muscle-tendon unit varies and can be described by *three mechanical characteristics*:

Force-length relationship

The length of the muscle affects the ability of the muscle to create tension. The force-length relationship documents how muscle tension varies at different muscle lengths. The variation in potential muscle tension at different muscle lengths also has an effect on how movement is created. The force-length relationship is just as influential on the torque a muscle group can create as the geometry (moment arm) of the muscles and joint (Rassier, MacIntosh et al. 1999). This also described the amount of force developed by muscle fibres at different sarcomere lengths (Gordon, Huxley et al. 1966). Increased overlap between actin and myosin (at shorter length) results in an increase in the active force that the muscle can develop up to a maximal level. At this point force development reaches a plateau and then begins to fall at shorter lengths. The decrease in force at shorter lengths is caused by excessive overlap, resulting in disruption of the myofilament lattice as the actin and myosin thick filaments increasingly interfere with one another, and as the myosin filaments push up against the Z-discs. The physical disruption of the regular spacing of their hexagonal lattice prevents effective myosin cross-bridge binding to the actin filaments, causing a loss of force. However, a muscle can create both active and passive forces (Figure 5). The active component of the force-length relationship is associated with the potential numbers of cross-bridges between the actin and myosin filaments. Peak muscle forces are generated when the largest number of cross-bridges can be formed and this is sometimes called the resting length. Potential active muscle tension decreases for shorter or longer muscle lengths because fewer cross-bridges are available for binding. The passive tension component shows that passive tension increases very slowly near the resting length but dramatically increases as the muscle is elongated. Passive muscle

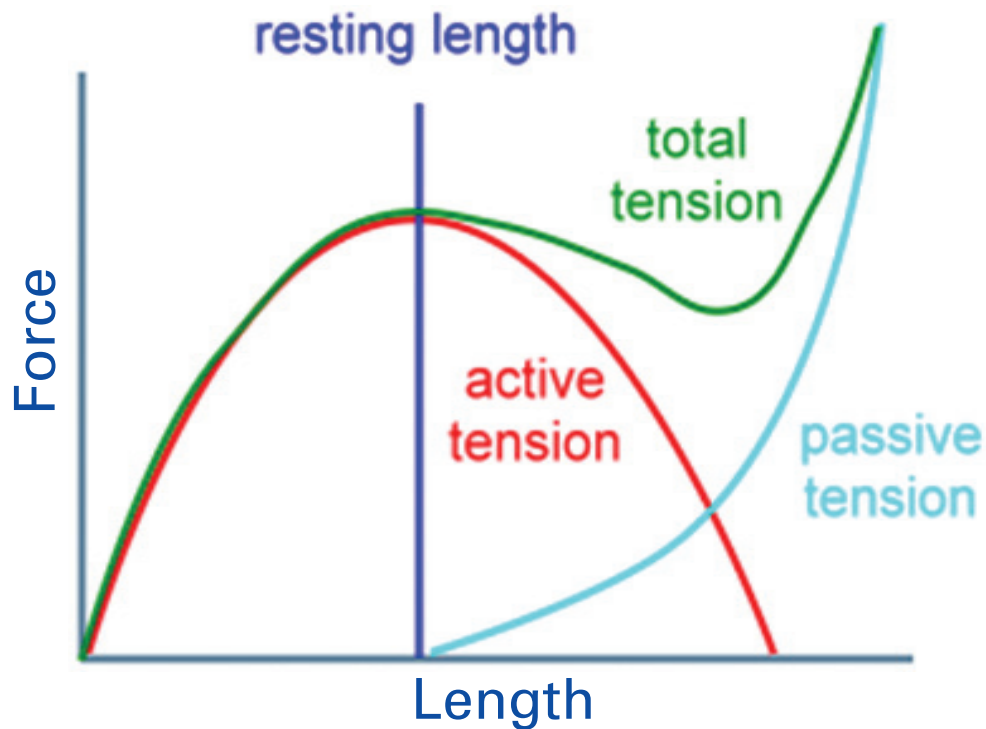


Figure 5. Force-length relationship of skeletal muscle. The active tension associates with the potential numbers of cross-bridges, peak muscles force can be generated when there are the most cross-bridges. The passive tension increases very slowly near the resting length but dramatically increases as the muscle is elongated (Adapted from: <http://www.pt.ntu.edu.tw/hmchai/BM03material/Muscle.htm>).

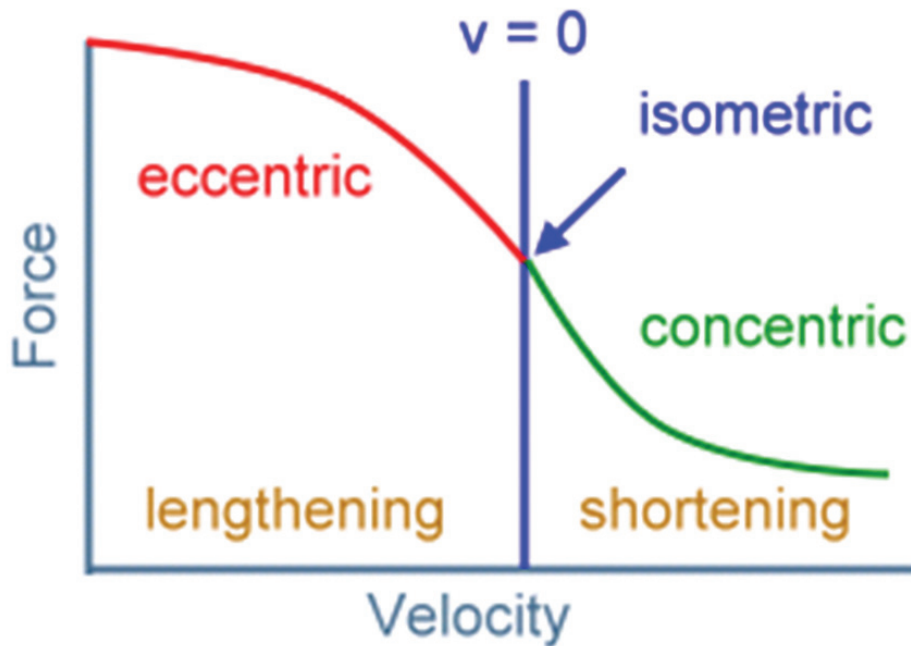


Figure 6. Force velocity curve for skeletal muscle. The force decreases with increasing velocity of shortening (concentric action), while the force can resist increases with increasing velocity of lengthening (eccentric actions) (Adapted from: <http://www.pt.ntu.edu.tw/hmchai/BM03material/Muscle.htm>).

tension usually does not contribute to movements in the middle portion of range of motion, but does contribute to motion when muscles are stretched or in various neuromuscular disorders (Salsich, Brown et al. 2000).

Force-velocity relationship

In addition to the effect of the length, the velocity of fibre shortening (and lengthening) also affects the amount of force that a muscle can develop. With an increase in shortening velocity, force decreases (Hill 1938). The decrease in force at greater rates of fibre shortening probably results from a decreased ability of unbound myosin cross-bridge heads to bind successfully to actin sites as the speed of filament sliding increases, in addition to the possibility that the force developed by each myosin is also reduced. However, the force-velocity curve (Figure 6) shows that the force the muscle can create decreases with increasing velocity of shortening (concentric actions), while the force the muscle can resist increases with increasing velocity of lengthening (eccentric actions). In vitro studies revealed that the forces in fast eccentric actions can be almost twice the maximum isometric force (Alexander 2000), and result in muscle damage by overstretching which is strongly related to the peak force (Stauber 2004). However, a study of bicycling eccentric contraction at different stresses and strains suggested that it is the muscle stretching rather than the peak stress reached that causes injury (Lieber and Friden 1993).

A muscle group can create a torque that depends on the previous action, activation, rate of force development and the combination of the characteristics of the muscle acting at the nearby joints. *In vivo* studies in repeated isokinetic testing have shown that the peak eccentric torques are higher than peak isometric

torques but not to the same extent as in isolated muscle preparations (Holder-Powell and Rutherford 1999), while concentric torques decline with varying slopes with increasing speed of shortening (Gulch 1994; Pinniger, Steele et al. 2000).

Force-time relationship

The force-time relationship refers to the delay in the development of muscle force for the whole motor unit and can be expressed as the time from the motor action potential (electrical signal of depolarisation of the fibre that makes an EMG signal) to the peak in muscle tension. The time delay that represents the force-time relationship can be split into two parts. The first part of the delay is related to the rise in muscle stimulation (active state or excitation dynamics). In fast and high-force movements the neuromuscular system can be trained to rapidly increase muscle stimulation (down to about 20 ms). The second part of the delay involves the actual build-up of tension (contraction dynamics). The contraction dynamics of different muscle fibre types tends to be about 20 ms for fast-twitch and 120 ms for slow-twitch muscle fibres (Burke et al. 1973). When many muscle fibres are repeatedly stimulated, the fusion of many twitches raise the tension generated so it takes even longer for force to build up in the muscle. The length of time depends strongly on the cognitive effort of the subject, training, the kind of muscle active and the activation history of the muscle group. The force-time relationship is often referred to as the electromechanical delay in electromyographic studies. This delay in the development of muscle tension has implications for the coordination and regulation of movement, and the deactivation of muscle (timing of the decay of muscle force) also affects the coordination of movements (Neptune and Kautz 2001).

The Motor unit

Muscle motor unit

The functional unit for neural control and muscular activity is the motor unit (Sherrington 1929). Motor units consist of α -motor neurons and all the muscle fibres innervated by those α -motor neurons. These muscle fibres are distributed across the muscle so that adjacent fibres are from different motor units. According to the excitation-contraction coupling, each time a muscle fibre is activated, an action potential is conducted from the nerve, along the muscle and into the fibre. Thus an electrical signal is emitted by the muscle fibre during individual activation. The propagation of action potentials along the membranes of active muscles fibres have been recognised as myoelectric signals (Sherrington 1929). Conduction velocities of the muscle action potential can be determined from the electromyographic power spectra and are proportional to fibre diameter; high conduction velocities can be attributed to increased fibre diameters (Eberstein and Goodgold 1980).

The Electromyogram (EMG)

Muscle activity patterns can be measured using electromyography, in which the myoelectric signal generated by the motor unit action potentials is detected by electrodes. The contraction of a muscle generates an electrical signal that can be measured as an electromyogram. Voluntary muscular activity results in an EMG that increases in magnitude with force. There are many variables that can influence the signal at any given time: velocity of shortening or lengthening of the muscle, rate of force build up, fatigue and reflex activity. Myoelectric patterns contain information on the timing, frequency and intensity of the myoelectric signals. This information allows quantification of muscle

activity. The intensity of the myoelectric signal indicates the activation level within the muscle. The force achieved by the muscle depends on this activation level, the number and type of the muscle fibres activated, the contraction dynamics and the history of previous contractions (van Leeuwen 1992). Thus EMG provides information about the state of activity of the motor neurons, neuromuscular junction and muscle tissue at rest, during reflex contraction and during voluntary contraction. It is used as an aid in the localisation, diagnosis and evaluation of diseases of the motor unit (van Wessum, Sloet van Oldruitenborgh-Oosterbaan et al. 1999), the applications in horse have been used for assessing muscle activation patterns and providing a more complete understanding of the pathology of the muscles and nerves.

Kinematics of the equine back

The biomechanics of the equine back depend on the interaction between the spinal column and the spinal musculature. The vertebrae, vertebral articulations and ligaments are innervated segmentally by sensory branches of the dorsal rami and recurrent meningeal nerves (Haussler 1999). These nerves mediate nociception and proprioception within the vertebral column. The principle functions of the vertebral motion segments are segmental protection of the spinal cord and associated nerve roots, support for weight bearing and soft tissue attachment, and provision of segmental flexibility (Haussler 1999). Studies on cadaver specimens have shown that the ranges of motion of the intervertebral joints vary along the back. The greatest dorsoventral movement occurred at the lumbosacral and first thoracic intervertebral joints (Jeffcott and Dalin 1980). The greatest axial rotation and lateral bending was

measured in the mid-thoracolumbral spine (T11 and T12). The presence of the rib case stabilised the cranial thoracic vertebrae against axial rotation, however, axial rotation is coupled to lateral bending in the mid-thoracic spine. The caudal thoracic and lumbar spine is the least mobile region of the equine back (Townsend, Leach et al. 1983). In contrast, the most flexible area of the spine was the lumbosacral joint (Denoix 1987). Furthermore, the stiffness of dissected spines depends on the direction of loading with lateral stiffness being significantly lower than dorsoventral stiffness (Schlachter, Peham et al. 2004). These cadaver measurements, by their nature, cannot include the effect of active muscle forces on the mechanics of the equine back, and such data have to be taken from *in vivo* studies.

Kinematics of the horse back have been investigated in many different studies: for instance, some evaluated vertical displacement, range of motion (ROM) or flexion-extension in normal horse (Audigie, Pourcelot et al. 1999; Faber, Schamhardt et al. 2000; Haussler, Bertram et al. 2001; Licka, Peham et al. 2001a; Licka, Peham et al. 2001b; Robert, Audigie et al. 2001a). Since most of the weight is carried by the front limbs, the locomotion is normally forward, meanwhile the acutely- angled hind limbs present more picture of a catapult lever system which provides the main forward propulsive force. The angulations of the limbs and the arrangement of the musculature of the extremities in quadrupeds provide a construction that highly favours forwards motion. Thus the sequence of movements; walk, trot and canter occurred between the front limbs and hind limbs during locomotion (Nickel, Schummer et al. 1986). The back movements are strongly influenced by limb movement and back movements can

be suppressed by contraction of the epaxial muscles. In the following sections, the back kinematics that relate to natural forms of locomotion in the horse are described.

Walk

The walk is a symmetrical, four-beat, stepping gait with lateral footfall sequence. It is also the slowest form of forwards locomotion but probably one of the more complex gaits because of the variability in the overlap and lag time between limbs (Back and Clayton 2001; Clayton 2001). The footfall sequence begins with the left hind limb. The rhythm of the appendicular movements is accompanied to a certain extent by movement of the trunk. The head, neck and tail follow the movements of the four limbs, the head and neck nodding rhythmically and the tail swinging side to side. The head and neck are lowered at each swing phase of the front limbs and lifted during each stance phase. The trunk goes through horizontal and vertical undulations. The vertical undulations occur in every type of gait, consisting of a rhythmical rising of the croup and lumbar regions. The swinging horizontal trunk movements can only be seen at the normal and quick walk. As the hind limb enters the swing phase, the croup of that side is raised and the lumbar vertebral column is rather arched. The movements disappear when the foot is placed on the ground again. The undulating horizontal movements of the trunk occur at the moment of sagittal two-legged support, when the trunk and the centre of gravity are displaced to one side. Meanwhile the trunk is flexed a little and the head is swung over the weight-bearing side. Recently, studies in the lame horses have found that the overall flexion-extension ROM of the vertebral column was significantly reduced. The range of motion was significantly smaller only at T10, L1 and L5. There was a significant increase

in lateral bending ROM only at L5 (Gomez Alvarez, Wennerstrand et al. 2007). An analysis of the walk on the treadmill using three-dimensional accelerometers fixed to the front of a saddle (Galloux, Richard et al. 1994) showed that, at the walk, the amplitude of movement was higher in the vertical axis than in the transverse or longitudinal axes; rotation around the transverse axis (pitching motion) was higher than rotation around the longitudinal axis (rolling) and vertical axis (twisting). Furthermore, the twisting movement was greater in the walk than trot.

Trot

The trot is a symmetrical, two-beat, leaping gait in which the diagonal limb pairs move more or less synchronously and the diagonal support phases are separated by aerial phases (Clayton 2001). The trot is faster than the walk, it is used by all domestic mammals, and the horse in particular can trot for considerably long periods. The two diagonal pairs of limbs are synchronised during active sequence, the centre of gravity is, thus carried by the diagonal two-legged support (Nickel, Schummer et al. 1986). This means that in the horse, before the diagonal supporting limbs are lifted off the ground, the hind limbs which provide the forwards impulse also push the trunk upward. This forwards and upwards push is necessary for the front limbs to be lifted off the ground before the forwards swinging hind limb is placed on the ground. When performing trotting movements, the whole trunk must be rendered more or less rigid in order to provide a firm basis for the limbs and their musculature. The head and neck are carried stiff and upright, tightly pulled into the trunk by the action of the neck muscles. The trunk itself performs only vertical movement. In sound horses a thoracic

extension and a thoracolumbar extension occur successively during the stance phase of trotting, the *longissimus dorsi* is active in the second part of each diagonal stance phase and ceases its activity in the early swing phase of the corresponding hind limb. These findings suggest that the back extension occurring throughout the first part of the stance phase is a passive phenomenon (Audigie, Pourcelot et al. 1999). The back was in extension when the net of rotation of the thorax relative to the pelvis was clockwise as seen from the left side. This occurred during the last part of the diagonal limbs. During the remaining period of stride cycle the back was flexing (Faber, Johnston et al. 2001).

The vertebral ROM in the flexion-extension plane increases significantly during lameness. This increase was individually significant at T10 and T13. There is also a significant decrease in lateral bending and axial rotation of the sacral bone (Gomez Alvarez, Wennerstrand et al. 2007). There is a little modification of the dorsoventral mobility of the back in moderate front limb lameness, the sinusoidal pattern of the curve remains symmetrical between successive diagonal stance phases (Denoix 2001). In contrast, symmetry of the flexion and extension vertebral angle curves is changed with hind limb lameness (Pourcelot, Audigie et al. 1998). Thoracic and thoracolumbar extensions are reduced during the lame diagonal stance phase and increased during the sound diagonal stance phase. This correlates with the lower weight-bearing and propulsion of the painful limb (Denoix 2001). However, the front limb that allows the horse to continue in work causes it to shift its weight more to the hind limbs and the altered movement can also strain the back (Marks 1999). As a compensatory mechanism in front limb lameness, the force of the lame

limb shifts to the hind limbs in the lame diagonal and to the sound front limb during the sound diagonal (Weishaupt, Wiestner et al. 2006). Another study in subtle hind limb lameness demonstrated hyperextension and increased range of motion of the thoracolumbar back, but also decreased range of motion of lumbosacral segments (Gomez Alvarez, Bobbert et al. 2008).

Canter

The canter is an asymmetrical, three-beat, leaping gait with a transverse sequence of limb placements. An aerial phase follows lift-off of the leading front limb. The canter is a variation of the gallop in which the horse travels at relatively slow speed with the leading hind and trailing front limbs moving more or less synchronously (Clayton 2001). At canter, the body is not thrust forward as in the walk or the trot; it is rather catapulted forward with great force and speed. The trunk bridge actively participates in this movement to varying degrees. The body axis will be less oblique to the direction of travel. However the trunk performs rocking movements across the diagonal along with it being propelled, so that it almost rolls forward over the four limbs from behind (Nickel, Schummer et al. 1986).

The Back problems

Skeletal muscle constitutes the largest single mass in a horse's body, comprising over one third of the total body weight (Webb and Weaver 1979). This large mass of tissue is an integral part of the mechanisms that allow the horse to maintain posture and perform exercise. The horse is an elite athlete and has been ridden in different sports for centuries, however, both the type work and the intensity of competition predisposes it to back injuries. The horse's back is central to the normal

function of musculoskeletal system and its ability to carry a rider (Ridgway and Harman 1999). Many back problems are associated with soft tissue damage to the muscles and ligaments of the thoracolumbar spine. Damage to the epaxial muscles is the common cause of back injuries with 38.8% incidence of case reporting with back problem (Jeffcott 1980). Preliminary data from horses with chronic back disorders show an increased fibrous: muscle tissue ratio, a decrease in muscle depth and a change in pennation angle in *longissimus dorsi* (Weller and Piercy, 2008, unpublished data). The back conformations tend to predispose to back injuries; lordosis (ventral deviation of the spine) will put extra weight strain on epaxial muscles result in intermittent soft tissue injury, the short backed with reduced flexibility of spine tends to exhibit more vertebral lesions, the long backed have more spinal flexibility but seems to be more prone to muscular or ligamentous strain (Jeffcott 1979). From the previous observation, age is not such an important factor in equine back disorders (Jeffcott 1977). However, marked lordosis may develop in aged animals and is observed frequently in brood mares, although this deformity can be severe, it is rarely associated with clinical signs (Cauvin 1997). In saddle horses exostoses sometimes develop on the summits of the lumbar spinous processes, bringing these into painful contact with their neighbours (kissing spine) and resulting in minor local deflections of the vertebral axis (Dyce, Sack et al. 2002). Axial skeletal disorders are most commonly recognised in adult athletes, particularly show jumpers and eventers; heavy framed, long-backed thoroughbreds are predisposed to axial soft tissue injuries; standardbreds, quarter horses and other short-backed animals have a higher incidence of

vertebral injuries such as overriding dorsal spinous processes, this condition is also common in warmbloods and in racing thoroughbreds; while congenital spinal disorders, including sacralisation of the last lumbar vertebra, hemivertebrae (wedge-shaped vertebral bodies causing spinal deformities) and block vertebrae (fusion of several vertebral bodies), are more common in Arab horses (Cauvin 1997). Developmental syndromes, such as osteochondrosis, are rare in the thoracolumbar spine, but can affect the lumbar articular processes. Acquired kyphosis (roach back) can occur in young thoroughbreds in association with flexural limb deformities. Skeletal lesions, including degenerative disease of the articular processes and spondylosis deformans, are common incidental findings, and are an occasional cause of back pain. The *longissimus dorsi* is the largest epaxial muscle and important to healthy biomechanics of the back. Damage to the *longissimus* muscles most frequently occurs during riding due to slips, falls or poorly executed jumps, and these events may be caused through fatigue or inadequate fitness (Jeffcott 1979, 1980). The role of the saddle in riding has also been concern for back problems: both the weight and saddle induce an overall extension of the back which may play a role in soft tissue injuries and the kissing spine syndrome (de Cocq, van Weeren et al. 2004). The clinical signs that are easily referred to spinal muscle pathology include atrophy of epaxial muscles, focal swelling and palpable tenderness, as well as enlarged muscles with increased tone. Recognised signs include a history of resentment to saddling up, the horse may buck on being at first mounted, reluctance to move backwards or reining back when being ridden, rigidity of the spine, shortened stride, hind limb lameness, and indicators of poor performance (Jeffcott 1985; Valberg 1999).

Conclusion

The horse's back consists of 18 thoracic vertebrae and 6 lumbar vertebrae. However, the shape of the horse's back is created fundamentally by the shape of its vertebrae, or more precisely by the shape of the bony extensions which radiate from the top and sides of the individual vertebrae. These are called spinous processes, and they are there for the purpose of attaching muscles and ligaments. The dimensions of the muscles, whether short and fat or long and spindly, depend on the calibre of the spinous processes. The height, angle and range of the spinous processes determine how much room there is for muscular development. The bony foundation is therefore directly responsible for the muscular contours of the back. The *longissimus dorsi* is the main extensor of the back and loins of the horse. This muscle performs different functions both along its length and also from its different regions across each segment.

The biomechanics of the horse back depend on the interaction between the spinal column and the spinal musculature. At the walk, the amplitude of movement was higher in the vertical axis than in the transverse or longitudinal axes; rotation around the transverse axis (pitching motion) was higher than rotation around the longitudinal axis (rolling) and vertical axis (twisting). Furthermore, the twisting movement was greater in the walk than trot. In sound horses a thoracic extension and a thoracolumbar extension occur successively during the stance phase of trotting, the *longissimus dorsi* is active in the second part of each diagonal stance phase and ceases its activity in the early swing phase of the corresponding hind limb. Additionally, the muscle activity of the *longissimus dorsi* is generally responsible for stability of the vertebrae column with isometric muscle

contraction against dynamic forces in walk and trot. At canter, the back performs rocking movements across the diagonal along with it being driven, so it rolls forward over the four limbs from behind. Therefore, Damage to the epaxial muscles is the common cause of back injuries and similarly the back conformations tend to predispose to back injuries. However to prevent the back injuries, 3D anatomical measures of the structure *in vivo* integrated with measures of function back motion and *longissimus dorsi* muscle activity would be ideal to understand in further detail the function of the horse's back.

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