Chapter 1

General introduction

Introduction

Biomechanics is the study of the mechanics of a living body, and includes kinematics (motion) and kinetics (forces) (Fung 1993). Force and motion can be seen as the product of the musculoskeletal system and are in fact determinants of athletic performance in virtually all equestrian disciplines. Therefore, it may be not surprising that musculoskeletal disorders with subsequent impairment of normal biomechanical function account for the majority of the cases of poor performance in horses (Ross and Dyson 2003). The most common disorder is lameness, but probably the most controversial and poorly understood is back dysfunction.

The thoracolumbar vertebral column, as bony basis of the back, forms part of the axial skeleton that bridges the gap between the limbs. There is a complex and intricate relationship between the biomechanics of the axial and appendicular skeleton. Maintaining an appropriate balance in this relationship is essential for correct locomotion and maximal athletic performance. However, relatively little is known about this relationship and about the mutual effects of dysfunction of one of the components.

Insight into the effects of back pain on one hand and lameness on the other on body mechanics will help us expand our understanding of the pathogenesis of these common orthopaedic ailments, improve diagnosis by identifying problems as primary or secondary, and better treat or prevent these disorders.

Anatomy and biomechanical concepts of the vertebral column

The vertebral column has important roles in locomotion. It accounts for weight bearing and provides soft tissue attachment sites, connects fore and hindquarters, and lends flexibility to the axial skeleton.

The equine vertebral column consists of 7 cervical, 18 thoracic, 5-6 lumbar, 5 sacral and 15-18 caudal vertebrae, which are strongly interconnected by joints, ligaments and muscles providing stability and motion. The column is organized in structural and functional segmental units formed by pairs of consecutive vertebrae. Each unit has bilateral dorsal synovial joints and an axial fibrocartilaginous joint with a thick intervertebral disk between the vertebral bodies. Each of these articulations only allows for subtle movements, but together they give the entire vertebral column a significant range of motion (Fig. 1.1).

The segmental motion is limited by the vertebral processes of each group of vertebrae. The thoracic back has mainly lateral motion due to the long spinous processes, which limit flexion-extension; the lumbar back offers mainly vertical motion (flexion-extension) due to the long and inter-articulated transverse processes; the sacral vertebrae are fused into one sacral bone that has a limited range of motion with respect to its neighbouring structures (ilium, last lumbar and first caudal vertebra). The cervical vertebrae have much freedom of movement and the first one, the atlas, articulates with the condyles of the occipital bone, providing great mobility to the cranium. The thoracic vertebrae also possess costal facet joints through which they articulate with the ribs, allowing interaction with the thorax.

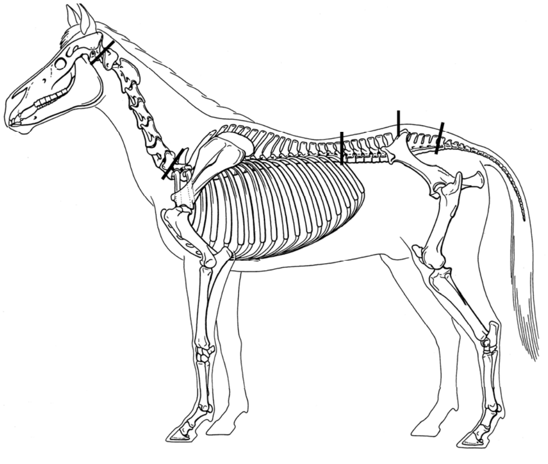

Figure 1.1. Skeleton of the horse: straight lines indicate the division of the vertebral column in cervical, thoracic, lumbar, sacral and coxigeal vertebrae (Adapted from: Dyce *et al* (2002) Textbook of veterinary anatomy. 3rd Ed., Saunders, Philadelphia).

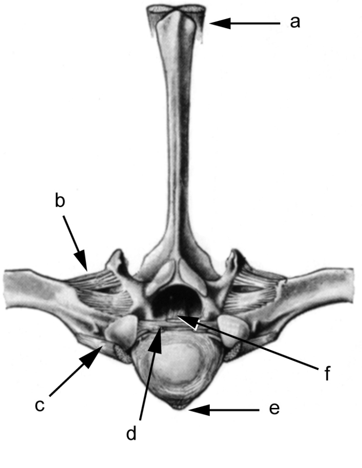

Figure 1.2. Vertebral ligaments: Cranial view of a thoracic vertebra articulating with the corresponding rib pair in the horse, a) supraspinal ligament; b), c) and d) costo-vertebral ligaments; e) ventral longitudinal ligament and f) dorsal longitudinal ligament. (Adapted from: Nickel *et al* (1986) The anatomy of the domestic animals: the locomotor system of the domestic animals. Vol 1. 5th Ed., Springer-Verlag Inc., New York).

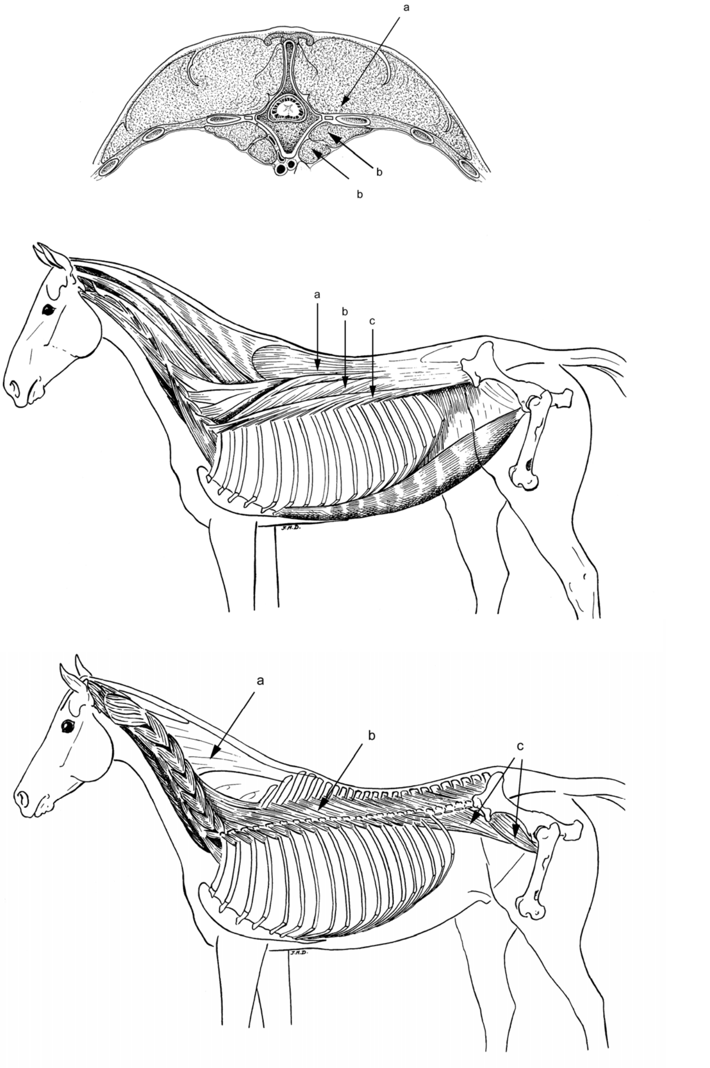

Figure 1.3 Vertebral muscles of the horse. Top figure: Transversal section of vertebral muscles at the level of lumbar vertebrae; a) epaxial muscles (iliocostalis, longissimus dorsi and spinalis), and b) hypaxial muscles (psoas major and psoas minor) (Adapted from: Dyce *et al* (2002) Textbook of veterinary anatomy. 3rd Ed., Saunders, Philadelphia). Middle figure: Longitudinal view of the superficial muscles of the back; a) spinalis, b) longissimus and c) iliocostal. Low figure: deep muscles of the back and nuchal ligament; a) nuchal ligament, b) multifidus muscle and c) iliopsoas muscle (psoas major and iliacus) (Adapted from: Denoix and Pailloux (2001) Physical therapy and massage for the horse. 2nd Ed., Manson Publishing, London).

Various short ligaments connect two consecutive vertebrae supplying stability to the segment, while longitudinal ligaments join all or most vertebrae, restricting motion of the entire thoracolumbar column (Fig. 1.2). Intrinsic vertebral muscles are divided into two groups: epaxial and hypaxial. The first group is situated dorsal to the transverse vertebral processes provoking back extension when contracting. These include *iliocostalis*, *longissimus dorsi*, *multifidus* and *spinalis* muscles. The second group is situated ventral to the transverse vertebral processes provoking back flexion; the major constituents of this group are *psoas major*, *psoas minor* and *iliacus* muscles. Both groups of muscles work together to maintain stability and generate vertebral motion (Fig. 1.3).

The current biomechanical concept of how the back functions was proposed by Slijper (1946). This concept describes the mammalian trunk as a bow and a string, where the bow represents the thoracolumbar vertebral column and the string is the ventral part of the trunk (Fig. 1.4). The bow and string function in a dynamical balance, influenced by other structures such as the abdominal mass, the limbs and the head (and neck). The gravitational force on the abdominal mass pulls the bow down resulting in extension of the back; protraction of the forelimbs and retraction of the hindlimbs have the same effect, while retraction of the forelimbs and protraction of the hindlimbs result in back flexion. Figure 1.5 gives a schematic representation of the muscular, tendinous and bony structures interacting in the bow-and-string model.

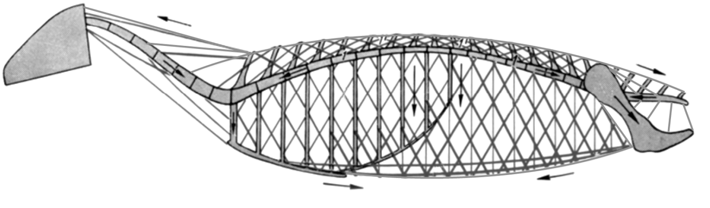

Figure 1.4. Bow and string model according to Slijper (1946) (Modified from: Nickel et al (1986) The anatomy of the domestic animals: the locomotor system of the domestic animals. Vol1. 5th Ed., Springer-Verlag Inc., New York).

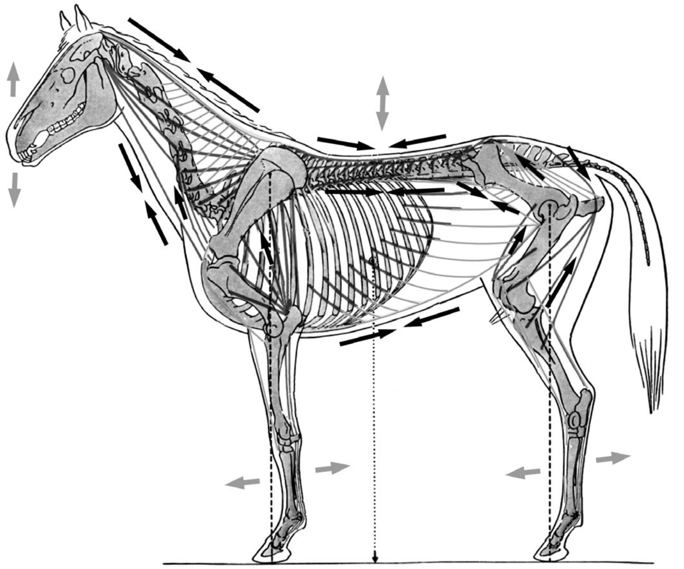

Figure 1.5. Muscular, tendinous and bony structures interacting in the bow-and-string model: black arrows represent the pulling direction of the tendons and direction of muscle contraction, and grey arrows represent the movement of the head, back and limbs in one plane (Adapted from: Nickel et al (1986) The anatomy of the domestic animals: the locomotor system of the domestic animals. Vol1. 5th Ed., Springer-Verlag Inc., New York).

In vivo vertebral kinematics and gait analysis systems

Research into equine vertebral kinematics started a few decades ago, when back problems were increasingly recognised as a serious issue in equine health and gait analysis systems came onto the market that allowed for detailed analysis of equine locomotion.

Clinical examination has always been, and still is, the method of choice for the evaluation of gait in the horse. Semi-quantitative scales are widely used to score lameness (Stashak 2002) but, although intra-observer variability is known to be remarkably low, these systems are subjective and not very suitable for the assessment of back movement, where significant and relevant changes in motion can be very minor and not well perceptible for the human eye. Gait analysis systems allow for the detailed examination of kinetics and kinematics during stance or locomotion. Kinematic analyses are carried out by using video or opto-electronic devices with specially designed software permitting the 3D analysis of markers located on selected landmarks. Kinetics is generally studied by using force plates/shoes, strain gauges and accelerometers. Recently, calculation of vertical limb forces from kinematics has been developed (Bobbert *et al*. 2007; McGuigan and Wilson 2003). This approach allows estimating the forces when kinetic devices are not available or circumstances do not permit the use of such devices.

One of the most commonly used marker types in kinematical studies in horses is the passive skin marker, which is glued directly to the skin over an underlying bony structure that serves as a landmark. The discrepancy between the movement of the skin marker and the underlying bony structure, the so-called skin displacement artefact, is a source of error that has been well recognised in human (Taylor *et al*. 2005) and equine gait analysis (van den Bogert *et al*. 1990; van Weeren and Barneveld 1986). In the horse a computer programme (Bacckin®[1]) has been developed based on invasively collected data (Faber *et al*. 1999, 2000; Johnston *et al*. 2002) that can calculate thoracolumbar angular motion patterns from skin marker-derived data. The programme thereby automatically corrects for the skin displacement artefact, although the data for lateral bending still have to be interpreted with caution.

Computerized gait analysis systems have been used to study vertebral motion of healthy horses (Audigie *et al*. 1999; Faber *et al*. 1999, 2000, 2001a, b, c, 2002; Haussler *et al*. 2000, 2001; Johnston *et al*. 2002, 2004; Licka and Peham 1998; Licka *et al*. 2001a, b; Pourcelot *et al*. 1998). These studies describe the movement patterns and ranges of motion of various segments of the vertebral column. The basic movements of the vertebral column are flexion-extension (FE) in the sagittal plane, which is equivalent to rotation around the transverse axis in an orthogonal coordinate system; lateral bending (LB) in the horizontal plane, which is rotation around the vertical axis; and axial rotation (AR) in the transverse plane, which is the rotation around the longitudinal axis. During walk and trot, FE motion of the vertebral column has a bimodal sinusoidal pattern in one stride cycle; lateral bending and axial rotation have a single curve per stride (Faber *et al*. 2000, 2001a). As locomotion is generated in the hindquarters, there is a caudal-to-cranial time shift in the vertebral motion patterns within a stride cycle, with increasing delay towards the cranial end of the thoracolumbar spine (Faber *et al*. 2000) (Fig. 1.6).

[1] Qualisys Medical AB, Gothenburg, Sweden.

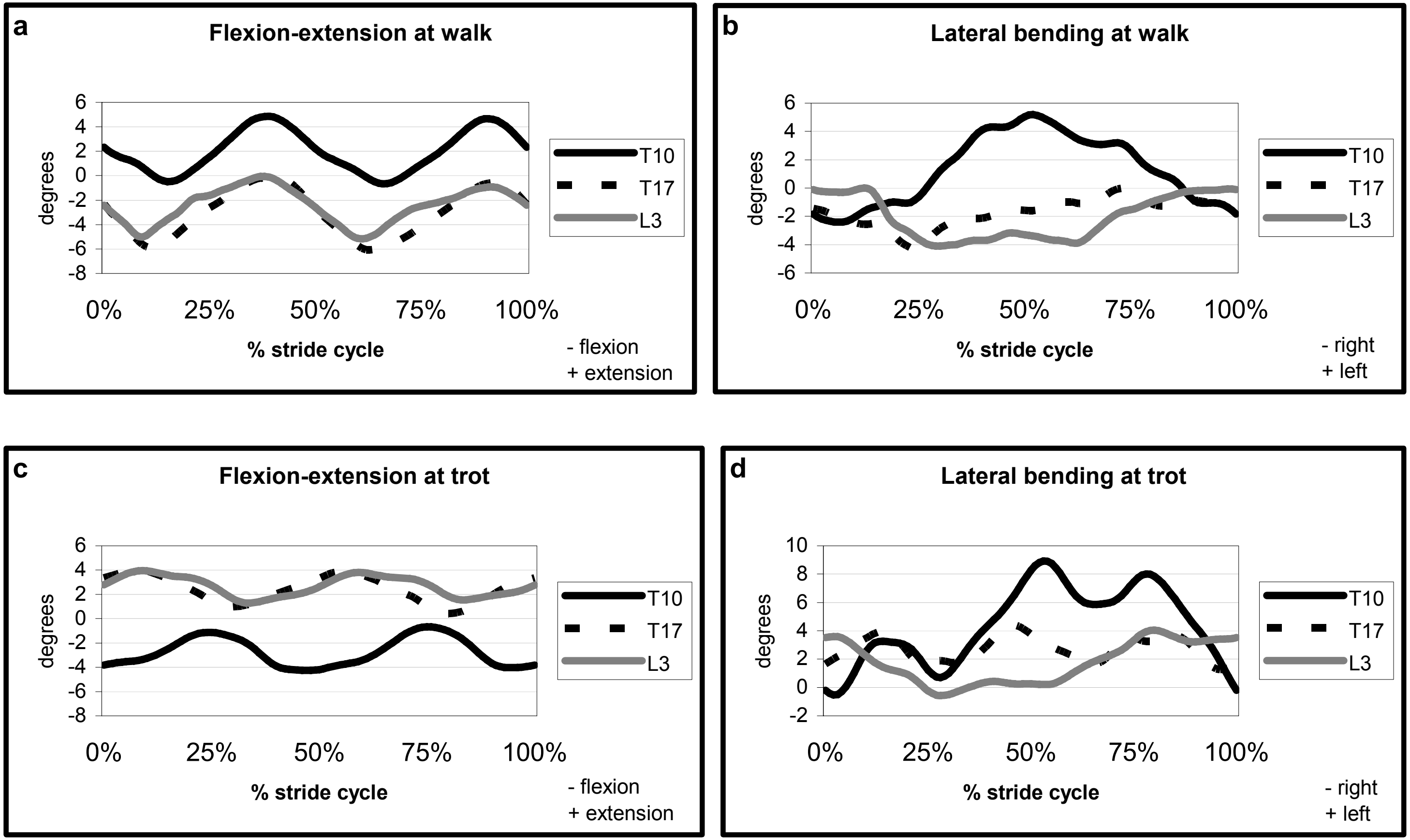

Figure 1.6. Example of angular motion pattern of three vertebral angles (T6-T10-T13, T13-T17-L1, L1-L3-L5) in one horse a) flexion-extension at walk; b) lateral bending at walk; c) flexion-extension at trot; d) lateral bending at trot.

Lameness and back pain

Musculoskeletal pain can be seen as a protective mechanism, as it gives an early warning to the individual when there is a harmful or potentially harmful process in the body (Bergman 2007). There is little discussion anymore about the similarity of pain perception in humans and animals (Livingston 1994), and there is no doubt that musculoskeletal pain has the same function in animals. Nowadays, research on pain assessment and its effects on performance is receiving extra attention as an animal welfare issue in horses. Pain can be assessed by paying attention to behavioural signs (Ashley *et al*. 2005). Lowering the head, a rigid stance and reluctance to move are non-specific behavioural indicators of pain, while indicators of limb pain are weight shifting between limbs, limb rigidity, postural alterations, lack of mobility, etc. (Ashley *et al*. 2005).

Signs of back pain are in general rather vague and unspecific and therefore of limited use in diagnosis of back pain. Normally, the main sign is poor performance and the rest of the signs are unspecific. Palpation can be performed of the superficial structures only, and sensitivity to palpation does not necessarily mean that there is a clinically relevant back problem. Attempts have been made to objectify quantify back pain in the horse. Mechanical nociceptive thresholds have been investigated in the axial skeleton of horses using an algometer by Haussler and Erb (2006a, b), but unfortunately the use of this tool is still not common practice for pain assessment by equine veterinarians.

Back problems can be due to a great diversity of causes. These can be divided into primary, secondary and alleged or apparent. Primary back pain can be located in soft tissue, vertebral bone or articulations. Secondary back pain can be due to lameness, and pelvic or neck injury (Jeffcott 1999). Minor spinal muscle soreness is frequently secondary to lameness (Marks 1999).

Understanding the relationship between back pain and lameness has always been a challenge and an important goal in equine orthopaedics (Dyson 2005). In a population of horses presented for orthopaedic problems, 26% had concurrent lameness and back pain upon palpation (Landman *et al*. 2004). Dyson (2005) reported that, in the majority of horses with primary thoracolumbar or sacroiliac pain, overt lameness was not a feature, but many horses showed restricted hindlimb propulsion, poor hindlimb engagement and a low-grade toe drag. However, apart from these clinical observations, little work has been done to investigate the relationship between back and limb motion.

There is ample kinematical work on lameness and there is especially much evidence of the effect of foot pain on linear and temporal stride parameters and angular motion patterns of the limbs (Buchner *et al*. 1995, 1996b; Galisteo *et al*. 1997); and on the motion pattern of trunk and head (Buchner *et al*. 1996a; Denoix and Audigie 2001; Keegan *et al*. 2000; Uhlir *et al*. 1997; Vorstenbosch *et al*. 1997). Moderate lameness has been reported to affect back motion also. Pourcelot *et al*. (1998) showed in a single case study that the thoracolumbar back presented less extension during the lame diagonal stance phase at trot, but increased extension during the sound diagonal stance phase at trot.

When it comes to the effect of back problems on limb motion, the situation is less clear. It was shown in an experimental study that relatively severe induced back pain provoked stiffening of the back, but affected stride parameters only marginally (Jeffcott *et al*. 1982). In natural cases, patients with back pain seem to reduce the flexion-extension motion in their backs and the axial rotational motion of the pelvis (Wennerstrand *et al*. 2004). In a recent treadmill study on horses, in which implanted pins in the dorsal spinous processes were used as a pain model and to measure vertebral motion, vertical displacement was decreased in several vertebral segments (Haussler *et al*. 2007).

Back pain affects back motion and may or may not affect limb kinematics. Pain in the limbs leads to lameness, which in fact is synonymous to alteration of limb kinematics and will affect both back motion and motion pattern of the head. An altered head motion pattern is one of the key elements in the diagnosis of (forelimb) lameness (Stashak 2002). Considering that the head is an extension of the axial skeleton, altered head motion in its turn will affect back motion to some extent. This will happen in the case of lameness, but also when head and/or neck are forced into extreme and sometimes unnatural positions as is not uncommon during training for certain equestrian disciplines such as show jumping and dressage. The total picture of the motion patterns of the head and the axial and appendicular skeleton is very complicated because of the mutual interactions between these constituting elements of the entire skeleton, which are tightly connected through bony, muscular and ligamentous links. In a sound horse, the entire system is in balance. However, if pain affects one of the elements (vertebral column, limbs, and head) the balance will be lost, affecting the entire system of interconnected motion chains. Understanding this interaction can lead to better diagnosis, treatment and prevention of back problems.

Treatment of back pain

Given the elusive and complicated character of back pain in the horse, it will be hardly surprising that there is a wide variety of treatments that are advocated in case of (presumed) equine back pain. The main objectives of all of them are pain management, and reduction of tension and inflammation.

Medical management of back pain includes the use of steroidal and non-steroidal anti-inflammatory drugs, muscle relaxants and others. Depending on the type of drug, application may be either systemically or locally at the site of any pathology such as arthrotic facet joints or places where neighbouring spinous processes make contact, the so-called “kissing spines”.

Medical treatment is very often accompanied by some kind of complementary therapy, in many cases a form of physical therapy. Physical therapy may consist of tissue stimulation by electrical, magnetic, light, ultrasound, or laser energy, or massage and/or therapeutic exercise. Acupuncture and chiropractic treatment are other commonly used complementary techniques in the management of equine back pain. The objective of physical therapy is to enhance the natural healing process of the tissue through the modulation of inflammation, tissue proliferation and remodelling (Bromiley 1999). The effects of massage are reduction of pain and tension and improvement of blood flow (Bromiley 1999). The Chinese concept of acupuncture is based on the manipulation of energy that is supposed to flow through meridians or channels, promoting tissue healing and diminishing pain (Ridgway 1999). Chiropractic care uses short-lever, high-velocity, low-amplitude, controlled thrusts applied to specific joints or tissues to induce a therapeutic response by inducing changes in joint structures, muscle function and neurological reflexes (Haussler 1999).

There is anecdotal evidence that some of these approaches, together with an appropriate tack and saddle fit, correct shoeing, rest and adequate exercise and training may improve back pain and/or help to prevent back problems, but very little scientific data are available supporting these claims for clinical effectiveness.

Purpose of the thesis

The purpose of this thesis was to improve the understanding of the biomechanical relationship between motion patterns of the axial and appendicular skeleton of the horse, using kinematical analysis. To achieve this goal, the kinematics of the back and/or limbs (including in some cases ground reaction forces derived from kinematics) were studied in horses that were experimentally exposed to either specific head and neck positions, induced lameness, induced back pain, or chiropractic treatment, all of which might influence the balance in the motion chains that lies at the basis of the concerted action of limbs and back in the horse.

Outline

In **Chapter 2** the effect of different head and neck positions on thoracolumbar kinematics is investigated. Theoretically, the position of head and neck is supposed to influence thoracolumbar vertebral kinematics (Denoix and Pailloux 2001), but this interaction has never been experimentally demonstrated in the horse. This chapter allows us to understand how and by how much the head and neck position affects back motion.

In **Chapter 3** the effect of subtle forelimb lameness on vertebral kinematics is the subject of study and in **Chapter 4** a similar approach is used to investigate the effect of subtle hindlimb lameness. It is known that moderate or severe lameness changes the movement of the head and neck (or pelvis). A moderate or severe lameness can therefore be supposed to have some effect on thoracolumbar kinematics as well. However, what about the claim that subtle or even subclinical lameness may be implicated in the pathogenesis of back pain? Does such a very subtle and hardly perceptible lameness cause any changes at all in thoracolumbar kinematic patterns that might help to support this claim? Chapters 3 and 4 answer this question.

In **Chapters 5 and 6** the focus shifts from the limbs to the back. Chapter 5 studies the effect of induced back pain on limb kinematics. If changes in head (and neck) motion affect spinal kinematics and changes in limb kinematics can be found to affect back motion, do pain-induced changes in back motion affect limb motion in a comparable way? In Chapter 6 the effect of induced back pain on vertebral kinematics is addressed. Can the effect of induced back pain on thoracolumbar kinematics be related to the anatomical location of the disorder? And how do back kinematics develop over time in response to a single-event injury?

In **Chapter 7** the effect of chiropractic treatment is chosen as an example of a complementary treatment modality of back pain. The knowledge and insights emanating from the previous six chapters are used to try to understand how the biomechanical changes in one element of the axial and appendicular skeleton may affect the others and to answer the question whether treating back pain reverses the biomechanical changes in the limbs and the back itself.

Chapter 8 is a general discussion that integrates the findings from chapters 2-7 and puts them in perspective. The chapter evaluates to what extent this thesis has succeeded in improving our understanding of the complex interactions between limbs and back function in equine biomechanics. It further focuses on the clinical and societal relevance of certain findings and identifies areas in which further research seems most urgent.