MYOFASCIA – THE UNEXPLORED TISSUE: MYOFASCIAL KINETIC LINES IN HORSES, A MODEL FOR DESCRIBING LOCOMOTION USING COMPARATIVE DISSECTION STUDIES DERIVED FROM HUMAN LINES

Vibeke Sødring Elbrønd[1*], Rikke Mark Schultz[2]

[1]*Department of Clinical Veterinary Animal Science, Faculty of Health Sciences, University of Copenhagen; Denmark.*
[2]*RMS Equine Practice, Karlebovej 22, DK- 2980 Kokkedal*.

***Corresponding author:**
Dr. Vibeke Sødring Elbrønd,
Dept. of Clinical Veterinary and Animal Science,
Div. of Veterinary Anatomy and Biochemistry,
University of Copenhagen,
Groennegaardsvej 7,
DK-1870 Frederiksberg C
Email: vse@sund.ku.dk

ABSTRACT

The precise functional role of connective tissue, and especially that of myofascia, remains largely unexplored. With this in mind, the present study has chosen to focus on an improved understanding of the interconnected web of fascia formed by connective tissue throughout the whole body, with particular consideration to force transmission, biomechanics of the whole body and fascia contractility. The specific aim of the present study was to reveal the inter-connective functionality of the locomotory system in a mammal other than humans, namely the horse.

Dissections of horses (n=26) were undertaken in order to verify the existence of, as well as compare the similar functional interconnected lines and structures to, those found in humans. This study found that it was necessary to redefine the human lines that have already been described, owing to variations specific to horses arising from fundamental anatomical differences between bipeds and quadrupeds. Nevertheless, the myofascial kinetic lines presented in this study provide an anatomical foundation for an improved understanding of locomotion. Indeed, one in which the whole body is considered in a holistic way, rather than the simplified description of the action of single muscles. It is concluded that the lines described in this study form the basis of a readily use-able tool that can be applied by practitioners to track the main cause of locomotory problems in horses afflicted with impaired performance.

***Keywords**: Biomechanics; Equine; Fascia; Functional lines; Locomotion; Myofascia*

1. INTRODUCTION

Very little attention has been paid to the connective tissue and its intimate anatomical associations to muscles such as the myofascia or indeed, the connections between muscles. In terms of embryology and the origins of connective tissue, it is believed to be mesodermal, representing a tissue that provides a three-dimensional interconnected network throughout the whole body (Paoletti, 2001; Klingler et al., 2014). In traditional anatomy, muscles are described as single units having an origin, insertion, function and internal relation as well as being either agonistic or antagonistic (Nickel et al., 1977; König et Liebich, 2009). A good example of the fascia web is the way in which the endomysium, perimysium and epimysium envelope the muscle fibers, the fascicle and finally the whole muscle, merging together to form the tendons or ligaments before they enter the periosteum and connect into the connective tissue skeleton of bones (Nickel et al., 1977; Huijing, 2003). According to Yucesoy and Huijing (2007), muscles, when intact with their connective tissue surroundings, are not isolated and independent entities but should rather be seen as collagenous linkages or connections between epimysia of adjacent muscles, thereby providing direct intermuscular connections. Furthermore, the intermuscular septa, interosseal membranes, periost and compartmental fascia serve to connect muscular and non-muscular tissues. Epimuscular myofascial force transmission occurring through these connections has major effects on muscular mechanics – including for example energy conservation, recoil and shock absorption (Yucesoy and Huijing, 2007).

The considerable importance of both areolar (“loose” connective tissue/superficial fascia) and dense connective tissue and thereby fascia tissue, has been revealed through recent research in humans (Schleip et al. 2012a). It has been shown that this tissue plays an important role in the locomotory system and thereby has an influence on biomechanics and posture of humans and animals alike (Schleip et al. 2012a). Purslow (2009) describes how the perimysium and epimysium can act as pathways for myofascial force transmission. Likewise, myofascial force transmission between both the agonistic and antagonistic muscles has been shown *in vitro* and *in vivo* in humans and rats (Carvalhais et al., 2013; Tian et al., 2012; Huijing et al., 2011; Yucesoy et al., 2010; Huijing et Baan, 2008). Maas and Sandercock (2008) suggested epimuscular myofascial force transmission *via* connective tissue to the Achilles tendon in m.soleus of tenotomysed cats. Moreover, according to Purslow (2002) the endomysium has an increased role in force transmission in injured muscles.

Research in the field of mechanobiology has shown different qualities of contractility of areolar and dense connective tissue (Langevin et al., 2013). In areolar connective tissue fibroblasts exhibit a fast (within minutes) dynamic cytoskeleton remodelling in order to adapt connective tissue tension (Langevin et al., 2004; Langevin et al., 2006; Langevin et al., 2013). Whereas tension in myofascia occurs more slowly when fibroblasts diversify into myofibroblasts and provide it with strong contractile properties often over long time periods (hours to weeks) (Langevin et al., 2011). Myofibroblasts are well known for their role in open wound healing where they contract the wound edges. It has been suggested that they may instigate a positive feedback mechanism, which is to say that the contraction forces increase with fascial tension - providing a static tension which is only released upon myofibroblast apoptosis (Tomasek et al., 2002). This contractility can provide fascial stiffness (Schleip et al. 2006a; 2006b; Van De Water et al., 2012; Klingler et al., 2014). Myofibroblasts have also been shown to be involved in fibrosis in scar tissue, and deformation of the surrounding connective tissue (Van De Water et al., 2013; Wipff et al., 2007). In humans, scar tissue formation and fibrosis leads to a loss of function and susceptibility to recurring injury (Best et al. 2013). According to Stecco and colleagues (2011) skin ligaments connecting the skin to the areolar connective tissue are visible using CT, MR and ultrasound and there is a further connection into the deep fascia. Therefore, it is important to consider how scar tissue in skin, fascia and muscles might influence the function of the structures associated with the deeper and more profound parts of the locomotory system.

It is also important to consider the role of myofascial tension in body balance and posture just as one does in terms of agonist and antagonist muscles (Nickel, 1977; König and Liebich, 2004). According to Stecco and colleagues (2011) there is increasing evidence that fascia plays an important role in movement perception and coordination. Tomasek and coworkers (2002) state that "…tissue tension is an essential regulator of tissue function…" both for visceral and somatic tissue. Furthermore, Masi and colleagues (2010) describe the importance of human resting myofascial tension in terms of postural balance, something that is supported by the biomechanical principles of myofascial elasticity, tension and stress. Understanding the fascia as an interconnected web with fascial force transmission, dynamic and static contractility affecting body posture and balance, introduces the importance of being knowledgeable about myofascial distribution, its connections throughout the body, and its effects on locomotion and posture.

In order to describe posture and motion of the whole body, myofascial kinetic lines consisting of rows of interconnected anatomical structures, which functionally direct the basic motion patterns of the musculoskeletal system, should be considered. These interconnections of muscles, tendons and fascia, have already been described in humans by several authors, among them Busquet, Struyf-Denis and Myers as presented by Schleip and colleagues (2012) and Richter and Hebgen (2009). Denoix and Pailloux (2009) describe the dorsal and ventral muscular chains in horses as "creating a functional unity" and due to such myofascial connections, any form of biomechanical disorder can be expected to create problems within the chain or at some distance. The term "chains" has its origin in the well--recognized "Bow and String" theory (Sleijper, 1946). Sleijper (1946) stated that the epaxial spinal muscles work as antagonists to the abdominal muscles in order to maintain body balance. The "stay apparatus" is another well-recognized structure for maintaining posture. Several researchers have studied separate parts of the passive stay apparatus on respectively the front limb and the hind limb under different clinical and pathological conditions. Gussekloo and colleagues (2011) studied the effect of differences in tendon properties on the functionality of the passive stay apparatus in horses, thereby taking major tendinous structures into account. However, nobody seems to have coupled the passive stay apparatus to the rest of bodily function, balance and posture.

Thomas Myers was the first to dissect the lines in human cadavers and presented his results in the book entitled "Anatomy Trains" – also available in DVD format (Myers, 2009). He describes 10 lines, 4 superficial and one profound from head to toe (or if you wish, the other way around since there is no definition of beginning or end), 4 lines on the arms, and one line from the arm to the lower extremities (see table 1).

In this study we have chosen to use the definition of the fascia as proposed and discussed at the Fascial Research Congress 2012 (Schleip et al., 2012b), that is to say "...fibrous collagenous tissues which are part of a body wide tensional force transmission system…". With a few exceptions this includes almost all types of connective tissue, since they are all regarded as being integrated in the locomotory system.

The aim of this study was, therefore, to reveal the inter-connective functionality of the locomotory system of the horse. Two hypotheses were tested, namely; 1) that it is possible to isolate and define fascial tissue of the equine locomotory system, comprising a continuous 3-D viscoelastic matrix providing structural support, and 2) that the existence of diverse lines related to lateral bending, extension, flexion and rotation are not only comparable with the human lines, but also lend support to existing biomechanical theories such as "bow-string" and the "passive stay apparatus".

2. MATERIALS AND METHODS

2.1 Animals

Twenty-six horses of different breeds, e.g. riding horses, ponies and Icelandic horses, were dissected. There were both mares and geldings covering an age range of 5 to 35 years. All the horses were euthanized for humane reasons unrelated to this study.

2.2 Photography

A Ricoh GX200 camera was used for imaging the dissections and the isolated lines, whilst a Canon EOS 6000D camera was used for imaging the painted, live horses. The images were adjusted using Photoshop Cs4 software. The paint used was theatre face paint, Grimas, (2001 De Haarlem, the Netherlands)

2.3 Equine Lines

By intensive study of the equine anatomy in the literature (Nickel et al., 1977; Budras, 2009; König et Liebich, 2009; Constantinescu & Schaller, 2012) theoretical comparison between the anatomical description of the human lines (Myers 2009) and possible equine lines were made. Considerations, with regard to differences between quadrupeds and bipeds in terms of their anatomy and biomechanics, were made. On the basis of which, theoretical suggestions to the equine line were derived.

In the practical part of the study the horses were euthanized and immediately skinned. The structures of the single lines were then identified and dissected with direct and stump dissection techniques. The fascial connections between the muscles and on the bony attachments were closely scrutinized. Bony attachments were dissected and isolated mostly by means of blunt dissection, lifting the structures of the bone.

Specific rules, as presented by Myers (2009), were followed when dissecting. These rules comprise, i) the collagen fibers in any given line should be aligned in the same functional direction, ii) the structures of the lines should be situated at the same level of the body, iii) the overall function of the structures in any given line should be similar, and iiii) the muscles in a line should have a span over more than one joint.

For illustration purposes the lines were painted on a living horse (see Fig 2 and 3).

3. RESULTS

This study provided an opportunity to look at the gross and functional anatomy in a new broader and more kinetic perspective. We did not make any “new” anatomical discoveries but with the main focus on the fascia and myofascia interconnections we were able to arrive at a clearer understanding and impression of the overall interactions that exist throughout the body as a whole. With the help of the dissections it became clear that the bony attachments from muscles, tendons and ligaments were not “finally” inserting into the periost and bone but that part of the fibers continued into the “next” structure/structures and formed a continuous line or continuum of tissue. We found that it was possible to lift the connective tissue attachments from the bones with the aid of blunt dissection and thereby follow the continuation of the lines.

The course of the lines became very clear when we looked closely at the fiber directions of the fasciae e.g. the fascia of the m. gracilis crossing over in front of and under os pubis (see Fig.1c), and the fibres in the fascia genus running distally into the lig. patellare (capsula articularis) of articulatio genus with both straight and oblique fibres. Additionally some muscles had their origin directly from the fascia e.g. m. splenius from fascia spinocostotransversarius, which clarifies the force transmission between fascia and muscles and supports this theory.

3.1 Superficial Dorsal Line (SDL)

The Superficial Dorsal Line (SDL) (see fig. 1a and fig. 2a,b and c: green line) has its origin in the hind limb phalanx media, facies plantaris with the insertion of the tendo m. dig. sup., the tightly associated structures such as the fascia digiti, fascia plantaris, lig. metatarseum transverseum superficiale (previous: lig. anulare proximale), m. interosseus medius and the retinaculum flexorum. In a proximal direction the superficial tendon attached to the tuber calcanei on the os calcaneus, into a tight, strong and branching fascia that distally connected into the origo and the body of m. interosseus medius. Proximally the fascia continued into the tendo calcaneus communis. This tendon consisted of the tendons and fascia tissue from m. flexor dig. sup., the two heads of m. gastrocnemius; the tendons from m. biceps femoris pars caudalis, and m. semitendinosus. The epimysium of the muscle belly of gastrocnemius was arranged into the overlying fascia cruris, which laterally radiated into m.biceps femoris pars caudalis and medially into m. semitendinosus. These two muscles attached on the tuber ischiadicum and then continued into the lig. sacrotuberale latum. From here the line radiated further on into the ligament and into the group of spinal muscles termed errectors; extensors; extrinsic or epaxial muscles (m. spinalis; m. longissimus dorsi, and m. iliocostalis) from where epimysial radiations into the fascia thoracolumbalis were observed. M. longissimus capitis and m. semispinalis capitis led the line from the thoracic region and lower cervical vertebrae onto the crista nuchae of the os occipitalis. From there m. temporalis and fascia temporalis arose and inserted onto the processus coronoideus of the os mandibularis. The perimysium of m. temporalis was found to fuse into the m. masseter.

3.2 Superficial Ventral Line (SVL)

The Superficial Ventral Line (SVL) (see fig. 2 a,b and c; blue line) has its origin in the hind limb on the os phalanx distalis at the insertion of the tendon from m. extensor dig. longus and lateralis and involved the tightly related and connected fascial structures: fascia digitalis; fascia dorsalis pedis and retinaculum extensorum. Proximally the line passed over the articulatio tarsi and branched into the dorsally situated extensor muscles: m. tibialis cranialis; m. extensor dig. longus and m. peroneus tertius. The latter having developed into a fibrous band positioned in a groove in between the other two extensors. The overlying fascia as well as the peri- and epimysium of the three muscles were found to be closely interwoven into a dorsal extensor compartment. SVL followed these fascial relations proximally towards the stifle and into the fascia genus. In the deeper part of the extensor compartment SVL attached to the tuberositas tibia and split into the ligamentum patellae lateralis et intermedius. In the proximal part m.quadriceps femoris, vastus rectus was included. The origo of this muscle belly was situated on the os ischii just cranial to the articulatio coxae and in close proximity to the lig. ass. caput femoris, an offspring from the tendo prepubicus. M. rectus abdominis had its origo from the tendo prepubicus and continued the line cranially through m. rectus thoracis. This proximity led into the contact of the peri- and epimysium of m. rect. abdominis with which the line and contact were brought forward to the origo at os sternum and the ventral part of pars cartilagines of arcus costarum on the last ribs. From here the fascia ran directly into the m. rectus thoracis towards costa prima. We found a short mechanical link over the os sternum to the manubrium sterni and further on, into the insertion of m. sternomandibularis that brought the line up to the origo on the ramus mandibularis and finally to the fascia masseterica and the m. masseter.

SDL and SVL connected through the fusion of the tendinous branch of the temporal muscle and the deep layers of m. masseter on the head. In the hind limb they joined through the branches of the suspensory ligament into the extensor tendon and on the phalanx distalis and with the attachment of the superficial flexor tendon on phalanx media.

3.3 Lateral Line (LL)

The Lateral Line (LL) (see Fig. 2 a,b and c; orange line) originates in the hind limb from os phalanx distalis, facies dorsalis, at the insertion of the tendon from m. extensor dig. lateralis and m. ext. dig. longus and included the same structures as the SVL namely the tightly related and interconnected fascial structures: Fascia digitalis; fascia dorsalis pedis and retinaculum extensorum. At the level of the articulatio tarsi the LL line split into the tendo m. extensor digitalis lateralis and two thick fascia sheets, which separated the space (lateral extensor compartment) dorsal and plantar to the muscle. Proximally we observed that the two fascia sheets united in the caudolateral region and attached to the os fibula. The LL united in the lateral collateral femorotibial ligament, the surrounding fascial tissue and the fascia cruris. From here LL was found to take two proximal pathways. The first passed through the mid part of fascia lata and m. tensor fascia lata to the tuber coxae and the other comprising the caudal part of the fascia lata and into the m. gluteus superficialis and from here to the tuber coxae. At this point the LL partly broke one of the rules as it seemed to split up into a superficial and a profound layer - but both layers were still regarded to be in the superficial layers of the body. In addition to this the profound layer broke yet another rule all the way from the tuber coxae and along the trunk. Here the fibres were arranged in a criss-cross pattern as the line passed through the aponeurosis and fasciae tissue of m. obliquus externus et internus abdominis to the arcus costalis, and further on through the m. intercostales interni et externi. These structures were arranged in this angulated network. The m. intercostalis externi et interni were found to be covered on each side by a sheet of fascia thoracolumbalis profundus named fascia spinocostotransversarius as far forward as the os costale primum, medial to the scapula. The origin of m. splenius cervicis et capitis were isolated from fascia spinocostotransversarius and were found to pass towards the origo at processus mastoideus os temporale where their insertion was isolated.

The superficial sheet of the LL became integrated into m. cutaneus trunci, which was present in the fascia thoracolumbalis superficialis. In the cranial direction this sheet integrated into the cranially positioned m. cutaneus omobrachialis, which was found to be attached onto m. brachiocephalicus as well with an origo at the proc. mastoideus at the os temporale.

3.4 Spiral Line (SL)

The Spiral Line (SL) (see Fig. 3 a, b and c: green, light green line) has its origin cranially at the origo on the proc. mastoideus os temporale of m. splenius and follows this muscle dorso- laterally on the neck of the horse to the fascia nuchae, where in the region of C6-C7-T1-T2-T3 it crossed under the funicular part of the ligamentum nuchae to the contralateral side into m. rhomboideus pars cervicalis et thoracis. On the medial surface of the scapula, the peri- and epimysium of m. rhomboideus merged into the fascia fibres related to m. serratus ventralis thoracis and from there directly into m. obl. externus abd. and continued across the linea alba heading to the contralateral side where it merged into the fibres of m. obl. interna abd., which attached to the tuber coxae. From here the SL continued with the fascial fibers in the fascia lata and the m. tensor fascia lata into the extensor compartment. On the dorsum tarsi the fibers continued into the cunean part of the tendo m. tibialis cranialis on the medial side. The line redirected proximally through a mechanical link on the plantar surface of the tarsus picking up the lateral tendon of m. peroneus tertius and the tendinous structures of m. ext dig lat. Here the line continued in a proximal direction towards and into the profound part of m. biceps femoris towards the ligamentum sacrotuberale latum. The fibers from here merged over the sacrum through the lig.

sacroiliaca dorsales where they crossed over the dorsal midline to the contralateral side. The rest of the line followed the SDL along the back, thorax and neck, ending at os occipitale close to proc. mastoideus os temporale contralateral to the origin.

3.5 Functional Line (FL)

The Functional Line (FL) (see fig. 3 a,b and c: blue and light blue line) was found to have its origin on the caudomedial face at the distal end of the humerus with the fascial attachment at the origo of m. latissimus dorsi. The fascia continued into the fascia thoracolumbalis in a dorsocaudal direction and crossed the dorsal midline, over the lumbar vertebrae, to the contralateral side (fig. 1 b). From here the fibers continued distally into the fascia latae/genus and over vastus lateralis of the m. quadriceps femoris into lig. patellae lat. et intermedius onto the tuberositas tibiae. Here the oblique fibers fused with oblique fibers from the ligamentum patellae medialis. In the proximal direction these fibers attached to the peri- and epimysium of m. gracilis and m. adductor longus. Fibres crossed over at the ventral aspect of os pubis (see fig. 1c) and were directed cranially into the aponeurosis of the fascia sheets of m. rectus abdominis. The fibers followed the muscle and fasciae in a proximal direction along the thorax and branched into the m. pectoralis ascendens. A fascial connection with m. latissimus dorsi was dissected between the olecranon and the thorax ipsilaterally.

3.6 Front Limb Lines (FLL)

The Front Limb Lines (FLL) (see fig. 3c). Two functionally related front limb lines were found i) a Front Limb Protraction Line (FLPL) (fig. 3c; yellow) and ii) a Front Limb Retraction Line (FLRL) (fig. 3c: pink). The FLL originated cranially from the fascia cervicalis profunda, cranioventrally from the fascia pectoralis, caudodorsally from the fascia thoracia profunda and thoracolumbalis, and caudoventrally from the fascia axillaris. The dorsal part of the scapula was found to be the center of rotation for both the protraction and retraction lines. Both lines were found to have a cranial as well as a caudal approach to the scapula. Being aware of the movements of the scapula during protraction and retraction makes it easier to understand how the lines act within the proximal part but also to project them to the distal part in the front limbs.

The cranial part of FLPL (fig.3c; yellow) had its origin in the fascia cervicalis profunda, which arose in the occipital region of the head. It was followed via m. brachiocephalicus and m. omotransversarius to the distal part of the margo cranialis scapula, where it connected with m. supraspinatus. From a caudal direction the line approached the scapula in the fascia trunci with a cranial direction into m. trapezius pars thoracica and a secondary sheet, which inserted into m. rhomboideus thoracis. From a dorsal direction the line adjoined m. supraspinatus, where it fused with the cranial part of the line. The distal part of the line was related to those structures which extended the front limb. At the level of the brachium the line followed m. biceps brachii, lacertus fibrosus to m. extensor carpi radialis and then into the tendo m. extensor dig. communis with a final insertion on the processus extensorius on the dorsal aspect of the phalanx distalis.

The FLRL (fig. 3c; pink) also had its origin in the fascia cervicalis profunda in the dorsal part which included the thin

m. trapezius pars cervicalis and the much larger m. rhomboideus cervicis. Both muscles, and thereby also the line, attached to the dorsal part of the margo cranialis scapula and connected into m. infraspinatus. From a caudal aspect, the line arose in the fascia thoracolumbalis and proceeded into m. latissimus dorsi and then to m. triceps brachii, m. tensor fascia antebrachii and fused with the cranial part of the line within m. infraspinatus. In a distal direction towards the brachium, the two lines continued over the olecranon and ventro-medially to the m. dig. flexores into the flexor tendons, which traversed through the canalis carpalis and attached to the os phalanx media and distalis due to the insertion of the tend. m. flexor dig. superficialis et profundus, respectively.

4. DISCUSSION

This study reveals that full-body myofascial kinetic lines are present in the horse. The lines were found to be very similar to the human lines described by Myers (2009) although clear differences were found, which were explained by the anatomical variations present between bipeds and quadrupeds. Furthermore, the addition of their known function in terms of the structures of the lines, lends support to their overall participation in spinal motion.

In comparison to the human lines described by Myers (2009) the SDL follows the SBL well. There is a difference at the head, where the human line ends in the epicranial fascia and the equine line ends in the temporal muscle and fascia. It can be discussed as to whether m. interosseus (suspensory ligament) in the hind limb is involved in the equine line. On one hand, it is a profound structure on the plantar surface of the os metatarsale and should not be part of the line. Yet on the other hand its branches surround the fetlock joint superficially and merge into the extensor tendon, which can be considered another link between the SDL and the SVL. Another argument for its relation is the close cohesion to the stay apparatus, which is considered as being one unity (Gussekloo et al., 2011). Whether m. semimembranosus should be included into the SDL is questionable. On one hand the muscle is included in the group of hip extensors (hamstrings) as also stated in humans by Myers 2009, on the other hand the insertion and the function in the horse is more likely to warrant its inclusion in the group of adductors. It might therefore be regarded as a connection between the SDL and the FL through the tight fascial connection between m. semitendinosus and m. semimembranosus. Furthermore, the interactive dissections revealed that the kinetic element in this line was present and supported by the observations of m. gastrocnemii caput laterale et mediale; m. biceps femoris caput caudalis, and m. semitendinosus forming a functional sling which is active only when the stifle is extended.

The SVL in horses seems to fit better than the SFL in humans in some areas. For one thing, it shows a closer connection at the acetabulum caused by the lig. accessorium caput femoris, which is absent in humans. For another, there is a point of the cranial/proximal part of the thorax where the horse has a m.rectus thoracis and humans only have a thin layer of fascia. On the neck the lines differ due to the difference between m.brachiocephalicus in equines and m.cleidomastoideus in humans. Horses have no muscle directly from the sternum to the proc. mastoideus os temporale but instead from the sternum to the mandible and from the lateral surface of the shoulder to the processus mastoideus. Only m. sternomandibularis is part of the SVL in the horse. The courses of the SDL and the SVL follow the “Bow and String”- theory in part, an explanation proposed initially by Sleijper in 1946, and subsequently by several other authors (Denoix, 2009; König, 2009; Weeren, 2010). The difference being, that the SDL and the SVL connect the whole body from the phalanx of the hindlimb to the mandibula. Important actors of the passive stay apparatus as m. peroneus tertius and m. flex. dig. superf. were found to be part of SVL and SDL, respectively, as well as parts of the fine-tuned balancing system of the hind limb. This knowledge adds to our understanding of why proper balance in the teeth and articulatio temporomandibularis (TMJ) (Evrard, 2002; Vogt, 2011) as well as proper trimming and shoeing are important for the performance of the horse (Adams, 1987; Ross and Dyson, 2003).

From a theoretical point of view the lines act on the biomechanics of the spine. Looking at what is already known and accepted in terms of the function of the muscles of the SDL, the line provides extension of the spine and the coxal joint and flexion of the lower limb. In contrast, the SVL acts as an antagonist through flexion of the spine and the coxal joint, and extension of the lower limb. When the two lines balance each other, the spine will be in a neutral position. Similar muscles and fascia influence the posture of humans (Masi et al., 2010; Myers, 2009), and it is likely that these lines can be used to evaluate the static and dynamic posture of the spine in the horizontal plane (flexion/extension) in horses. From a dynamic point of view Rhodin (2009) concludes that extreme neck elevation (neck extension) increases hindlimb flexion and lumbar back extension in high-level dressage horse ridden on a treadmill. Lesimple (2012) found that neck posture and muscular activities are closely correlated, thus horses with concave necks (cervical extension) were found to have a high level of muscle activity in the back. These findings lend support to this line theory.

This study found that the LL in the horse has two courses at the pelvis, and at the neck, depending on the horizontal position of the spine in flexion or extension, which can be compared to the human lines. During extension of the spine (SDL activation) m. gluteus superficialis and m. splenius are more active and during flexion of the spine (SVL activation) m. tensor fascia lata and m. brachiocephalicus are more active. This leads one to assume that in a neutral spinal position these muscles balance each other. In contrast to the LL in humans, the equine LL has two layers, one on either side of the scapula caused by the sagittal orientation of the scapula in the horse and the previously mentioned difference of m. brachiocephalicus compared to m. cleidomastoideus in humans. In terms of their function, the muscles of the LL provide lateral flexion of the body by unilateral contraction and the two LL´s function in an antagonistic manner to one another, balancing the body when straight.

It is proposed that together the SDL, the SVL and the LL outline and balance the body in the horizontal and vertical planes, and that the two helical lines appear to control the spinal rotation of the body.

This study found that the SL has three crossing points relative to the midline on the trunk and the neck - two dorsally over C6 and C7 and at the tuber sacrale, and one on the ventral aspect at the mid abdominal region. Furthermore, the SL follows the human line very closely.

Functionally, it is known that the action of the muscles of the SL give rise through contraction of the neck part to lateral neck flexion with the two sides balancing each other. Contraction of the ventral part at the region of the abdomen, provides flexion and rotation of the spine which is supported by the findings of Stubbs and colleagues (2006). In contrast, contraction of the dorsal part provides spinal extension and rotation in the opposite direction. In this way the ventral and dorsal parts of the SL act as antagonists.

This study also found that the FL is very similar to the human line, comprising two passings at the midline, one dorsally through the fascia thoracolumbalis, and one ventrally over the os pubis through the crossing fibres of m. gracilis (see fig. 1c). Vlemming and colleagues (1995) suggest that the gluteus maximus muscle and contralateral latissimus dorsi muscle are functionally coupled, especially during rotation of the trunk in humans. Moreover, Carvalhais and colleagues (2013) provided evidence of force transmission between these two muscles through the thoracolumbar fascia *in vivo* which supports the course of the FL. Due to the known function of the muscles involved in the FL, its dorsal part will provide front limb retraction and contralateral hindlimb retraction, as well as spinal extension and rotation. Its ventral part counteracts with a spinal flexion and opposite rotation thereby acting as an antagonist.

The three major movements of each vertebra are around: 1) the horizontal axis: flexion and extension, around 2) the vertical axis: lateral flexion, and around 3) the sagittal/longitudinal axis: axial rotation (Townsend, 1983; Evrad, 2002; Weeren et al., 2010). In the light of the aforementioned functional anatomy, it can be argued that the five lines described in this study are more than capable of providing these three movements of the spine. It should be noted, however, that vertebral lateral flexion and rotation are always coupled movements (Denoix, 1999; Haussler, 2001; Faber, 2001; Denoix, 2009), which might suggest that the LL and the helical lines also work simultaneously. Their close connection to movement around the horizontal plan has already been described earlier in this manuscript.

Finally, it should be mentioned that the FLL differs from the “Arm Lines” found in humans, as we have only been able to describe two and not four lines. They comprise a protraction line and a retraction line. The difference might be due to the greatly reduced rotation and adduction/abduction properties of the equine front limb compared to the human arm. Further studies might, however, reveal more front limb lines.

Just as with muscles, the lines collaborate closely within a fine-tuned and balanced mechanical and functional network. Interconnections, such as those presented in Table 2, between the individual lines, are supported by the fact that they share common structures. The SDL, the SVL and the LL are interconnected at the skull as well as in the phalanx of the hind limb. Additionally the SVL and the LL share the parts of the m. brachiocephalicus over which they balance and direct their forces. The superficial and the helical lines also share structures internally, and act together with the front limb lines. These findings support a full body model of balance and function that includes not only the trunk, but also includes the connections with the limbs too.

5. CONCLUSION

This study, which is the first to describe myofascial kinetic lines in a mammal other than humans, uses well-described and documented anatomical structures, and integrates new knowledge about the importance of fascia and its interconnectivity. In comparison with the human lines described by Myers (2009), this study identified 7 myofascial kinetic lines with some variations specific to horses, owing to inherent anatomical differences between bipeds and quadrupeds. For example, Myers (2009) describes a “Deep Front Line” in humans, which has been more appropriately renamed the “Profound Ventral Line” in the horse, and it is currently the subject of a more detailed investigation to be published at a later date.

This new knowledge concerning the importance of fascia and connective tissue, which forms a continuous web and serves to connect the whole body, should be seen as presenting the traditional static view of anatomy at an altogether higher level. The myofascial kinetic lines presented in this study provide an anatomical foundation for an improved understanding of locomotion, one in which the whole body is considered in a holistic way, rather than the simplified description of the action of single muscles and, for example, vertebrae. Thus, as a result of the interconnections between fascia and their dynamic and static contractility, it is conceivable to imagine how a biomechanical problem in one region, could easily spread to another part of the body, for example lameness in one leg occurring as the result of scar tissue in the fascia and muscle tissue of a diagonally opposed leg.

6. PERSPECTIVES

This study reveals a new concept with regard to the current understanding of equine kinaesthetic, biomechanics and functional anatomy. It is suggested that the equine lines described in this study can help describe both static and dynamic posture in terms of spinal flexion/extension, lateral flexion and rotation, all of which can be influenced by fascia contraction. Furthermore, it is proposed that the lines described in this study form the basis of a readily useable tool that can be applied by practitioners to track the main cause of a locomotory problem and understand the compensatory patterns in a horse with impaired performance. Finally, these findings highlight the need for continued research into equine fascia from a cellular *in vitro* level to *in vivo* studies of function and biomechanics.

7. SUPPORTING INFORMATION

“The ARRIVE Guidelines Checklist” is followed in the manuscript

8. ACKNOWLEDGEMENTS

The study was supported in part of the Danish foundation of Promotion of Veterinary Science and the IVCA (The International Veterinary and Chiropractic Association). These funds supported the expenses in relation to the research and publication costs, however, they had no influence on the research nor on the content of the submitted manuscript.

The authors would like to thank Lennart Engberg Carlsen and Vibe

Bøgelund Hansen for their technical assistance, Mette Bloch Christiansen for photography/illustrations and permission to paint her horse, Hanne M. Holm for technical assistance with the figures, Adrian P. Harrison for proofreading and not least the owners of the horses for their generous donation.

9. AUTHOR CONTRIBUTION

VSE and RMS designed the project, contributed data, analyzed the data, made the figures and wrote the manuscript.

10. CONFLICTS OF INTEREST

The authors are not aware of any conflicts of interest associated with this study. VSE is employed full-time in the Faculty of Health & Medical Sciences and RS is self-employed – neither authors received any payment for their work, nor was this study sponsored commercially.

REFERENCES

Adams OR (1987) Trimming and shoeing of the normal foot. In: *Lameness in horses abridged 3th ed*., pp. 393-401. Lea & Febiger, Philadelphia, PA, USA.

Best TM, Gharaibeh B, Huard J, (2013) Stem cells angiogenesis and muscle healing: a potential role in massage therapies. *Postgrad Med J* **89**, 666-670.

Budras K-D, Sack WO, Röck S (2009) *Anatomy of the horse, First ed*, Schlütersche Verlagsgesellschaft mbH & Co KG, Hannover, Germany,

Carvalhais VO, Ocarino J de M, Araújo VL, et al. ST, 2013. Myofascial force transmission between the latissimus dorsi and gluteus maximus muscles: an in vivo experiment. *J Biomech* **46**, 1003-1007.

Constantinescu GM, Habel RE, Sack WO (2012) *Illustrated Veterinary Anatomical Nomenclature. 3rd revised ed*, (ed Schaller O). Enke Verlag, Stuttgart, Germany.

Denoix J-M (1999) Spinal biomechanics and functional anatomy. *Vet. Clin. N. Am: Equine Pract.* **15**, 27-40.

Denoix J-M, Pailloux J-P (2009) *Physical therapy and massage for the horse, 4th ed*, pp. 52 – 55. Manson Publishing Ltd 2001, UK.

Evrard, P (2002) La collonne cervicale, thoracique au lombaire. In *Ostéopathie vétérinaire. Introduction á l'Ostéopathie structurelle appliquée au cheval, 1st ed*, pp.283-395. Olivier éditeur, Thy-Le-Château, Belgique.

Faber M, Johnston C, Schamhardt H, et al. (2001) Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. *Am J Vet Res* **62**, 757-764.

Gussekloo SWS, Lankester J, Kersten W, et al. (2011) Effect of differences in tendon properties on functionality of the passive stay apparatus in horses. *The Am J of Vet Res* **72**, 474-483.

Haussler KK, Bertram JEA, Gellman K, et al. (2001) Segmental in vivo vertebral kinematics at the walk, trot and canter: a preliminary study. *Equine Vet J* **33**, 160-164.

Huijing PA (2003) Muscular force transmission necessitates a multilevel integrative approach to the analysis of function of skeletal muscle. *Exercise and Sport Science Reviews* **31**, 167-175.

Huijing PA, Baan GC (2008) Myofascial force transmission via extramuscular pathways occurs between antagonistic muscles. *Cells Tissues Organs* **188**, 400-414.

Huijing PA, Yaman A, Ozturk, et al. (2011) Effects of knee joint angle on global and local strains within human triceps surae muscle: MRI analysis indicating in vivo myofascial force transmission between synergistic muscles. *Surg Radiol Anat* **33**, 869-79.

Klingler W, Velders M, Hoppe K, et al. (2014) Clinical relevance of fascial tissue and dysfunctions. *Curr Pain Headache Rep* **18**, 439.

König HE, Liebich HG (2009) *Veterinary Anatomy of Domestic Mammals, 4th ed*, (eds König HE, Liebich HG) pp. 277 – 278, Schattauer, Stuttgart, Deutschland.

Langevin HM, Cornbrooks CJ, Taatjes DJ (2004) Fibroblasts form a body-wide cellular network. *Histochem Cell Biol* **122**, 7 – 15.

Langevin HM (2006) Connective tissue: a body-wide signalling network? *Med Hypotheses* **66,** 1074-1077.

Langevin HM, Bouffard NA, Fox JR, et al. (2011) Fibroblast cytoskeletal remodeling contributes to connective tissue tension. *J Cell Physiol* **226**, 1166-1175.

Langevin HM, Nedergaard M, Howe AK (2013) Cellular control of connective tissue matrix tension. *J Cell Biochem* **114**, 1714-1719.

Lesimple C, Fureix C, De Margerie E, et al. (2012) Towards a postural indicator of back pain in horses (*Equus caballus*). PLoS ONE **7**, e44604.

Maas H, Sandercock TG (2008). Are skeletal muscles independent actuators? Force transmission from soleus muscle in the cat. *J Appl Physiol* **104**, 1557-1567.

Masi AT, Nair K, Evans T, et al. (2010) Clinical, biomechanical, and physiological translational interpretations of human resting myofascial tone and tension. *Int J Ther Massage Bodywork* **3**, 16-28.

Myers, T (2009) *Anatomy Trains – Myofascial meridians for manual and movement therapists, 2nd ed*, Churchill Livingstone, Elsevier, England.

Nickel R, Schummer A, Seiferle E, (1977) Bewegungsapparat. In *Lehrbuch der Anatomie der Haustiere I, 5.ed*, pp. 231-232. Verlag Paul Parey, Berlin und Hamburg, Deutschland.

Paoletti S (2001) Embryologie. In *Faszien-Anatomie, Structuren, Techniken. 1. ed*, pp.1 – 15. Urban & Fischer Verlag, München, Deutschland.

Purslow PP (2010) Muscle fascia and force transmission. *J of Bodywork & Movement Therapies* **14**, 411-417.

Rhodin M, Gómez Alvarez CB, Byström A, et al. (2009) The effect of different head and neck position on the caudal back and hindlimb kinematics in the elite dressage horse at trot. *Equine Vet. J* **41,** 274-279.

Richter P, Hebgen E (2009) Models of myofascial chains. In *Trigger Points and Muscle Chains in Osteopathy*, *1st ed*, pp. 10-26. Georg Thieme Verlag, Stuttgart, Germany.

Ross MW and Dyson SJ (2003) Horseshoes and shoeing. In: *Diagnosis and management of lameness in the horse, 1st ed*, pp. 269-270. Saunders, Elsevier, St. Louis, Missouri, USA.

Schleip R, Klingler W, Lehmann-Horn F (2006a) Fascia is able to contract in smooth muscle-like manner and thereby influence musculoskeletal mechanics. In: *Proceedings from the 5th World Congress of Biomechanics*, (ed Liepsch D), pp. 51--54. Medimond international proceedings, Munich, Germany.

Schleip R, Naylor IL, Ursu D, et al. (2006b) Passive muscle stiffness may be influence by active contractility of intramuscular connective tissue. *Med Hypotheses* **66**, 66-71.

Schleip R, Findley TW, Chaitow L, et al. (2012a). *Fascia - the tensional network of the Human Body. 1st ed*, (eds Schleip R, Findley TW, Chaitow L, et al.), pp.159 – 60. Churchill Livingstone, Elsevier Ltd., UK.

Schleip R, Jäger H, Klingler W (2012b). What is 'fascia'? A review of different nomenclatures. *J Bodywork and Movement Ther* **16**, 496-502.

Sleijper EJ (1946) *Comparative Biologic-anatomical on the Vertebral column and Spinal musculature of Mammals investigations, 1st ed*, N.V. Noord-Hollandche Uitdervers Maatschappij, Amsterdam.

Stubbs NC, Hodges, PW, Jeffcott LB, et al. (2006) Functional anatomy of the caudal thoracolumbar and lumbosacral spine in the horse. *Equine Vet J* **38**, 393–399.

Tian M, Herbert RD, Hoang P, et al. (2012) Myofascial force transmission between the human soleus and gastrocnemius muscles during passive knee motion. *J Appl Physiol* **113**, 517-523.

Van De Water L, Varney S, Tomasek JJ (2013) Mechanoregulation of the myofibroblast in wound contraction, scarring and fibrosis: Opportunities for new therapeutic intervention. *Adv Wound Care (New Rochelle)* **2**, 122-141.

Vleeming A, Pool-Goudzwaard AL, Stoeckart R, et al. (1995) The posterior layer of the thoracolumbar fascia. Its function in load transfer from spine to legs. *Spine* **20**, 753-758.

Vogt C., 2011. Zusammenhang zwischen Kiefergelenkemechanik und Ganzkörperstatik by Ros K. In: *Lehrbuch der Zahnheilkunde beim Pferd, 1st ed*, pp. 35 – 39. Schattauer GmbH, Stuttgart, Deutschland.

Weeren PR, McGowan C, Haussler KK (2010) Development of a structural and functional understanding of the equine back. *Equine Vet J* **42,** 393-400.

Wipff PJ, Rifkin DB, Meister JJ, et al. (2007) Myofibroblast contraction activates latent TGF-beta 1 from the extracellular matrix. *J Cell Biol* **179**, 1311-1323.

Yucesoy CA, Baan G, Huijing PA (2010) Epimuscular myofascial force transmission occurs in the rat between the deep flexor muscles and their antagonistic muscles. *J Electromyogr Kinesiol* **20**, 118-126.

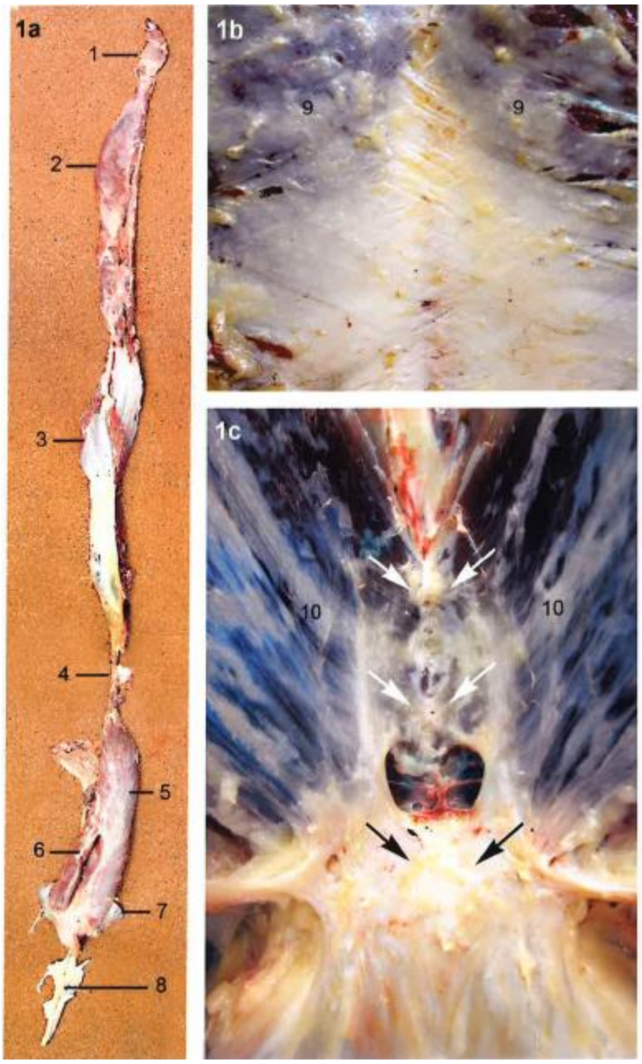
Yucesoy CA, Huijing PA (2007) Substantial effects of epimuscular myofascial force transmission on muscular mechanics have major implications on spastic muscle and remedial surgery. *J Electromyogr Kinesiol* **7,** 664- 679.

Table 1
Myofascial line nomenclature in humans and horses. The left column lists the nomenclature of the lines in humans as presented by Myers (2009). The right column presents the nomenclature changed in this study in order to accommodate to the quadruped positions of equines. * to be presented at a later date pending further detailed investigation.

Human Myofascial Lines	**Equine Myofascial Lines**
Superficial Back Line (SBL)	Superficial Dorsal Line (SDL)
Superficial Front Line (SFL)	Superficial Ventral Line (SVL)
Lateral Line (LL)	Lateral Line (LL)
Spiral Line (SL)	Spiral Line (SL)
Functional Line (FL)	Functional Line (FL)
*Deep Front Line (DFL)	*Profound Ventral Line (DVL)
Superficial Back Arm Line (SBAL)	Front Limb Protraction Line (FLPL)
Superficial Front Arm Line (SFAL)	Front Limb Retraction Line (FLRL)
Deep Back Arm Line (DBAL)	
Deep Front Arm Line (DFAL)	

Table 2
Myofascial lines share structures. These lines are presented in the left column and the shared structured are listed in the right column.

Lines	**Shared structures**
SDL and SL	Mm. errector spinae
SVL, FL	M. rectus abdominis
FL, FLRL	M. latissimus dorsi and fascia thoracolumbalis
SVL, LL	Connection between m. brachiocephalicus and m. sternomandibularis
SP, FLPL	M. rhomboideus cervicis
LL, FLPL	M. brachiocephalicus
LL, SL	Tuber coxa, Proc. masteoideus
LL, SL	Proc. masteoideus


1a
1
2
3
4
5
6
7
8
1b
9
9
1c
10
10


2a
2b
2c

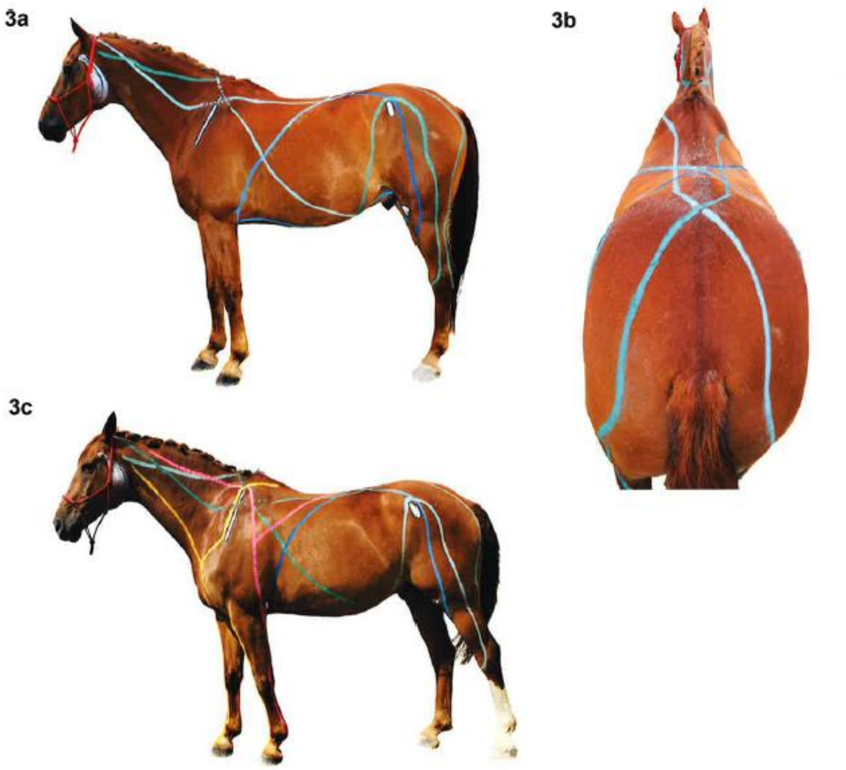


FIGURE LEGENDS

Fig. 1a shows the dissected and isolated superficial dorsal line (SDL). Cranial is in upwards direction. 1*: fascia and m. temporalis;* 2 *and* 3*: mm. errectores spinae (*2*: mm. spinales et semispinales;* 3*: fascia et mm. ilicostales et longissimus thoracis et lumbales);* 4*: lig. sacrotuberale latum;* 5-6*: hamstrings (*5*: m. semitendinosus;* 6*: m. biceps femoris pars caudalis);* 7*: fascia and m. gastrocnemius;* 8*: tendo calcanei, tendo m. flex. dig. superficialis et m. interosseous medius.*

Fig. 1b and 1c are close-ups of dissected and isolated crossing-overs of the functional line (FL), which is a helical line. The horse was hanging in the legs with the head downwards. Figure 1b shows the dorsal fascia cross-over in the lumbo-sacral fascia aligned with the m. gluteus medius dexter et sinister (9). Notice the very clear interwoven collagen fibres crossing the midplane of the body. Fig. 1c illustrates the ventral crossing-over (arrows) of the functional line (FL). The crossing over is seen in the epimysium of m. gracilis (10) ventral and cranial to os pubis. The crossing-over is continuous in the full length of the muscle with the only interruption from the entrance to canalis femoralis (between the black and white arrows)

Fig.2 presents the superficial dorsal line (green), the superficial ventral line (blue) and the lateral line (orange) painted on a horse. The dotted part of the superficial ventral line (blue) and the profound part of the lateral line (orange) illustrate parts of the lines passing underneath the scapula. Fig. 2a is a lateral aspect of the three lines illustrating the arrangement of the lines on the trunk and the extension of the lines in the head and in the hind limb. In fig. 2b the split of the superficial dorsal line in a lateral section including the fascial connection between m. biceps femoris pars caudalis and m. gastrocnemius caput lateralis and a medial section including the fascial connection between the m. semitendinosus and the m. gastrocnemius caput medialis. Fig. 2c is a close up of the interconnection between the three lines in the head with the os mandibularis and articulatio temporo-mandibularis as the region of the interconnection.

Fig. 3 shows the course of the helical lines painted on a horse: The Functional Line (FL), blue and light blue colours, the Spiral Line (SL) green and pale green and in addition the Front Limb Lines: Front limb Protraction Line (FLPL) yellow and Front LImb Retraction Line (FLRL) pink. Fig. 3a. illustrates the two helical lines on the full body of the horse. The dotted parts of the lines illustrate the part situated underneath the scapula. In fig. 3b the two helical lines and the dorsal crossing-overs from a caudo-dorsal perspective is illustrated and in fig. 3c the front limb lines are painted on top of the helical lines. An interpretation of the full span of the two helical lines is available by combining fig. 3a and 3b. The FL starts in the regio axillaris, splits up in a dorsal and a ventral part and reunite on the contra-lateral hind limb distal to the tuberositas tibia. Both parts cross-over the midplane. The SL has 3 crossing-overs. Two dorsal (fig. 3a and b) at the regio sacralis and scapularis respectively, and one ventral in the mid abdominal region (fig. 3a). The helical part of the line starts in the upper part of regio colli lateralis at the origo of m. splenius. It continues from here on the dorso-lateral side of the neck, and crosses over in the regio interscapularis to the contra-lateral side. From here it continues in a caudo-ventral direction, crosses over in the regio umbilicalis to the side of origin and proceeds to the hock in the lateral muscle and facia compartments of the hind limb. Distal and plantar to the hock it redirects in a proximal direction and follows the caudo-lateral compartment of the hind limb into the lig. sacrotuberale latum. From here it runs into the dorsal sacral ligaments and crosses over the midplane to the contra-lateral side of its origin. In the rest of the cranial approach it follows the SDL. In fig. 3c the front limb lines (FLPL and FLRL) are painted. Each of the arm lines has a cranial and caudal inlet, which is integrated in parts of the different lines and as illustrated in the figure in both of the helical lines.

